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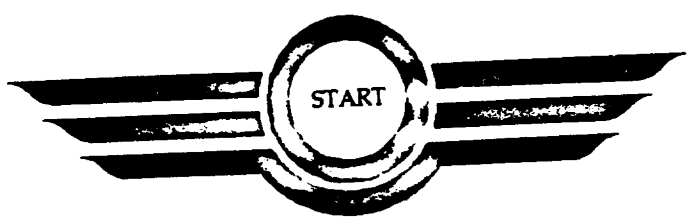
Stormwater NPDES Related Monitoring Needs



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Stormwater NPDES Related Monitoring Needs

Proceedings of an Engineering Foundation Conference

Edited by Harry C. Torno

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ABSTRACT

This proceedings, ***Stormwater NPDES Related Monitoring Needs***, consists of papers presented at the Engineering Foundation Conference held in Colorado, August 7-12, 1994. The Conference brought together 90 experts in the field of urban stormwater management to discuss the current state of the U.S. Environmental Protection Agency's Nonpoint Pollution Discharge Elimination System (NPDES) regulations related to discharges of urban stormwater, and the monitoring requirements under those regulations. The objective was to summarize the current state of stormwater monitoring with respect to meeting these regulatory requirements, and to lay out an agenda for the future. Technical sessions included: 1) An overview of stormwater monitoring needs; 2) locating illicit connections; 3) system runoff characterization; 4) NPDES compliance monitoring; 5) policy and institutional issues o NPDES monitoring; 6) BMP monitoring for data transferability; 7) monitoring receiving water trends; and 8) stormwater and best management practice (BMP) monitoring. There were also extensive discussions, as well as a number of adhoc meetings. A major conclusion reached by the conferees was that existing monitoring requirements will not yield the information necessary to determine impacts on the environment or to evaluate the effectiveness of BMPs.

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FOREWORD

The Urban Water Resources Research Council (UWRRC) of the American Society of Civil Engineers has for 30 years been a leader in the transfer of urban stormwater technology among researchers, practitioners and administrators. One of the principal means of accomplishing this transfer has been through a series of Engineering Foundation Conferences, held in the United States and abroad, as well as International Symposia and technical sessions at professional conferences.

The Council has recognized for some time that there have been numerous concerns related to the monitoring requirements of the current U. S. Environmental Protection Agency NPDES regulations, and particularly those governing discharges of stormwater to the environment. Because of these concerns, and because the Council itself felt that there were many technical and administrative problems with these regulations, the Council organized this Conference on stormwater NPDES related monitoring needs. It was the aim of the Conference to bring together experts in all fields related to these needs, including those from the regulatory agencies and the regulated community. What resulted was a mix of perspectives and expertise representing industry and state and local governments, together with their technical staffs and consultants.

All of the papers presented in the regular sessions were by invitation, and were reviewed and accepted for publication by both the Conference Chairman and by the Proceedings Editor. Papers in Appendix A (Poster Papers) were unsolicited, and only received an editorial review for format, etc. All papers are eligible for discussion in the Journal of the Water Resources Planning and Management Division of the American Society of Civil Engineers (ASCE). All papers are eligible for ASCE awards.

The Proceedings are organized by "session", corresponding to the actual conference sessions. Formal papers are presented first, followed by a session discussion which may include both material presented by an author which is not necessarily in his paper, as well as comments/questions from participants, and the answers to those questions furnished by the author (or, in some cases, by other conference participants).

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ACKNOWLEDGEMENTS

The Conference organizers gratefully acknowledge the financial support of the U. S. Environmental Protection Agency and the Engineering Foundation, without which the Conference would not have been possible.

Particular thanks are due to the Conference organizing committee:

Ben Urbonas, Chairman
Michael B. Cook, Co-Chair
Christine B. Andersen, Co-Chair
Harry C. Torno, Proceedings Editor
Charles Beck
David R. Dawdy
William H. Frost
Jiri Marsalek
Tavit Najarian
A. Charles Rowney
Betty Rushton
Shaw L. Yu

These individuals gave generously of their time and energy to insure that the Conference would be a success.

Further thanks are due to the Conference co-sponsors, who provided guidance and support throughout, and especially to Michael Cook, William Swietlik, William Tate, Kevin Weiss and Robert Goo, all members of the EPA Support Group.

Thanks go also to the session Chairpersons, who were responsible for organizing their individual sessions, and ensuring that Conference deadlines were met.

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Particular thanks go to John Doerfer, Rich Horner, Wayne Huber, Larry Roesner, and Harry Torno, who diligently kept notes on the session discussions.

Finally, the Conference organizers would like to acknowledge the efforts of the Engineering Foundation staff - Dr. Charles V. Freiman, Director, Mrs. Barbara Hickernell, Director of Conferences, and Mr. Michael Salgo (ASCE, ex-officio member of the Engineering Foundation Board of Directors), who cheerfully and efficiently provided logistical and administrative support to the Conference.

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Overview Summary of the Conference

Ben Urbonas, M.ASCE[1] and Harry C. Torno, M.ASCE[2]

Abstract

The Urban Water Resources Research Council of the American Society of Civil Engineers sponsored an Engineering Foundation Conference on Stormwater NPDES-Related Monitoring Needs, which was held August 7-12, 1994, in Crested Butte, Colorado. The Conference was prompted by concerns that, while we as a nation are spending millions of dollars on stormwater monitoring, we still are not able to predict the effects of stormwater discharges on the environment, particularly in the long term. Moreover, we are faced with even larger expenditures in the future.

The purpose of the Conference was to explore current needs and available technology associated with stormwater monitoring, and to bring together regulators, the regulated community, and their consultants, to determine what we, as professionals and as a nation, need to do to achieve the various goals set forth for stormwater in the Clean Water Act, and the municipal and industrial NPDES regulations that implement that act.

This summary provides a brief overview of the key points raised in the papers presented at the Conference, and of the discussions that surrounded those papers and related matters. The papers and discussions presented a reasonably balanced view from the viewpoint of the regulator, the regulated community, and researchers who are endeavoring both to provide the technical information necessary to meet regulatory requirements at reasonable cost, and to protect the environment.

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<u>Introduction</u>

200 or so cities and counties in the U.S. have been required, by Part II of the U. S. Environmental Protection Agency's municipal NPDES separate stormwater discharge permit application, to spend large sums of money (estimated by some at about $60 million) to collect stormwater data. Many questions have been raised about both the validity of the requirement to collect these huge amounts of data, and the validity of the data itself, particularly in terms of evaluating the impacts on the environment and the usefulness of corrective measures which might be required.

For example, the Dallas-Fort Worth area spent approximately $2.9 million to satisfy Federal requirements, and industry in that area may have had to spend even more. It has become apparent that these costs are to a large extent the result of a profound lack of understanding, on the part of both the regulators and the regulated community (including their consultants), of the cost and complexity of obtaining meaningful stormwater quantity and quality data.

The goal of the Conference, therefore, was to bring together the regulated community, along with their experts and consultants, and the regulators, for the purpose of exploring where monitoring technology stands at this time, and determining the monitoring needs related to separate stormwater systems. The exchange that occurred at Crested Butte is documented in these Proceedings, in both the papers that were presented, and in the discussions that ensued. The following discussion summarizes the main issues raised at the Conference.

<u>Thoughts and Observations</u>

There was general agreement that current water quality standards, which tell us little about the <u>environmental health</u> of the nation's receiving waters, may be a significant detriment to the improvement of environmental quality. They are a huge resource drain (time, energy, money), and most stormwater professionals cannot support the requirements of these standards as being cost-effective. Furthermore, the standards impair effective communication between regulators and the regulated community, and confuse issues like what research should be done. Similarly, end-of-pipe measurements of pollutant discharges, which are used in the implementation of the water quality standards, tell us nothing about the impact of those discharges on the environment.

Such standards are not used in Canada or New Zealand, for instance. They choose instead to look at watersheds or basins in their entirety, and to establish, in a holistic sense, pollution control requirements which address overall environmental improvement.

Effective stormwater monitoring, whether physical, chemical or biological, is very difficult and expensive. Currently, NPDES regulations (and the individual

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regulators, whose interpretations of those regulations may vary considerably) require permittees to collect vast amounts of stormwater monitoring data. Much of the data collected pursuant to these requirements appears to be inappropriate and of little value, either locally or nationally, either to the regulator or the permittee.

Individuals in regulatory agencies charged with writing regulations and/or permits, and with their implementation, frequently do not have enough training and experience, considering the technical and administrative complexities involved. There is considerable concern on the part of regulated communities and industries that permit writers will continue to use the results of current monitoring, whether meaningful or not, to justify additional monitoring and additional control requirements, and that the costs involved will be prohibitive.

Toxic concentrations of certain pollutants are sometimes found in stormwater, but there is a question about the degree of stress they cause because of:

- The short-term exposure of the biota to these toxicant concentrations (there is, in fact, little data available on the duration of the exposure).
- The form of the constituent that is measured. Most measurements are of total recoverable concentrations of a pollutant, whereas, in reality, the dissolved or ionic form is the real toxicant. For instance, one typically measures total recoverable concentrations of lead, rather than the ionic (toxic) form.

Very little meaningful monitoring is being directed toward measuring the actual effect of stormwater discharges on the short- or long-term health of the environment. Furthermore, there is no consensus on how this monitoring should be done.

Despite considerable research, we have generally been unable to identify reliable indicators (which can substitute for the monitoring of a wide range of pollutants or toxic effects) of pollution or of environmental degradation. The search continues, but we have a long way to go in establishing these indicators, if indeed it can be done at all.

Cause and effect relationships in urban ecosystems will be very difficult to determine. Experiments will need to be designed with each specific site in mind. Rigid national protocols will not help, and may in fact hinder sound local experimental design. It will nonetheless be necessary to have general scientific guidance at the national level so as not to sacrifice good science for regulatory expedience.

Some leading biologists, biochemists, ecologists, etc. have undertaken the study of the effects of urban stormwater discharges on the environment, particularly in

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England and the U.S. This involvement, which is critical if the programs alluded to here are to be successful, has already served to broaden the knowledge base, and to facilitate communication between disciplines which have, in the past, not had much interaction.

There is a clear need for large, nationally-funded investigations that can direct sufficient resources, provide sound experimental design, and provide adequate quality control, to, over time, permit environmental scientists and engineers to draw conclusions concerning environmental health, to evaluate alternatives for controlling or improving stormwater quality, and to determine how best to utilize our limited resources to achieve the greatest benefits.

Excellent progress has been made in developing techniques for locating illicit connections, which are a significant source of contamination of stormwater. This progress has been reported in these Proceedings, and in several EPA documents. Despite this progress, however, some further work is still necessary.

Source control of pollutants is a critical fundamental need. All projects which reported lead concentrations from urban runoff, for instance, clearly indicated that lead concentrations are lower now than they were, say, ten years ago, and that these reductions can be directly attributed to the use of lead-free gasoline.

Diazinon continues to be a ubiquitous urban environmental pollutant. Virtually all of the studies reported at the Conference found diazinon present in urban runoff from residential areas - to the extent that there were suggestions that it could be used as an indicator of the presence of this runoff. Thus, it may be necessary to re-evaluate its importance as an environmental pollutant.

Similarly, automobile brake pads and atmospheric deposition seem to be significant sources of copper in stormwater, and programs for their control, similar in nature to the use of unleaded fuel to reduce lead emissions, may be required (and may also be most cost-effective).

Funding constraints at the local and state level are impediments to reaching the goal of a better environment. EPA's estimates of funding requirements have, for the most part, been too low. Local administrators frequently have difficulty in justifying the cost of stormwater monitoring programs to their constituents because there is no perceived benefit - stormwater is not viewed as a serious environmental problem. At the same time, although less federal funds are available (EPA's funding situation is often no better than that of the local communities), local governments still must comply with NPDES regulations.

Despite the many ongoing projects which are evaluating best management practices (BMPs) for the enhancement of stormwater quality, there is a lack of consistency in the way monitoring data are being collected, the type and form of information being reported, and the methods for drawing conclusions (and reporting those conclusions) from the data. Most such evaluations appear to lack a design engineer's perspective, in that they do not permit the use of the information gathered to develop more effective and reliable designs. As a result, the data base available for BMP design is very limited.

There is a consensus that the meaningful monitoring of receiving waters is the most difficult technical problem currently facing us. If these monitoring programs are to provide us with the requisite information on the health of the environment, and on the impacts that stormwater discharges will have on that environment, they must be very carefully designed - both the programs and their physical, chemical and biological components - by environmental scientists in a wide variety of disciplines working in concert with engineers and planners.

There are several excellent examples of well-designed and managed programs in these Proceedings (see papers by Livingston, and by Shaver and Maxted), so it is clear that such projects are possible. They typically require, however, the co-operation of a number of levels of government, of multiple local agencies, and of industry. They must, in addition, have the involvement of the best experts in the engineering and scientific community.

Conclusions

We learned much from each other at Crested Butte about NPDES-related stormwater monitoring. In particular, we learned that, in spite of all that we now know, we understand very little. It is clear that laws, rules, regulations, and best intentions will not change that fact. Only good research programs, involving the best engineering and scientific minds, will improve our level of understanding.

If we are to acquire this understanding, we must stop wasting monitoring resources on the "laundry list" type of monitoring encouraged or required by our current regulations. We must instead move towards well-designed and adequately funded national and regional scientific study programs and research efforts.

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WELCOME FROM THE UWRRC AND PERSPECTIVE

Jonathan E. Jones, P.E., M.ASCE[1]

ABSTRACT

This paper briefly summarizes highlights of previous urban water resources-related conferences sponsored by the American Society of Civil Engineers and Engineering Foundation that relate to the issues that will be discussed at this conference.

On behalf of the nearly 100 members of the American Society of Civil Engineers (ASCE) Urban Water Resources Research Council (UWRRC), I welcome you to Crested Butte. I hope that you and the members of your families take advantage of the wonderful recreational opportunities that the area has to offer. The UWRRC appreciates the excellent work of the Conference Organizing Committee. We also sincerely appreciate the financial and other assistance provided by the U.S. Environmental Protection Agency (EPA), Engineering Foundation, and ASCE.

The UWRRC has been a leader in urban stormwater quantity and quality management issues for over 30 years. I thought that it might be instructive to look through the proceedings of previous conferences initiated by the UWRRC to see if the issues/needs that we are talking about in 1994 were identified earlier. Not surprisingly, they were. Consider the following direct quotations from the cited conferences:

1974: URBAN RUNOFF QUANTITY AND QUALITY

Study should be directed to eight specific areas of information needs:

1. Identification and evaluation of sources of pollution reaching urban runoff.

---

[1] Chairman, ASCE UWRRC, and Vice-President, Wright Water Engineers, Inc., Denver, Colorado.

2. Improvement of methods for identifying and measuring the pollutants reaching urban runoff.

3. Determination of conditions relating or affecting the production of specific pollutants, including the time and rate of pollutant production.

4. Application of such information to an expanded program of data collection.

5. Specification of legislation and organizational requirements appropriate to desired methods of control.

6. Determination of any incompatibilities between objectives of urban flood control and control of water quality in urban runoff.

7. Determination of opportunities in sewer design for reducing water quality problems including the effects of non-structural measures.

8. Determination of design factors when treatment of urban runoff is involved. The design problem becomes more complicated. In fact, urban drainage is an entirely new "ball game" when treatment is involved.

1978: WATER PROBLEMS OF URBANIZING AREAS

Priorities identified for immediate research:

1. Sources and effects of urban runoff pollution.
2. Control of non-point source and urban runoff in urban areas.
3. Improve local stormwater management for multiple purposes.
4. Alternative water quality criteria, taking into account effects of urban runoff.
5. Relationship of urban runoff to channel evolution.
6. Relationship of stream corridors to water quality.
7. Predicting eutrophication in urbanizing areas.

8. Management alternatives, including land use control, for lakes and wetlands in urbanizing areas.

9. Impact of alternative funding approaches on water quality strategy.

10. Groundwater management, including protection of recharge areas in urbanizing areas.

11. Demonstrated improvement of institutional arrangements for water management in urban areas.

__1982: STORMWATER DETENTION FACILITIES - PLANNING, DESIGN, OPERATION, AND MAINTENANCE__

Important research needs:

1. Systematic evaluation of the performance of existing detention facilities to relate their effectiveness to basin design characteristics.

2. Research leading to improved understanding and better predictive techniques related to transport and accumulation of pollutants in saturated and unsaturated groundwater systems below detention facilities.

3. Characterization of stormwater pollutants in terms of parameters related to the design and performance of detention facilities.

__1986: URBAN RUNOFF QUALITY - IMPACT AND QUALITY ENHANCEMENT TECHNOLOGY__

Identified research needs:

1. We need to know more about the field performance of some control technologies including vegetative buffer strips, infiltration/exfiltration, wet and dry detention with filtration, and wetlands.

2. Performance criteria should be developed for commonly used materials such as filter cloth, particularly when used as a silt fence.

3. To the extent feasible, control technology failure should be documented and shared.

4. We need additional research to define inspection, maintenance, and operation requirements or tasks and associated costs.

5. The early emphasis on quantity at the expense of quality must not be replaced by a new emphasis on quality at the expense of quantity. We need case study data to highlight the importance of simultaneously addressing quantity and quality.

1989: URBAN STORMWATER QUALITY ENHANCEMENT - SOURCE CONTROL, RETROFITTING, AND COMBINED SEWER TECHNOLOGY

Conference participants developed the following list of prioritized research needs:

1. Receiving water impacts, including development of receiving water quality standards.
2. Real-time monitoring techniques, including water quality, flow, and treatment plant operational parameters.
3. Effects of wet weather flows on treatment plant performance.
4. Rehabilitation of urban streams - techniques for restoring capacity and aesthetic appeal.
5. Pollutant transport and transformation mechanisms in sewers.
6. Evaluation of the performance of treatment devices.
7. Effects of infiltrated runoff on the environment.
8. Review/comparison, on a worldwide basis, of storm and combined sewer regulations and standards.

After reflecting upon these and other conference proceedings, there is clearly a "continuous thread" that runs through the discussion at these conferences. The issues that we were discussing 20 years ago remain relevant and important today.

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Proceedings of the Research Conference on Water Problems of Urbanizing Areas, held at New England College in Henniker, New Hampshire on July 16-21, 1978. Published by ASCE, New York, New York.

Proceedings of the Conference on Stormwater Detention Facilities - Planning, Design, Operation and Maintenance, held at New England College in Henniker, New Hampshire on August 2-6, 1982. Published by ASCE, New York, New York.

Proceedings of an Engineering Foundation Conference on Urban Runoff Quality - Impact and Quality Enhancement Technology, held at New England College in Henniker, New Hampshire on June 23-27, 1986. Published by ASCE, New York, New York.

Proceedings of an Engineering Foundation Conference on Urban Stormwater Quality Enhancement - Source Control, Retrofitting, and Combined Sewer Technology, held at the Central Sporthotel and Conference Center in Davos, Platz, Switzerland, October 22-27, 1989. Published by ASCE, New York, New York.

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TRENDS IN NPDES MONITORING FOR STORM WATER

June 1994

by

Michael B. Cook[1], Kevin J. Weiss[2], and William F. Swietlik[3]

INTRODUCTION

Traditionally, monitoring requirements under the National Pollutant Discharge Elimination System (NPDES) program have emphasized analyzing pollutants in discharges at the end the end of the pipe. However, EPA anticipates that a number of recent initiatives will be changing the direction of monitoring in general and, when coupled with the evolving needs of the storm water program, will result in more comprehensive, improved and better integrated approaches to monitoring storm water in the future.

OVERVIEW OF NEW INITIATIVES

EPA is participating in a number of initiatives that will shape and improve the Agency's monitoring and data collection efforts. Five initiatives that will directly impact monitoring in the NPDES storm water program include:

- the Intergovernmental Task Force on Monitoring Water Quality (ITFM)
- the EPA- National Goals Project
- the Office of Water- NPDES Watershed Strategy
- the Office of Water environmental indicators project.
- the Office of Wastewater Management storm water environmental indicators project.

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[3] Chief, Storm Water Section (4203), United States EPA Headquarters, 401 M Street S.W., Washington DC 20460.

Intergovernmental Task Force on Monitoring Water Quality (ITFM):

The ITFM was established in 1992 to develop a strategy to solve a number of problems associated with water-quality monitoring activities[4]. The Task Force grew out of the recognition that environmental programs are moving beyond single-media, technology-based approaches towards holistic programs based on risk reduction and pollution prevention. As environmental programs change to more holistic risk-based approaches, monitoring needs become more complex, with new emphasis on:

- Watershed, ecosystem and geographically based programs,
- Biological resources, ecology and habitat,
- Nonpoint source remediation programs,
- Wetlands and coasts, and
- Sediment quality.

The mission of the ITFM is to develop and implement an integrated, voluntary, nationwide strategic plan that provides recommendations for achieving effective collection, interpretation, and presentation of water-quality data to improve the availability of information for decision making at all levels of the government. The strategy was developed in 1992[5]. The goal of the strategy is to provide water-quality data that meet the following four objectives:

1) define water quality status and trends;

2) identify existing and emerging water quality problems;

---

[4] The ITFM is a federal/state/tribal partnership with representatives from 20 agencies and organizations. ITMF members include: the Army Corps of Engineers, Department of Energy, National Oceanic and Atmospheric Administration, National Park Service, Office of Management and Budget, Tennessee Valley Authority, U.S. Department of Agriculture, U.S. EPA, U.S. Fish and Wildlife Service/National Biological Survey, U.S. Geological Survey, Arizona, California, Colorado, Delaware River Basin Commission, Florida, New Jersey, Ohio, Potahatomi Community, South Carolina, Washington, and Wisconsin. The ITFM is chaired by EPA, and the USGS is vice chair.

[5] See "Ambient Water-Quality Monitoring in the United States - First Year Review, Evaluation, and Recommendations", ITFM, December 1992.

3) develop and implement policies and programs for water-resource management and regulation; and

4) evaluate water programs effectiveness.

The strategy includes both a national committee to develop monitoring guidelines and standards, and regional committees to tailor those guidelines to regional needs and to encourage agency participation in the strategy. Tasks planned by the national committee are shown in Table 1. Products that have been or are being developed by the ITMF are shown in Table 2.

EPA National Goals Project:

EPA is in the process of developing a set of broad environmental goals for the Agency. The project's goal is to produce, by Earth Day, April 22, 1995, a set of ambitious, realistic and measurable environmental goals to be achieved in the next century. As part of this effort, the Agency has identified three goals which relate to controlling pollutant sources to surface waters: clean surface waters, safe drinking water, and ecological protection. The Agency is in the process of identifying measures that can be used to evaluate progress towards meeting these goals.

In a complementary effort, the Office of Water issued a Strategic Plan to provide a framework for Office of Water goals and measures of success. A key part of this plan are a series of national environmental goals and environmental indicators. The plan also calls for working closely with the States to put together action plans for reporting on these goals and indicators over time.

As part of the plan, the Office of Water has established four major strategic goals for water programs, shown in Figure 1. Each goal contains one or more subgoals:

♦ PROTECT AND ENHANCE PUBLIC HEALTH (meet designated uses)

- Safe Drinking Water
- Safe Fish and Shellfish Consumption

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Table 1 - Tasks of the ITFM National Committee

1. Develop, for each monitoring objective, a set of questions to address issues.
2. Develop QA/QC guidelines for all aspects of the strategy.
3. Develop and update a core list of environmental indicators.
4. Determine the comparability of field and laboratory methods.
5. Develop station selection guidelines.
6. Promote data sharing among major information systems.
7. Identify formatting of ancillary data needed to interpret water-quality data.
8. Promote the development and standardization of data-analysis techniques.
9. Develop unified formats for reporting water-quality information.
10. Develop and organize training for personnel of participating agencies.

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Table 2 - Products Developed or Being Developed by the ITFM

Product	Description
National Charter	A charter for a permanent national body to guide the implementation of the ITFM recommendations and to facilitate further collaboration of the many Federal, State, Tribal, regional, local, private, and voluntary organizations that are involved in monitoring.
Monitoring Framework	A framework for monitoring water quality which defines the components that a monitoring program should consider in order to ensure that it accomplishes its objectives.
Indicator Selection Criteria	Criteria with which to select parameters that measure progress in achieving water-quality goals.
Environmental Indicators Recommendations	ITFM recommendations of indicators to measure whether water-quality uses designated by the State are being met.
Methods and Data Comparability Council Charter	A charter for a Methods and Data Comparability Council to foster the development and use of performance-based methods of collection and analysis in a manner which will result in the acquisition of data of known quality. The Council will address some of the biggest obstacles to sharing data among monitoring agencies and other users.
Use of Ecoregions, Reference Conditions, and Index Calibration	An examination of reference conditions as a tool in biological assessment, and the use of the ecoregions concept as a way to categorize landscapes on which assessments are carried out.

These products are described in more detail in "Water-Quality Monitoring in the United States-1993 Report of the Intergovernmental Task Force on Monitoring Water Quality," ITFM, January 1994.

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- Safe Aquatic Recreation

◆ CONSERVE AND ENHANCE ECOSYSTEMS (meet designated uses)

- Biologically Healthy Water Resources

◆ IMPROVE AMBIENT CONDITIONS

- Improved Surface Water Ambient Concentrations of Toxic and Conventional Pollutants
- Ground Waters Meet Water Quality Objectives
- No Net Loss of Wetlands
- Extent of Contaminated Sediments is Reduced

◆ REDUCE POLLUTANT LOADINGS (point and nonpoint sources)

- Reduced Toxic Pollutant Loadings
- Reduced Conventional Pollutant Loadings

NPDES Watershed Strategy:

In March of 1994, EPA issued the NPDES Watershed Strategy. The Strategy is a first step toward the goal of integrating the NPDES program into a comprehensive, multi-program approach to addressing surface water, ground water, and habitat concerns on a watershed basis. The NPDES Watershed Strategy outlines national objectives and implementation activities to (1) integrate NPDES program functions into broader watershed approaches; and (2) support the development of State-wide basin management approaches.

One of the six essential areas identified in the Watershed Strategy is monitoring and assessment. Action items identified in the Strategy to support monitoring and assessment include:

- Develop a State-wide monitoring strategy to assure the most effective targeting of limited monitoring resources and coordinate collection and analysis of NPDES, nonpoint source, and other watershed data.

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- Establish point source ambient monitoring requirements where appropriate to support assessment of watershed conditions; this action may provide opportunities for group monitoring plans for multiple discharges to the same basin.

- Promote comparable data collection, analysis, and utilization by all stakeholders (e.g. NPDES, 303(d), 304(l), and 319) through revisions to information collection and management systems (e.g., permit applications and compliance monitoring, PCS, TMDL development, 305(b), NEP, STORET, and water body systems)

As the NPDES program moves further towards embracing the watershed strategy, monitoring in the NPDES storm water program, as in all NPDES program areas, will need to evolve to be fully supportive.

<u>The Office of Water Environmental Indicators Project:</u>

The Office of Water is proposing to evaluate progress in meeting the goals of the Strategic Plan by using a number of environmental and programmatic indicators. These indicators, when adopted, will have a strong influence on the purpose, direction and types of monitoring employed in Office of Water programs in the future. Recommended preliminary indicators for the strategic goals are outlined in Table 3. To complete this effort a significant amount of work remains, including:

- selecting indicators that major participants can agree on,
- establishing a nationwide monitoring and data system that:
  - uses information from various sources to support management systems and report on progress towards national goals,
  - uses comparable collection, reporting and analytical methods,
  - stores data of known quality in systems that can "talk" to each other,

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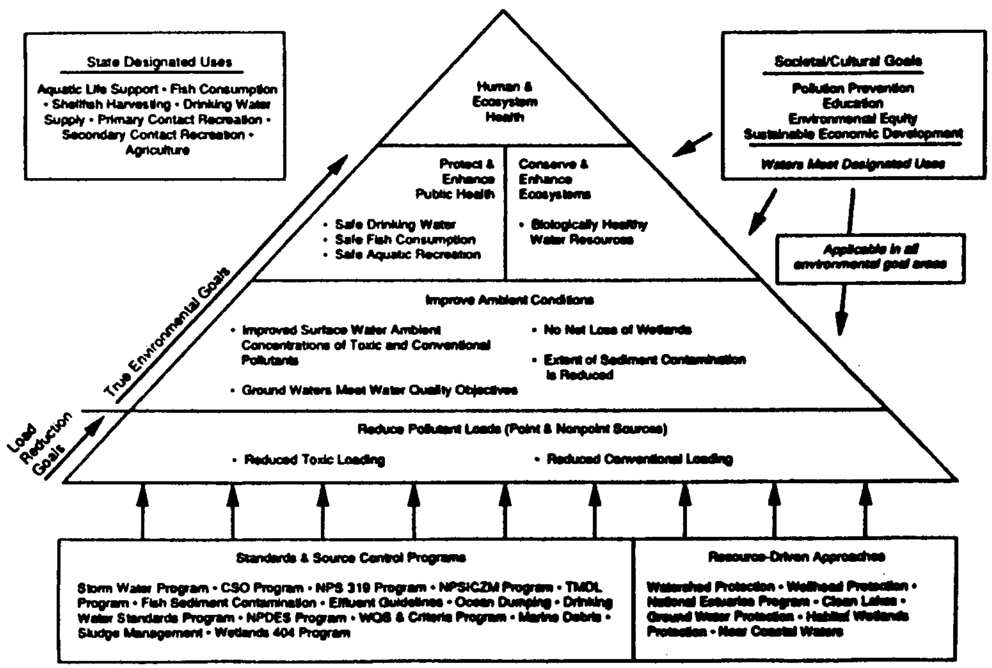
Figure 1 - Office of Water Strategic Goals



- has clear roles and responsibilities and focusses use of available resources from many sources (EPA, other Federal agencies, States, utilities, etc.).

In fiscal year 1995, EPA will be taking two major steps towards implementing the Office of Water Strategic Plan. The first step will be funding a series of State pilot projects to test selected environmental indicators. Eight States[4] will be implementing the pilot projects, lasting 18 to 24 months, using indicators from the list of 33 national indicators developed by EPA. The States will use the indicators to measure success towards reaching the goals of protecting human health, conserving and enhancing ecosystems, improving ambient conditions, and reducing pollutant loadings. These pilot projects will be our first real attempt to test "on the ground" whether the necessary steps to implement and track environmental indicators over time can be successful. The pilots will serve another important purpose--to determine if selected environmental indicators can compliment or substitute over time for some of our current programmatic measures of success for State water programs that are activity-based (such as number of permits issued and enforcement actions taken). We are very pleased with the enthusiasm shown by the States for the environmental indicators pilot project.

The Office of Wastewater Management Storm Water Environmental Indicators Project:

As a complement to the Office of Water environmental indicators effort, the Office of Wastewater Management is initiating a project that will identify and implement environmental indicators specific to the NPDES storm water program.

To accomplish this, EPA is issuing a series of grants to support the selection and implementation of storm water environmental indicators that can be used by municipalities and industries to assess the effectiveness of their storm water control efforts and to possibly provide data for the national environmental indicators tracking system. The project, which will be implemented for the most part in fiscal year 1995, includes:

[4] The States tentatively selected for the pilots are Maine, Delaware, Maryland, Georgia, South Carolina, Wisconsin, Ohio and possibly Nevada. In addition, EPA is considering a local project under the National Estuary Program in Oregon.

- compiling a summary of recent efforts to develop and implement environmental indicators for storm water discharges;
- holding a series of stakeholder meetings around the country to select environmental indicators for the storm water program, including a select list of indicators to be used for national tracking;
- preparing a report on the results of the stakeholder meetings describing the environmental indicators selected and the methodologies and criteria for implementation; and,
- awarding grants for a series of demonstration projects on implementing storm water environmental indicators.

It is the objective of this project that valuable information for selecting and implementing storm water program environmental indicators will be developed which should significantly guide the direction of storm water monitoring in the future.

Upon completion of the storm water environmental indicators demonstration projects, EPA hopes that numerous municipalities and industries will better understand, and be better equipped, to implement effective monitoring strategies for assessing their storm water management programs.

The data that is generated by municipalities, and other sources, if done in a consistent, quality fashion, should be applicable at the national level for tracking and assessing progress of the NPDES storm water program towards accomplishing the Office of Water strategic goals.

SUMMARY

Several national initiatives will directly impact the future of monitoring in the NPDES storm water program. The Intergovernmental Task Force on Monitoring Water Quality (ITFM) will be recommending that monitoring efforts be more holistic in nature and will be developing national and regional guidelines and standards for monitoring.

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Table 3 - Office of Water List of 33 Recommended Indicators

Goal	Objective	Indicators
Protect and Enhance Public Health	Safe Drinking Water	1. Waters Meet Drinking Water Supply Designated Use 2. Populations Served by Public Water Supply Systems with Wellhead Protection 3.* Populations Served by Public Water Supply Systems (ground and surface water) that Meet Drinking Water Standards 4. Blood Lead Levels in Children 5. Disease Outbreaks from Public Water Supplies
	Safe Aquatic Recreation	6.* Waters Meet Swimming and Secondary Contact Designated Uses 7. Beach Closures: Miles Closed and Organism Levels 8. Disease Outbreaks from Swimming
	Safe Fish & Shellfish Consumption	9.* Waters Meet Fish and Shellfish Consumption Designated Uses 10. Fish Advisories 11.* Waters with Fish Contaminant Levels of Concern to Human Health 12.* Shellfish Bed Closures 13. Disease Outbreaks from Fish and Shellfish Consumption
Conserve and Enhance Ecosystems	Biologically Healthy Water Resources, Including Lakes, Rivers, Streams, Estuaries, Coastal Waters, Wetlands, and Ground Water	14.* Water Meet Aquatic Life Designated Uses (including ground water discharges to surface water) 15. Fish (assemblage) or IBI-like Index 16. Benthic Macroinvertebrates (assemblage) 17. Habitat (physical structure) 18. Plankton and Periphyton Assemblages 19. Floral Composition 20. Faunal Composition

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Table 3 - Office of Water List of 33 Recommended Indicators (continued)

Goal	Objective	Indicators
Improve Ambient Conditions	Ground Waters Meet Water Quality Objectives	21.* Ambient Ground Water Quality
	Improved Surface Water Ambient Concentrations of Toxic and Conventional Pollutants	22.* Selected Water Quality Parameters 23.* Water Quality Standards Attainment
	Extent of Contaminated Sediments is Reduced	24.* Extent of Contaminated Sediments
	No Net Loss of Wetlands	25.* Loss or Gain of Wetland Acreage
Reduce Pollutant Loadings	Reduced Conventional Pollutant Loadings	26. Pollutant Loading to Ground Water from Underground Injection Wells 27.* Point Source Toxics 28.* Selected Conventional Pollutants: TSS, BOD, Fecal Coliform, and Nutrients 29. Key Wetweather Conventionals from CSOs
	Reduced Toxics Pollutant Loadings	30. Number of State and Local Governments Requiring Treatment of Stormwater Runoff from Rural, Suburban, and Urban Land Uses 31. Number of NPS Best Management Practices Implemented at State and Local Level 32. Key Wetweather Conventional Pollutants from Nonpoint Sources and Stormwater 33. Marine Debris

* Adequate data exists in the near term to establish baseline information.

The EPA National Goals Project will produce a set of realistic and measurable environmental goals to be achieved in the next century. The Goals Project will involve identifying monitoring that can be used to effectively evaluate progress towards meeting the goals.

Under the new NPDES Watershed Strategy, monitoring and assessment have been identified as an essential element to be addressed. Important objectives of the Strategy are the development of State-wide monitoring strategies to assure the more effective targeting of limited monitoring resources and the coordination of the collection and analysis of data, and the use of receiving water monitoring procedures where appropriate to support assessment of watershed conditions.

The EPA Office of Water is proposing to evaluate progress in meeting the goals of the EPA Strategic Plan by using a number of environmental and programmatic indicators. These indicators, when adopted, will have a strong influence on the purpose, direction and types of monitoring employed in water programs in the future.

Finally, the Office of Water, Office of Wastewater Management is planning the development of a set of environmental indicators that can be used specifically by storm water dischargers to evaluate progress towards meeting the goals of the NPDES storm water program and, more broadly, the strategic goals of the Office of Water.

These initiatives will result in a number of changes to monitoring approaches under the NPDES storm water program in the future. As monitoring requirements under the NPDES storm water program change and evolve, storm water professionals will be presented with unique opportunities to provide insight and expertise on innovative approaches to storm water monitoring at national, State and local levels.

American Public Works Point of View

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Abstract

Public works agencies are responsible for implementing the regulations regarding stormwater in the NPDES program. As such they become the agencies responsible for balancing environmental protection, community interests, political interests, financial constraints and the technical skills and resources necessary to carry out the goals of the Clean Water Act. To carry out this implementation role effectively there is a critical need to build the level of technical knowledge and understanding of stormwater quality and promote opportunities for sharing this information. Pressure for funding at the local level is creating tremendous resistance in communities across the country. Gaining community understanding and support requires the ability to clearly articulate environmental benefits and cost effective application of resource to address local problems. Without grassroots support, communities will become the biggest roadblocks to achieving the goals of the Clean Water Act.

Introduction

Since the reauthorization of the Federal Clean Water Act in 1987, the requirement that municipalities with populations greater than 100,000 obtain NPDES permits for separate storm sewer systems has been implemented. Across the country affected public works agencies responsible for stormwater have been developing

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stormwater quality programs and seeking permits from state environmental regulatory departments in those NPDES designated states or from EPA. The investment of resource in permit application and the sampling and data base development is significant. The resource requirement for implementation and monitoring of Best Management Practices (BMP's) covered by those permits will require an ongoing commitment.

In the early years following the 1972 adoption of the Federal Water Pollution Control Act when the primary focus of the clean water program was wastewater, up to 90% of the funding required for local agency implementation was provided from federal and state sources. Today, program costs are borne almost entirely at the local level. This fact, along with similar program funding shifts in virtually every area of local government agency programming, has presented real challenges to the implementation of the stormwater NPDES program. Coupled with that challenge is the fact that agencies across the country are scrambling to build stormwater programs based on relatively limited research and experience in the whole area of stormwater monitoring and BMP effectiveness.

Capturing and Sharing Information

Huge data bases of stormwater sampling and BMP monitoring information are being generated across the country through implementation of mandated stormwater programs. It is still uncertain when or how municipalities with populations less than 100,000 will be brought into the stormwater NPDES program. For those 200 or so communities already embarking on their first permit, there is much to learn and share. The focus of this conference is timely and critical to the effective use of the significant resource going into current permit development and implementation. It is essential that communities be able to learn from each other and share information reliably and effectively. In addition, EPA needs to be able to use the information being reported under these permits to base future Clean Water Act changes on improved understanding of stormwater quality problems. The Nationwide Urban Runoff Program (NURP), which served as the basis for the 1987 Clean Water Act amendments covering the stormwater quality program, was relatively limited, covering only 28 cities. The number of communities currently required to be permitted under NPDES and the type of data being generated should result in a far clearer picture of the need for future stormwater program regulatory changes if that data is captured and used effectively.

Not too long ago, it would have been unthinkable to expect communities to take on a research and development role for a problem of this magnitude. Unfortunately, today that is precisely where local communities find themselves. Strategies and techniques are being identified, tested and monitored in the hope that they will result in improved water quality conditions and that it will be feasible to accurately detect environmental improvements.

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In many cases, consultants working in partnership with public works agencies are providing the vehicle for technology transfer. Communities are now sharing experiences and information through common consultants, even as the regulatory agencies struggle to develop their own administrative programs. The attendance and participation at this conference reflects both this relationship and the strong common interest in sharing information and learning from other professionals engaged in the development and implementation of stormwater quality programs. This approach has been surprisingly effective but it is not adequate to handle the growing demand and need for transferable information. Authorization and funding of the National Academy of Sciences to evaluate research and development programs and provide an umbrella for better coordination and utilization of colleges and universities in expanding environmental research programs would be important and appropriate steps.

Funding

Program funding is a serious constraint. The issue of unfunded mandates has generated a tremendous local community lobbying effort in Congress and impeded the adoption of the new Clean Water Act. Across the country the demand for funding at the local level to support federal and state mandated programs, as well as those identified by local priorities, is continuing to grow. Revenue limitation initiatives are appearing throughout the states. The strategy used in many communities to implement a stormwater quality program has been the creation of a stormwater utility. That is not a problem-free option and may become even more difficult to initiate and manage over time. As an example, in Oregon there is a statewide initiative measure on the November 1994 ballot that would prohibit any new fees or changes to an existing fee without a public vote. In short, without local support for the implementation of local programs, funding will be more and more at risk. With an eye to the future and the goals of the 1972 Clean Water Act to "restore and maintain the chemical, physical, and biological integrity of the Nation's waters," it is critical to build a foundation of community consensus and support and not rely on the force of federal mandates to achieve these goals.

Building Community Consensus

Gaining community support, particularly where funding is involved, is becoming more and more difficult as public sentiment regarding government and governmental agencies continues to deteriorate. In testimony before the House Subcommittee on Water Resources and Environment this past May, EPA Administrator Carol Browner described the goal of the reauthorized Clean Water Act as "a better, more flexible clean water act that will result in increased protection for our water resources at a lower cost." Flexibility and cost effectiveness are minimum requirements for the achievement of local support. Better understanding of BMP effectiveness and the ability to shift resource from ineffective strategies to other,

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more environmentally beneficial ones are basic needs to ensure continued local support. The ability to demonstrate results and contain the otherwise spiraling resource demanded from urban residents are necessities for local program support. The ability to accurately describe the real benefits to a community that are derived from the development, implementation and maintenance of a local stormwater program is critical to gaining and sustaining local support.

Where Do We Go From Here?

The purpose of this conference is to target current needs and future directions. Months and months of work has gone into the drafts of Clean Water Act reauthorization bills that will not make it through Congress this year. Many of the individuals responsible for hammering out language in those bills are at this conference and undoubtedly have perceptions to share about possible next steps. Focusing on common goals for environmental protection and clean water will help to ensure that progress continues to be made as these needs are sorted out.

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Overview of Stormwater Monitoring Needs

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Abstract

Runoff pollution studies have attempted to quantify the stormwater pollution load contribution to surface waters since the early 1970s. This paper presents a select summary of what has been learned from previous stormwater monitoring programs and offers recommendations to help guide the future direction of such programs.

Introduction

Since the early 1960s, stormwater runoff has been recognized as a significant source of pollution to the nation's waterways. Since the early 1970s, there has been a growing body of runoff pollution research to quantify the stormwater pollution load contribution to surface waters and to characterize stormwater pollutant generation, transport, and fate. Recently, over 100 U.S. cities and numerous industries collected stormwater runoff data under the Phase I National Pollutant Discharge Elimination System (NPDES) stormwater permitting program. Additional stormwater runoff data will be collected as the Phase I NPDES permits are issued and in other stormwater programs around the world. Stormwater runoff data collection is also likely to be required under the Phase II NPDES program which will be defined this fall.

This paper presents a select summary of what has been learned from previous stormwater monitoring programs and offers recommendations help guide the future direction of such programs.

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What We've Learned from the Past

Since the early 1970s, runoff pollution research studies have attempted to quantify the stormwater pollution load contribution to surface waters and to characterize stormwater pollutant generation, transport, and fate. In the late 1970s, the "208 studies" implemented under Section 208 of the Federal Water Pollution Control Act Amendments of 1972 showed that stormwater generally contributed as much as half of the total pollutant load entering U.S. surface waters. This realization led to the U. S. Environmental Protection Agency's (USEPA) development of the Nationwide Urban Runoff Program (NURP) which was initiated to characterize the water quality of urban runoff and the potential for water quality impacts in receiving waters. NURP represents the largest research effort targeting urban stormwater runoff to date. Storm event monitoring was performed at 81 outfalls at 28 cities across the U.S. during the years 1978 through 1983.

The large number of sites monitored under the NURP program represented a wide variety of climatological conditions, land use types, land slopes, and soil types, thereby providing the basis for identifying similarities and differences among sites. Approximately 2,300 storm events were monitored, which corresponds to an average of 28 storms per outfall site. At a particular site, the monitoring was typically conducted over a 12-month period. Urban land uses monitored during the study included. residential, commercial, and limited light industrial. Several of the NURP cities also monitored receiving waters to characterize impacts of urban runoff on receiving water quality. A variety of receiving waters were monitored, including rivers, lakes and estuaries.

The NURP sampling program included a wide range of water quality constituents. For all of the 2,300 storms events monitored, constituents analyzed included total suspended solids (TSS), chemical oxygen demand (COD), biochemical oxygen demand (BOD), total phosphorus, dissolved phosphorus, total Kjeldahl nitrogen (TKN), nitrite + nitrate nitrogen, fecal coliforms, lead, zinc and copper. In addition, a limited number of grab samples were collected during 121 storms and were subsequently analyzed for priority pollutants. At the time, the priority pollutant list included 129 constituents.

The event mean concentration (EMC), which is defined as the total constituent mass in runoff divided by the volume of runoff during a given storm event, was established as the primary water quality statistic in the NURP study. EMCs were estimated at monitoring sites for individual storm events by collecting and analyzing flow-weighted composite samples of runoff generated by each event. At other sites, however, the monitoring consisted of a set of sequential discrete samples collected during a storm event. For these sites, EMCs were calculated by analyzing the hydrographs (flow vs. time) and pollutographs (concentration vs. time) from each storm.

USEPA analysis of the pooled national database from all of the project sites could not explain the variability of the pooled national EMC values by any single factor such as land use, soil type, land slope, climatology or geographic location. These and other transferability evaluations led to the development of a general characterization of urban runoff which can be used nationwide for estimating stormwater pollutant loadings from unmonitored areas. The pooled national NURP urban runoff characterization was recommended for use in planning level water quality studies, unless more localized water quality data are available. Another product of the NURP study was the development of standard monitoring and data analysis approaches which have been used by many subsequent stormwater pollution studies.

Since the NURP study, other stormwater monitoring studies have continued to quantify the pollution load contribution to surface waters and to characterize stormwater pollutant generation, transport, and fate. The U.S. Geological Survey (USGS), for example, has developed an urban storm runoff database consisting of data for over 1,100 storms for 98 urban stations in 20 metropolitan areas. The Federal Highway Administration (FHWA) investigated stormwater runoff loadings from highways by analyzing storm event monitoring data at 31 highway runoff monitoring sites in 11 states during the 1970s and 1980s.

NPDES Stormwater Monitoring

Recently, over 100 U.S. cities and numerous industries were required to collect stormwater runoff data under the Phase I National Pollutant Discharge Elimination System (NPDES) stormwater permitting program. Each Phase I municipality was required to characterize stormwater runoff by monitoring a minimum of 5 "representative" sites during a minimum of 3 storm events. The monitored sites were chosen to characterize discharges representative of commercial, residential, and industrial land use activities of the drainage area contributing to the system. The NPDES sampling protocols were derived from the NURP study. A composite sample from each storm event was analyzed for conventional pollutants (including nutrients, solids, oxygen demand, fecal bacteria) and for priority pollutants (toxic organic and inorganic compounds). Stormwater quality characterization data was based on estimating the EMC from a single flow-weighted composite sample prepared by combining discrete samples collected over the duration of the storm event. The intent of this permit application requirement was to ensure that the system discharges can be appropriately represented by the various existing data bases and to provide a basis for developing a monitoring plan to be implemented as a permit condition.

Use of Existing Data

A comprehensive analysis of all available storm event water quality data collected over the past 15-20 years has not been performed. A comparison of NURP data collected in the early 1980s with the NPDES data collected in 1991 - 1993 in the

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State of Michigan is presented below. Three of the NURP studies were located in Michigan (Washtenaw County, Oakland County, and the City of Lansing) with approximately 100 storm events monitored at eleven stations. As part of the NPDES stormwater permit application process, representative outfalls were recently monitored in the Michigan Cities of Warren, Flint, Ann Arbor, and Grand Rapids and at the University of Michigan. The Michigan NPDES data includes EMCs for approximately 75 storm events that were monitored at 27 stations.

The stormwater monitoring data comparisons presented below are based on the lognormal means of the data reported for each site. When data are characterized by infrequent extreme observations, as often happens in water quality monitoring, it is appropriate to apply a lognormal distribution. Studies such as the NURP and FHWA programs described previously have shown that stormwater quality data are best represented by the lognormal distribution. The appropriate statistic to employ for comparisons between individual sites or groups of sites is the median value, because it is less influenced by the small number of large values typical of lognormally distributed data. However, for comparisons with other published data which usually report average values, the mean value is more appropriate.

Table 1 compares the Michigan NPDES EMCs for residential, commercial, and industrial land uses with the Michigan NURP and national NURP EMCs. It should be noted that the NURP sites did not represent any heavy industrial land uses, but rather light industrial park land use. In general, the mean Michigan NPDES EMCs are within the range of EMCs reported under the earlier studies with the exception of lead. For oxygen demand (biochemical oxygen demand (BOD) and chemical oxygen demand (COD)), Michigan NPDES concentrations are generally higher than NURP EMCs for residential and industrial land uses while Michigan NPDES concentrations are lower than NURP for commercial land uses. For total suspended solids (TSS), EMCs reported for the residential and commercial Michigan NPDES sites are as much as 40% lower than NURP EMCs while those for industrial land uses are similar to NURP EMCs. Nutrient (phosphorus and nitrogen) NPDES concentrations are very similar to national NURP EMCs for all three land use categories. However, lead EMCs reported for the Michigan NPDES sites which were monitored during 1991 through 1993 are an order of magnitude lower than those reported in the NURP and other earlier studies which include data collected during the mid-1970s through early 1980s. The primary reason for the decrease in lead EMCs is probably the increased usage of unleaded gasoline.

The previous monitoring studies such as the NURP and the recent NPDES monitoring programs provide stormwater pollution loading data on which to base estimates of stormwater pollutant loadings from a given area. In the case of the Michigan NPDES programs and other programs reviewed, the recent monitoring data compares well with that collected during previous studies. Therefore, continued emphasis on single land use "end-of-pipe" monitoring programs is

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TABLE 1
COMPARISON OF SELECTED STATE OF MICHIGAN MUNICIPAL NPDES MONITORING DATA TO NATIONAL RUNOFF DATA FOR RESIDENTIAL, COMMERCIAL, AND INDUSTRIAL LAND USE

Constituent	Units	EVENT MEAN CONCENTRATIONS (1, 2)							
		Michigan NPDES				Michigan NURP (6)		National NURP (7)	
		N	MAX	MIN	MEAN	N	MEAN	N	MEAN
RESIDENTIAL LAND USE (3)									
BOD	mg/L	43	125	2	26	58	16	134	11
COD	mg/L	43	316	27	102	71	85	913	83
TSS	mg/L	42	380	2	84	97	125	1,102	140
Total-P	mg/L	34	1.23	0.07	0.38	95	0.32	1,029	0.47
Dissolved-P	mg/L	34	0.98	0.02	0.18	88	0.07	344	0.16
TKN	mg/L	31	4.90	0.03	2.24	96	1.62	904	2.35
NO2 + NO3	mg/L	31	2.80	0.03	1.98	94	0.83	593	0.96
Lead, total	ug/L	43	200.0	3.5	48.7	71	116.8	802	180.0
Copper, total	ug/L	43	97.0	10.0	29.6	44	18.2	468	50.0
Zinc, total	ug/L	43	600.0	10.0	189.5	45	154.0	797	180.0
COMMERCIAL LAND USE (4)									
BOD	mg/L	19	140	1	21	8	52	171	14
COD	mg/L	19	150	26	80	9	99	243	92
TSS	mg/L	19	280	5	77	10	149	309	186
Total-P	mg/L	16	0.96	0.05	0.33	10	0.16	307	0.29
Dissolved-P	mg/L	16	0.90	0.02	0.17	10	0.07	62	0.17
TKN	mg/L	14	4.00	0.57	1.74	10	1.25	223	1.61
NO2 + NO3	mg/L	13	1.50	0.03	1.23	9	0.74	209	0.89
Lead, total	ug/L	19	150.0	1.5	49.3	10	56.9	291	235.5
Copper, total	ug/L	19	130.0	10.0	37.0	10	14.0	152	61.8
Zinc, total	ug/L	18	380.0	48.0	156.3	8	69.3	221	399.5
INDUSTRIAL LAND USE (5)									
BOD	mg/L	11	73	5	24	17	7	25	10
COD	mg/L	10	150	41	85	23	64	39	61
TSS	mg/L	11	271	5	149	38	143	61	123
Total-P	mg/L	7	1.14	0.06	0.32	35	0.49	56	0.49
Dissolved-P	mg/L	7	0.69	0.02	0.11	30	0.09	51	0.17
TKN	mg/L	7	3.60	1.00	2.08	36	1.49	53	1.53
NO2 + NO3	mg/L	7	3.60	1.30	1.89	35	0.71	40	0.79
Lead, total	ug/L	11	130.0	3.0	72.4	26	115.5	26	115.5
Copper, total	ug/L	9	172.0	12.5	58.0	13	30.1	18	31.7
Zinc, total	ug/L	11	1,230.0	140.0	670.8	14	233.5	20	979.8

NOTES:

(1) Values below the detection limit were analyzed at 50% of the detection limit.

(2) Event mean concentrations assume that the data are lognormally distributed.

(3) Values reported for the Michigan NPDES sites were calculated for 29 single family storm events and 14 multi-family storm events from sites located in the Cities of Ann Arbor, Flint, Grand Rapids, and Warren, and at the University of Michigan during 1992 - 93. Values reported are the averages of the single family and multi-family lognormal means.

(4) Values reported for the Michigan NPDES sites were calculated for 19 commercial storm events from sites located in the Cities of Ann Arbor, Flint, Grand Rapids, and Warren, and at the University of Michigan during 1992 - 1993

(5) Values reported for the Michigan NPDES sites were calculated for 11 industrial storm events from sites located in the Cities of Flint, Warren, and Grand Rapids during 1992.

(6) "Final Report of the Nationwide Urban Runoff Program," (NURP) USEPA, 1983, Tables 6-1 through 6-10 for the Pitt AA-N, Grace N, Grand R. Ot., and Waverly sites and "SEMCOG/Oakland County NURP Project Final Report," SEMCOG, 1983, Table 3 for the combined Beaver Trail and Sylvan Glen sites.

(7) NURP, USEPA, 1983, adapted from Table 6-12.

probably not warranted. However, many of the Phase I NPDES cities are proposing to continue this type of program for the 5-year permit term.

As mentioned previously, a comprehensive analysis of all appropriate storm event water quality data collected over the past 15-20 years has not been performed. We recommend that such analysis be completed to aid in the development of future monitoring programs. For example, the variability in EMCs among NURP sites was greater than any observable variability among geographic regions which made development of land-use specific or regionalized EMC estimates infeasible. Analyses of the NURP data for seasonal differences among EMCs were either not performed or not reported by the NURP team. Clearly these analyses, particularly investigation of regional, geographic, or seasonal differences among EMCs, need to be performed on the larger database of monitoring data available today to guide the direction of future stormwater pollution research.

Objectives of Future Monitoring Programs

Monitoring data collected under the existing Phase I NPDES stormwater permitting program has further supported the premise that stormwater runoff is a significant source of pollution to the nation's waterways. Data collected during development of the Phase I permit programs has been and will be used to aid municipalities and industries in the development and refinement of management programs to reduce stormwater pollutant loadings to U.S. surface waters. Most stormwater management specialists nationwide recognize, however, that effective management programs for protecting our nation's water resources should be based on a watershed basis instead of a jurisdictional basis. This sentiment is also reflected in the recent drafts of the upcoming Clean Water Act (CWA) Reauthorization; both the House and Senate CWA reauthorization bills include language to this effect.

It is our recommendation that nonpoint pollution management plans and the monitoring programs which support their development and implementation should include all nonpoint sources of pollution within a watershed. Many of the NPDES stormwater programs focus exclusively on characterizing stormwater pollution from an industry or a municipality. In urban areas, pollutants from other sources such as atmospheric deposition and contaminated river bottom sediments may also be significant and should be characterized to support a comprehensive management plan.

The current NPDES program relies on "end of pipe" monitoring data to assess the effectiveness of management programs implemented to reduce nonpoint pollution loadings to a receiving water. This approach does not provide local decision-makers with information regarding the performance of individual management measures and programs. We recommend that NPDES monitoring programs also characterize the performance of individual management measures such as detention ponds or source control activities within the watershed investigated. This action

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will provide local data to guide the development and refinement of management programs tailored to the characteristics of the local community. In addition, local data on the benefits of requiring costly management measures will aid local decision-makers in the implementation of stormwater management programs.

The overall objective of a nonpoint pollution monitoring program such as those required for NPDES permitting should be to support watershed management decisions by local decision-makers. Specific objectives should be:

1) to refine land use nonpoint pollution loading relationships within a watershed,

2) to provide quantitative information regarding the pollutant removal efficiencies that are achieved by structural and nonstructural best management practices (BMPs),

3) to provide sufficient field data to calibrate and verify pollutant loading estimates, and

4) to conduct special studies to characterize other sources of pollution (e.g., atmospheric deposition, contaminated sediments, biological/habitat assessment) to the extent possible.

Approach for Future Monitoring Programs

The Phase I NPDES stormwater permitting program required collection of monitoring data during the permit application process according to specific protocols outlined in the regulations. During the term of the permit, stormwater quality monitoring is also required but a municipality has more flexibility in devising the monitoring program. The time frame and costs associated with collecting an adequate urban stormwater database for planning, implementing, and evaluating stormwater management plans may, however, exceed the resources available. Consequently, it is recommended that all available existing data from local and regional studies be used. Additional data collection should be carefully planned to ensure that it does not duplicate previous efforts and can be used to augment the existing data. Data collected merely to meet permit requirements may be wasted if it does not support stormwater planning and management needs.

USEPA did not specify minimum standards for the monitoring program to be completed by Phase I municipalities and industries during the 5-year term of the permit but allowed the permitees to design their own programs. A review of monitoring programs proposed by a number of Phase I municipalities revealed that most programs specified continued characterization of land use nonpoint pollution loading relationships within their community by monitoring/sampling at most of the same sites monitored during the permit application process. The number of parameters analyzed, however, is typically substantially reduced from the number required during the permit application process. Further, most proposed programs reviewed specified on the order of 4 storm events sampled per site per year.

Most of the proposed permit term stormwater monitoring programs proposed to date do not include provisions for estimating the pollutant reductions achieved by the structural and nonstructural BMPs (objective 2 above) which already exist in the municipality or which may be implemented as part of a stormwater management plan. For structural BMPs, available pollutant removal performance data shows that pollutant removal efficiencies achieved by BMPs will vary from one storm to the next. After very large storm events or during wet periods, BMPs may exhibit low or negative efficiencies due to insufficient detention times, scour, or resuspension of sediments. Conversely, higher efficiencies may be achieved after smaller storms or during storms that occur after extended dry periods. For nonstructural BMPs, little pollutant removal performance data is available in the literature. For example, few stormwater quality monitoring programs have attempted to document the effectiveness of public education programs aimed at preventing such pollutants as used motor oil and lawn care products from entering receiving waters. Many of the management programs proposed as part of the Phase I NPDES municipal stormwater permit applications submitted to date, however, rely heavily on the use of nonstructural BMPs to reduce stormwater pollutant discharges to the "maximum extent practicable" (MEP) as required in the regulations. Future NPDES monitoring programs should therefore include provisions for defining the effectiveness of management programs implemented and for defining the MEP pollutant reductions for the municipality.

Stormwater monitoring programs to support NPDES stormwater permit programs should be designed to provide a reasonable level of statistical significance on an annual basis as well as over the 5-year permit term. This program design is necessary if regulatory agencies use annual and cumulative data for assessments of the effectiveness of management programs. For many pollutants found in urban runoff, the efficiencies of structural and nonstructural BMP program elements are likely to be on the order of 5% - 10% (nonstructural) up to 50% - 90% (structural). Citywide pollutant loading reductions for typical NPDES stormwater management programs developed to date are likely to be less than 25% for many pollutants under full implementation. In order to demonstrate the progress of local management programs over the 5-year permit term, the estimated mean EMCs from the municipal monitoring database should have a level of accuracy which will reflect reductions due to BMP programs. If the loading reductions achieved by the BMP programs are on the order of 5% - 50%, it will be difficult to draw any meaningful conclusions from the monitoring data if the estimated mean EMCs have a relative error which is much greater than the BMP efficiencies.

Those monitoring programs designed to provide a reasonable level of statistical significance on an annual basis as well as over the 5-year permit term will also demonstrate local benefits of the management program on an annual basis to local decision-makers and the public. Investigations of receiving water quality impacts may also be warranted to aid in management program assessments. The monitoring program should also allow for investigations of seasonal and other bias in the collected data over the 5-year permit term. A monitoring program designed around these recommendations should satisfy both objective 1 above, characterization of land use nonpoint loading relationships within a municipality, and objective 3 above, provide sufficient field data to calibrate and verify pollutant loading estimates as necessary.

In some urban areas, other nonpoint sources of pollution may cause water quality impacts equal to or exceeding those resulting from stormwater pollution loadings. For example, bottom sediments in receiving waters may be heavily contaminated and may introduce significant pollutant loads to the water column. Nonpoint source pollution monitoring programs should investigate such sources to provide data to guide the development of cost-effective watershed management plans. Guidelines for monitoring programs to characterize other nonpoint sources of pollution (objective 4 above) must be developed in accordance with the local situation.

Alternative Approaches for Future Monitoring Programs

There are alternative approaches in addition to monitoring the chemical quality of stormwater, which can be used to generate environmentally relevant information to guide the stormwater control plan for a municipal area. Biological and chemical monitoring of receiving waters enable both the evaluation of receiving water impacts and potential identification of stormwater pollutant sources, although these tools can be most effective when used in conjunction with traditional chemical analysis of stormwater (e.g., end-of-pipe monitoring). One advantage of including receiving water and biological monitoring in a stormwater monitoring program is that stream health can be directly assessed without relying solely on chemical surrogates and highly variable stormwater outfall data. In addition, use of biological monitoring may help address concerns about the aggregate affect of stormwater pollutants as well as the bioavailability of those pollutants. Another benefit of including chemical, biological and receiving water components in a stormwater monitoring program is that it may provide more cost-effective information to guide the direction of local stormwater management plans.

Data Analysis

A critical component of a stormwater monitoring program to support stormwater management plans is effectively utilizing the data collected in order to achieve the program's information goals and monitoring objectives. The conversion of data into information should begin with specified data handling procedures including adherence to quality assurance and quality control protocols. Statistical procedures for analyzing the collected data should be established to ensure that the information generated both matches the ability of the data to yield such

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information with confidence and matches the needs and expectations of decision makers. Finally, for NPDES permit monitoring programs, the results of the monitoring program should not be reported independently but as part of the overall report of the progress of the management program. Other information such as how much of the system was served by BMPs and how the results guided management program decisions should be part of the overall management program report to the regulatory agency.

Conclusions

A stormwater monitoring program to support a management plan to protect water resources such as is required under the NPDES stormwater permitting program should be developed on a watershed basis and should be tailored to address as many local sources of nonpoint pollution as possible. The development of the monitoring program should be based on an inventory of all local sources of NPS pollution (e.g., urban runoff, contaminated river bottom sediments) and available local, regional, and national data to characterize those sources. In addition, provision for assessing the success of the management program should be made in the monitoring program. Local data on the pollutant removal efficiencies of preferred structural and nonstructural management practices should be collected to aid local decision-makers in the development, implementation, and refinement of the management program. Investigations of receiving water impacts or biological assessments may also provide valuable data to guide local nonpoint pollution management policies. Most of the recent NPDES monitoring data reviewed compares well with that collected during previous studies. Therefore, continued emphasis on single land use "end-of-pipe" monitoring programs is probably not warranted.

Stormwater monitoring programs to support NPDES stormwater permit programs should be designed to offer a reasonable level of statistical significance on an annual basis and over the entire permit term. This program design is necessary if regulatory agencies use annual and cumulative data for assessments of progress of management programs. This design will also demonstrate local benefits of the management program on an annual basis to local policy-makers and the public. The monitoring program should also allow for investigations of seasonal and other bias in the collected data. A critical component of a stormwater monitoring program to support stormwater management plans is the effective handling and use of the data collected.

Continuing research is also needed in the area of stormwater pollutant generation, transport, and fate. The authors recognize that such research is beyond the scope of the NPDES stormwater permitting program. This research is necessary, however, to develop new management practices in the continuing quest to restore and protect the nation's water resources.

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HOW TO MONITOR *ONLY* THE IMPORTANT PARAMETERS

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ABSTRACT

On-line ranked sensitivity analysis of complex, continuous, deterministic models allows determination of the important processes, parameters and variables. For this purpose, the model must be complex to the next degree, and the sensitivity analysis must be thorough and complete; e.g. parameters must have been optimized. Written for a drag-and-drop Windows environment, the shell *PCSWMM for Windows* aims especially at sensitivity, calibration and error-analysis (SCEA). SCEA is rendered semi-automatic for the United States Environmental Protection Agency's Storm Water Management Model, supporting about 10^2 differently named, and 10^4 - 10^5 total, parameters for the RUNOFF module alone. Fuzzy logic is used to interpret the ranked parameter sensitivity in various RUNOFF state-variable spaces, and to reduce the scope to a computable effort. An application of the recommended methodology to the Redhill Creek in Hamilton, Ontario, displayed the most significant parameters for three objective functions automatically, and required 33 minutes CPU time on a '486 PC.

INTRODUCTION

In North America and elsewhere, engineers and others are working to restore the damaged environment, especially aquatic habitats and ecosystems that have been displaced or destroyed. Unable (or unwilling) to address the elimination of the root cause of these problems (human population intensification and associated lifestyles), engineers seek instead to prescribe engineering solutions, usually in the form of further but gentler landscape interventions.

To do this, they need first to understand the complex aquatic ecosystems being modified and, typically, degraded. Best available models (BAMs) are accordingly used to help find the cheapest of many potential arrays of assorted best management practices (BMPs), but their inherent complexity renders the model applications uncertain. Field data monitoring is necessary therefore to authenticate the modelling, a troublesome task, since

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the methodology for resolving model complexity is still emerging, and few universally-acceptable guidelines exist.

In the end, regulators are pressed to impose blanket and costly monitoring requirements in their search for expediency and uniformity in dealing with the pervading uncertainty. Thus expensive analyses of large numbers of water samples for obscure pollutants has become common if not mandatory. Costs have sky-rocketed and often the results are not useful. As a result, developers, the public, politicians and others are skeptical about the benefits of expensive sampling projects, and of very expensive analyses for trace contaminants.

Fortunately a simple solution is readily at hand: on-line ranked sensitivity analysis to determine which of the important processes, parameters and variables that are relevant to the damaged ecosystem, should be pursued first. Of course, the BAM used in the study must be at least more complex than is required for the current planning, design or operational exercise. In other words, the model should include code explicitly describing all processes that are significantly active in this problem or application. And the sensitivity analysis must be thorough and complete, not the arbitrary and casual task commonly practised today. For example, the parameters must be optimal before being finally ranked for sensitivity, and the procedure must be efficient. For managing the monitoring, continuously computing the ranked sensitivity is a fundamentally important component activity.

Written for a drag-and-drop Windows environment, the shell *PCSWMM4 for Windows* (James, 1994) aims especially at sensitivity, calibration and error-analysis (SCEA) for design applications using large-scale, long-term, continuous modeling at high spatial and temporal resolution. SCEA is rendered semi-automatic for version 4.3 of the United States Environmental Protection Agency's (U.S.EPA's) Storm Water Management Model (SWMM4.3). For a single run of the urban hydrology module (RUNOFF) alone, the shell supports over 10^2 different, and circa 10^4 total, parameters. Fuzzy logic is used to manage the complexity, and to interpret the ranked parameter sensitivity in various RUNOFF state-variable spaces. Here in this paper we deal only with ranked sensitivity; the fuzzy logic is to be published elsewhere later.

BACKGROUND DEVELOPMENT

In accord with common practice, the artificial distinction between *field-data-gathering* on the one hand, and *modeling* for planning, design and operation on the other, is highlighted by this conference. Our very terms of reference at this meeting suggest that there is a dichotomy, that the two activities are somehow separable. They are not. Both are mandated, adopted or indulged for the sole purpose of determining the probable behaviour of an aquatic system, normally as the result of anthropogenic impacts, including modifications aimed at eco-restoration.

Distinguishing between the two activities places narrow limits on professionalism. Almost by definition, professional engineers are both skilled data-gatherers *and* skilled model-users (i.e. problem-solving designers). In this paper I suggest that all these skills can and should be rolled into one coherent single skill. For example data-gatherermodeller-engineers in the field could use enhanced code with their special models to determine whether the sample about to be taken is worth it, and the same modeller-data-gatherer-engineers at the workstation could use special programs which read the data remotely and are linked to their models to determine whether the process about to be modelled is worth the effort. Such computer programs are only now emerging, and not yet commonly available.

What is needed is a method whereby data gatherers control the modeling, while modelers in turn control the data monitoring. Clearly the special software postulated above would underpin an acceptable methodology, one that keeps the costs of the two components of the study in balance with their expected benefits, the balance to be found in terms of the credibility of the recommended optimal array and capacities of BMPs. In other words, a methodology that relates the effort of the information-processing (monitoring, modeling and their synthesis) on the one hand, to the importance of the restoration effort (planning, design and operational effort to restore the *as-is* or *to-be* damaged ecosystems, often to some *as-was* state) on the other.

Part of the problem may be that funding and resources flow from two different lines in the budget, or through two different departments. (Often the agency responsible for natural resources provides the data-gathering resources, and the agency responsible for the environment, the modeler-analysis resources.) A rule may be tentatively proposed at this stage: *Avoid funding studies where specialists perform only one of the two study components without control of the other.*

VERSION 4.3 OF PCSWMM FOR WINDOWS[1]

Pursuing the benefits of the ever-improving hard- and software environment, the shell (*PCSWMM4 for Windows*) described in this paper was written by Rob James for a drag-and-drop, Windows operating system. So far as is known, this is the only shell to focus especially on sensitivity, calibration and error-analysis (SCEA) for design applications using large-scale (say 1000 and more elements) and long-term (say 75 years) continuous modeling at high resolutions (elements of say 100 ft length, 1 acre extent and integration intervals of 60-seconds); the shell was chiefly written for the currently latest version (4.3) of the United States Environmental Protection Agency (U.S.EPA) program called the Storm Water Management Model (SWMM4; see Huber and Dickinson, 1988). Contrariwise, several papers in the peer-reviewed literature, claim that these specifications are impossible to achieve.

Of course the shell also includes the usual graphics user interfaces that are windows, interactive, menu-driven and pointing-device oriented (GUI-WIMP; note that these gooey wimps are not what they sound like - they were created to be *robust*). Pre- and post-processors for data input and output interpretation are included. But most significantly, SCEA is rendered semi-automatic for approximately 10^2 different hydrologic parameters and a total number of parameters in the order of 10^4, depending

[1]This part of the paper has been abstracted from the user documentation for *PCSWMM for Windows* - see James, 1994.

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on the processes active, and the spatial resolution. James and James (1993) describe the genesis of PCSWMM4.

Various objective functions, performance evaluation functions and error functions are used in *PCSWMM for Windows*. Since the error analysis is linear, with first and higher order sensitivity gradients, the procedures depend on user-intervention at various levels. Intensive, interactive user-dialog demands that the terms used are carefully defined, especially if they differ in important ways from much of the literature, which has heretofore been understandably loose. So, for clarity, the terms used are once again defined in the following terse discussion:

Modeling has the simple purpose of evaluating the likely performance of potential arrays of various BMPs in an impacted watershed, and determining the "best" array, according to some presumed, prevailing values. If we had prior knowledge of all such performance, sufficient to determine reasonably precise optimal BMP capacities, then modeling would of course be a waste of time. The corollary to this is that, if we had available prior field observations of the performance of all arrays of all types of BMPs for all aquatic systems and physiographies, again we would not need to model. *Because these two alternatives are infeasible, given the inherent complexity, we may conclude that modeling will remain necessary for the forseeable future.*

Processes underlying the BMP performance are imperfectly known, even for the *as-is* system, the best-known of the arrays to be modelled, and thus the computed model output is uncertain. The *to-be* (proposed interventions, the so-called *what-if?* scenarios) and *as-was* systems (pre-development, especially if pre-forest-clearance or pre-agricultural) are even more uncertain. This is especially true of surface water pollutant processes. Field data monitoring is required to validate the models; if the model were certain for all arrays then monitoring would of course be a waste of time. *Because even the best available codes are uncertain models of proposed BMP arrays, field data monitoring will also remain necessary for the forseeable future.*

PCSWMM4 for Windows is a *shell* - code that is written around existing code, usually to provide better human interaction. In this case the existing code is *SWMM4.3* - a collection of programs comprising hundreds of files, hundreds of routines, and scores of thousands of lines of FORTRAN source, object and executable code; more specifically SWMM4.3 refers to the U.S.EPA official issue, compiled and linked using Ryan-McFarland products, and downloaded during or after June, 1994. It makes little sense to test a *program* for SCEA.

On the other hand, a *model* (here a deterministic surface water quality model), is more accurately described as the combination of both 1. a program, together with 2. its input datafiles, such as a SWMM application. A model may have a useful life extending over decades. In this sense, SWMM is a misnomer. Both the program and the model evolve over time. Thus models may become very complex, integrating over time encyclopedic knowledge of component processes as it becomes available, applying it to vast databases as the databases build over time, examining potentially thousands of arrays of best management practices (BMPs) as they are put forward from time-to-time, re-running each array for say 75 years of hydro-meteorologic and physical topo-hydrographic data. A further rule may now be posed: *A model can and should be tested for SCEA and the uncertainty always reported as a part of the computed output. Indeed not to do so, is likely a dereliction in design engineering ethics.*

Chief among the variables in the input data file that distinguish a model, are *parameters* - coefficients that are input, but less likely to form very long time-series at a fine time resolution, and that generally control independent component processes. Some parameters are readily quantified within narrow limits, but others cannot be measured in the field at all - *calibration* is the only way that reasonable values can be estimated for the latter.

An important attribute of parameters is *parameter sensitivity* - the influence of a parameter's value on the model output. Parameters are said to be sensitive when relatively small changes in the value of a parameter significantly affect the computed *objective function*, such as event peak concentration, or event total constituent load. This attribute may be determined by *sensitivity analysis:*

1. varying model coefficients or parameters one at a time, with the amount varied being representative of the uncertainty in the parameter being analyzed,
2. dividing the resulting normalized change in computed response by the dimensionless parameter change, to give the *normalized sensitivity gradient*, and
3. ranking the resulting modulus of the sensitivity gradients, highest to zero, with an explanation for the rank order.

Among the reasons why the modeling exercise is a challenge are:

1. every application is different,
2. every design question poses new hydrologic interventions, and
3. the hydro-met input time-series may for simple problems be sub-divided into at least nine major event-types.

All of these complications materially change the relative sensitivity.

The most important processes are the *dominant processes* - those hydro-pollutional processes, coded into the program, which, when coupled with the input datafile, are active and represent large percentages of contribution to the computed objective function. For example, ground surface infiltration and impervious-area overland-flow are processes coded into SWMM; on urban areas at low rates of rain, impervious-area overland-flow dominates, and ground surface infiltration is utterly insensitive, if considering peak pollutant and flow flux rates. Dominance is related to specific *state variable space* - the combinations of input variables that relate to one or more status variables that most indicate the dominant processes, and that trigger changes of the dominance of those processes, among others that are all coded into the program. Lack of space prevents a discussion here of the fuzzy logic and state variable space approaches used in *PCSWMM4 for Windows*.

Clearly, these procedures encourage users to explore the SCEA for each application and may be said to be *heuristic* - relating to exploratory problem-solving techniques that use self-educating ideas. Dealing with large numbers of processes, sub-spaces, time-series, parameters, objective functions, event types, and performance-evaluation functions can be confusing for novices, and the water quality processes may be more readily understood if they are deemed to be fuzzy. A *fuzzy process* is a process that may be expressed in relative terms, and that has different levels of dominance, dependent on one or more state variables. For example, the modeling of spatially-and-time-averaged (STA) pollutant build-up and wash-off is a fuzzy process when the water transfer rate (such as rainfall droplets or evapo-transpiration) at the ground surface level oscillates from zero to low rates: under these conditions, is *pollutant build-up* or *pollutant wash-off* dominant, or relatively more significant?

Ultimately, the point is to reduce the *error* - the difference between an objective function for a computed and an observed time series. Thus the *best* values of parameters are sought. *Parameter optimization (estimation) or calibration* is a procedure to discover the approximate global optimum of an array of modeling parameters, each of which can only be discovered by estimation, and are not directly measurable in the field, at least not with precision. *Calibration* is completed when a *performance evaluation function*, defined as a measure of degree of fit between measured and computed objective functions, is minimized.

On ethical principles, we deal here only with *continuous modeling* - a simulation that models both the dry and wet processes of pollutant hydrology, with a continuous, long-term record of atmospheric and hydrologic data. In contrast, *event modeling* is a simulation of short, defined storm events using a model that ignores (usually) dry weather processes, and uses subjective start-up conditions. When using events for SCEA, the situation is different from routine event modeling: start-up conditions are known, and certain processes are inactive rather than ignored.

PCSWMM4 for Windows is a *decision support system* - code that manages the simulation system, as opposed to the internal process codes (collectively called the *engine*). This methodology also involves:

error analysis - the computation of the likely error that a computed response may incur;

dissaggregation - the degree to which the physical components of a system are modeled by increasing the number of defined processes;

discretization - the number of spatial components selected to represent the physical system that has been dissaggregated into processes, and the degree to which the physical parameters are averaged (lumped) spatially and temporally;

model complexity - a measure of the number of uncertain parameters in the model. Models should be neither too complex nor too simple for the problem and problem-solving environments.

By *environment* we mean the space with its objects that surrounds a thing that is considered to be more important. Principal among the purposes of the modeling effort is to design an optimum array of *best management practices (BMPs)* - landscape interventions that temporally divert, store or treat urban stormwater runoff to remove pollutants, reduce flooding or provide other amenities.

Finally the method must be *computable* - a simulation that can be performed in a working day (eight hours) using, and providing computed output that can be contained on, typical engineering office workstations, comprising (say) 500 megabyte (Mb) hard disk and a 486-66 motherboard with 16 Mb dynamic memory (DRAM).

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SENSITIVITY GRADIENTS

Sensitivity gradients are computed by *PCSWMM4 for Windows* by generating input datafiles that are very large; m times larger than single event runs (m is defined below). Since the constituent pseudo-events are very short, and efficiencies have been made in constructing the datafile, the runs are quite quick, even for datafiles for which m is large, say $m = 10^5$ or larger.

Normalized sensitivity gradients (NSGs) are computed by dividing A, the differences in the computed relative objective function, by B, the relative difference in the input parameter value, for all relevant parameters. All NSGs are accumulated and ranked. Plots are also limited to the most significant parameters, since most parameters have negligible sensitivity. Typical examples are given later.

Time savings are achieved by automatically running the model once, but for m appropriate pseudo-events, where: $m = (aN + 1)$ and N is the number of parameters to be analyzed for sensitivity. For the RUNOFF module:

$$N = \Sigma[(11{*}CA+14)+(8{*}PI)+(3{*}WE)+(20{*}CA)+(5{*}CA)+(6{*}LU+11{*}PO+12{*}CA+4]$$

In this equation, the summation is done over all RUNOFF calls, and the terms in the right hand side refer to the following broad categories of processes: catchments, pipes, weirs, groundwater, erosion and pollutants respectively (snowmelt, pumps and orifices have been excluded here). Variables in these equations are:

- a = 2 for both linear and parabolic sensitivity curves,
- a = 4 for fifth-order sensitivity polynomials,
- CA = number of sub-catchments in each call,
- PI = number of pipes and gutters,
- WE = no. of weirs,
- LU = no. of land uses defined, and
- PO = no. of pollutants.

These equations are given for a single objective function, and only one event type. Although not all objective functions are relevant to all parameters, it should be borne in mind that 20 different objective functions, and nine event types are available, so the theoretically maximum m is of the order of 10^7. Of course the actual number of runs will be much less, and easily computable.

APPLICATION TO THE REDHILL CREEK IN HAMILTON, ONT.

The City of Hamilton's urban drainage system comprises an area of about 120 sq. km which generally drains northward through twenty major combined sewer outfalls to Hamilton Harbour and Coote's Paradise. Three major drainage basins have been identified: Chedoke Creek in the west, Redhill Creek in the east, and the Central Business District incorporating the downtown core.

Redhill Creek consists of three main branches and several smaller tributaries. The watershed lies mainly within the City of Hamilton and the Town of Stoney Creek.

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Headwaters of the main branch are located in the south-west corner of the City of Hamilton, above the escarpment, known locally as "the mountain". Flowing first eastward, the creek tumbles over Albion Falls, then meanders northward until it reaches its mouth near the Hamilton Water and Wastewater Treatment Plant, located at the south-east corner of Hamilton Harbour. Finally the Redhill Creek outfalls to Windermere basin, a notoriously-polluted, shallow, receiving water body, part of Hamilton Harbour.

Land-use classification in the datafiles used here was derived in 1984 by Mark Robinson from aerial photographs (Robinson and James, 1984). Redhill Hill Creek covers a drainage area of 66.4 sq. km. Land use within the drainage area has changed over time, from an agricultural base to urban. In 1984, 20% of the area was serviced by a combined sewer system, and 43% of the area was devoted to non-urban activities, located in the upper, southern part of the watershed. Residential and industrial subdivisions are being developed on former fruit and dairy farms. Figure 1 is an outline of the watershed, and Figure 2 shows a schematic of the drainage system. Table 1 gives the datafile used in this study. Parameter values used here are those that were optimized in 1984 against a limited dataset by Robinson (Robinson and James, 1984).

Sensitivity analysis involved running *PCSWMM4 for Windows* three times, once for each of three input functions selected from a library of such input functions:

1. SDHI - short-duration, high-intensity rain,
2. SDLI - short-duration, low-intensity rain, and
3. SDMI - short duration, medium-intensity rain.

Each single run computed NSGs for three objective functions simultaneously:

1. peak flow in CFS,
2. peak BOD concentration in mg/L, and
3. peak suspended solids concentration in mg/L.

Choosing 44 parameters per run that were most likely to be applicable was quite simple, since most of the remaining parameters would be obviously meaningless in this application. Figures 3 to 8 provide the computed ranked sensitivity for the most interesting of these nine cases, using a uniform doubt or uncertainty of 5% for most parameters, for the sake of expediency and illustration here. In this paper, all Figures and Table 1 are presented following this page, and the results and conclusions to be drawn are presented at the end. To save space, Table 2, the list of dominant variables is placed here (in it, STA denotes *spatially-and-time-averaged*):

Table 2: Dominant variables

Variables	*descriptions*	*variables*	*descriptions*
ddfact	= STA pollutant build-up coefficient	g6	= conduit Manning's n
ddpow	= STA pollutant build-up exponent	qfact(1,k)	= STA build-up limit
decay	= STA infiltration rate decay constant	rcoef	= STA washoff coefficient
f1(k,to)	= fraction of another constituent	warea	= area of sub-catchment
gdepth	= conduit start-up depth	washpo	= STA washoff exponent
gylen	= length of curb	wlmax/wlmin	= STA max/min infiltration
gwidth	= conduit invert width, pipe diameter	wstore2	= STA perv. depression storage
g3	= conduit invert slope	ww(3)	= percent imperviousness

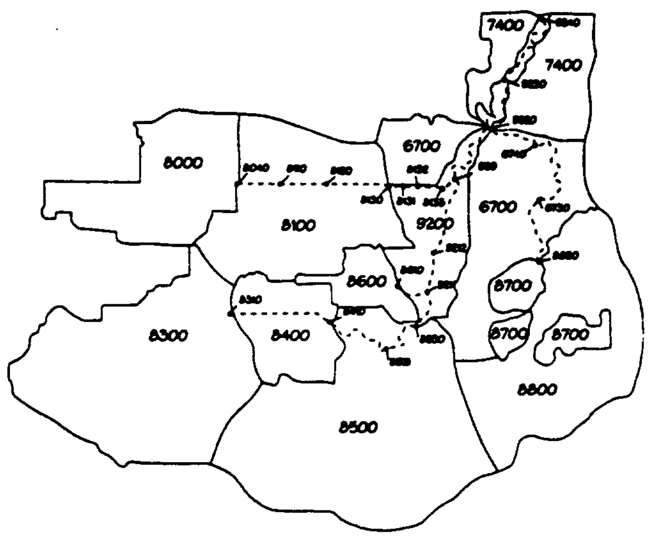

Figure 1: Redhill Creek watershed

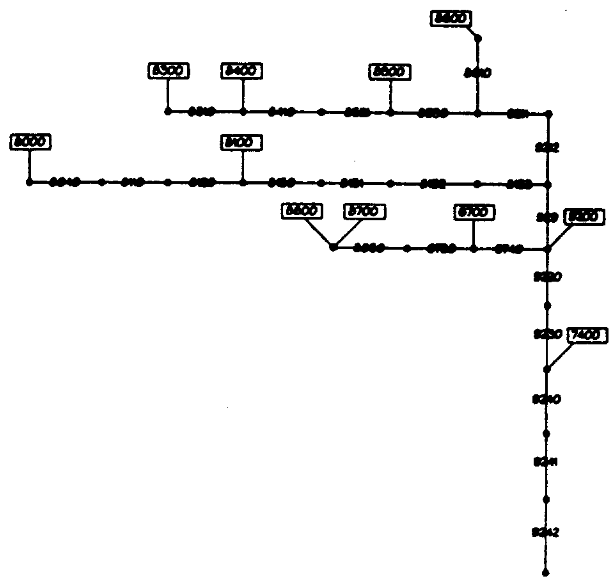

Figure 2: Redhill Creek stormwater model schematic

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Table 1: Redhill Creek stormwater model datafile

```
* redhill1.dat
* This datafile is updated from CHI Report 111: Continuous SWMM modelling of summer
* stormwater quality in the Redhill Creek. Robinson and James. Feb 1984.
* Appendix C. pp 80-81.
*
$RUNOFF
A1  'REDHILL CREEK TO QUEENSTONE ROAD CROSSING'
A1  'CONTINUOUS MODEL JANUARY-DECEMBER 1989'
* control data
*   METRIC ISNOW NRGAG INFILM KWALTY IVAP NHR NMN NDAY MONTH IYRSTR
B1      0     0     1      0      1    0   0   0   01     5     89
* print control
*    IPRN(1) IPRN(2) IPRN(3)
B2        0       1       0
* time steps
*     WET  WET/DRY   DRY  LUNIT    LONG
B3  3600      7200 43200      4  891031
* optional data
*  pctzer  regen
B4   25.0   0.01
*
* no snowmelt simulated
*
* Rainfall control data - will be supplied herein
*    ROPT
D1     0
* rain data
* The following precipitation data was converted from H. Stirrup SWMM data file format
* Original file: bun89_1h.dat.  Date of conversion: 7/26/94
* Converted to SI units (in)
*    KTYPE   KINC KPRINT KTHIS KTIME KPREP    NHISTO   THISTO TZRAIN
E1       0     10      1     0     0     1    10        60.0    0.0
*     RAIN(1)......RAIN(10)
E3    0     0     0     0     0     0     0     0     0     0
*
* no evap data entered
*
* Gutter/pipe data
*   NAMEG    NGTO    NPG  GWIDTH GLEN SLOPE  GS1  GS2 ROUGH  DFULL GDEPTH
G1   8310    8410     2    18.0 7820 .0020  0.0  0.0  .010      0      1
G1   8410    8521     1    20.0 3560 .0500 2.67 0.63  .025    3.6      1
G1   8521    8530     1    16.0 3100 .0500 1.60 0.10  .025    2.6      1
G1   8530    9211     1    34.0 2100 .0500 2.17 1.00  .025    5.2      1
G1   8610    9211     3       0    0     0    0    0     0      0      0
G1   9211    9212     1    30.0 2150 .0246 3.68 2.28  .025    5.7      1
G1   9212     929     1    19.0 5000 .0160 4.76 2.62  .025    5.2      1
G1   8040    8110     1     9.5 2500 .0050    0    0  .018    9.0      1
G1   8110    8120     1    10.0 2700 .0050    0    0  .018   10.5      1
G1   8120    8130     1    10.5 3600 .0050    0    0  .018   11.5      1
G1   8130    8131     1    11.0  650 .0050    0    0  .018   12.0      1
G1   8131    8132     1     8.5 1000 .0280    0    0  .018    8.5      1
G1   8132    8133     1    10.0 2375 .0100    0    0  .018   10.0      1
G1   8133     929     1    60.0  180 .0170    2    2  .050    2.5      1
G1    929    9220     1    26.5 4100 .0500 1.21 0.81  .025    4.3      1
G1   8850    6730     1    12.0 2100 .0214 1.00 1.00  .025    3.4      1
G1   6730    6740     1    12.0 4950 .0121 1.00 1.00  .025    3.4      1
G1   6740    9220     1    12.0 3100 .0032 1.00 1.00  .025    3.4      1
G1   9220    9230     1    40.0 4200 .0500 2.50 1.35  .025    5.2      1
```

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Table 1, continued

```
* Subcatchment data
*     JK NAMEW  NGTO  WIDTH  AREA  %IMP    SLP  IMPN PERVN IMPDS PERDS   MAX   MIN   DECAY
H1     1  8300  8310  39300  2516.  0.0   0.01  .017  .025  .050  .200  3.00  0.30  .00115
H1     1  8400  8410  31500   633. 15.0   0.04  .017  .025  .050  .200  3.00  0.30  .00115
H1     1  8500  8530  30000  3483.  0.0   0.02  .017  .025  .050  .200  3.00  0.30  .00115
H1     1  8600  8610  14300   355. 23.0   0.02  .017  .025  .050  .200  3.00  0.30  .00115
H1     1  8000  8040  30400  1336. 24.0   0.02  .017  .025  .050  .200  3.00  0.30  .00115
H1     1  8100  8130  16600  1736. 22.0   0.02  .017  .025  .050  .200  3.00  0.30  .00115
H1     1  8800  8850   6060  2235.  0.0   0.02  .017  .025  .050  .200  3.00  0.30  .00115
H1     1  8700  8850   2700   595. 17.0   0.02  .017  .025  .050  .200  3.00  0.30  .00115
H1     1  6700  6740  75600   997. 15.0   0.02  .017  .025  .050  .200  3.00  0.30  .00115
H1     1  9200  9220  20400  1471.  0.0   0.24  .017  .025  .050  .200  3.00  0.30  .00115
* H1     1  7400  9240  47330  1053. 44.0   0.02  .017  .025  .050  .200  3.00  0.30  .00115
*
* No groundwater simulated.
*
* Pollutant data
* quality control data
*   NQS JLAND IROS IROSAD DRYDAY CBVOL DRYBSN RAINIT REFFDD KLNBGN KLNEND
J1    4     3    0      0      2    19      1      0    0.5      0      0
* land use groups
*   LNAME      METHOD JACGUT    DDLIM  DDPOW  DDFACT  CLFREQ AVSWP DSLCL
J2  'SCOMB'       0      0     1.E06    1.0     1.0    30.0   0.5    10
J2  'OPEN '       0      0     1.E06    1.0     1.0    30.0   0.5    10
J2  'SSEP '       0      0     1.E06    1.0     1.0    30.0   0.5    10
* constituent groups
*   PNAME  PUNIT NDIM KALC KWASH KACGUT LINKUP   QF1   QF2    QF3 QF4 QF5 WASHPO RCOEF CBFACT CONCRN REFF
J3  'SS '  'MG/L'  0    0    0     0      0   315.0  1.00  50.00  0   0   1.0   40.0    0      0   0.5
J3  'BOD'  'MG/L'  0    0    0     0      0    10.0  0.20   0.30  0   0   1.0   40.0    0      0   0.5
J3  'P  '  'MG/L'  0    0    0     0      0     1.0  0.05   0.05  0   0   1.0   40.0    0      0   0.5
J3  'N  '  'MG/L'  0    0    0     0      0     3.0  0.45   0.45  0   0   1.0   40.0    0      0   0.5
* constituent fractions
*     KTO KFROM     F1
J4      2     1   .0200
J4      3     1   .0020
J4      4     1   .0050
* surface quality data
*    NAMEW   KL    BA     GQ   PSHED(1-10)...
L1    8300    2   603   1460   0  0  0  0  0  0  0  0  0  0
L1    8400    3   727   2000   0  0  0  0  0  0  0  0  0  0
L1    8500    2   587   1612   0  0  0  0  0  0  0  0  0  0
L1    8600    3   207    568   0  0  0  0  0  0  0  0  0  0
L1    8000    1  1690   4655   0  0  0  0  0  0  0  0  0  0
L1    8100    1  2186   6017   0  0  0  0  0  0  0  0  0  0
L1    8800    2   240    560   0  0  0  0  0  0  0  0  0  0
L1    8700    3   698   1917   0  0  0  0  0  0  0  0  0  0
L1    6700    1   902   2800   0  0  0  0  0  0  0  0  0  0
L1    9200    2     0      0   0  0  0  0  0  0  0  0  0  0
* L1   7400    1   962   2644   0  0  0  0  0  0  0  0  0  0
* Printing data for .OUT file
*  NPRNT  INTERV
M1     1       1
*  NDET  Startp(1) Stoppr(1)
M2   1          0         0
*   IPRNT(1) ... IPRNT(NDPRNT)
M3  9242
$ENDPROGRAM
```

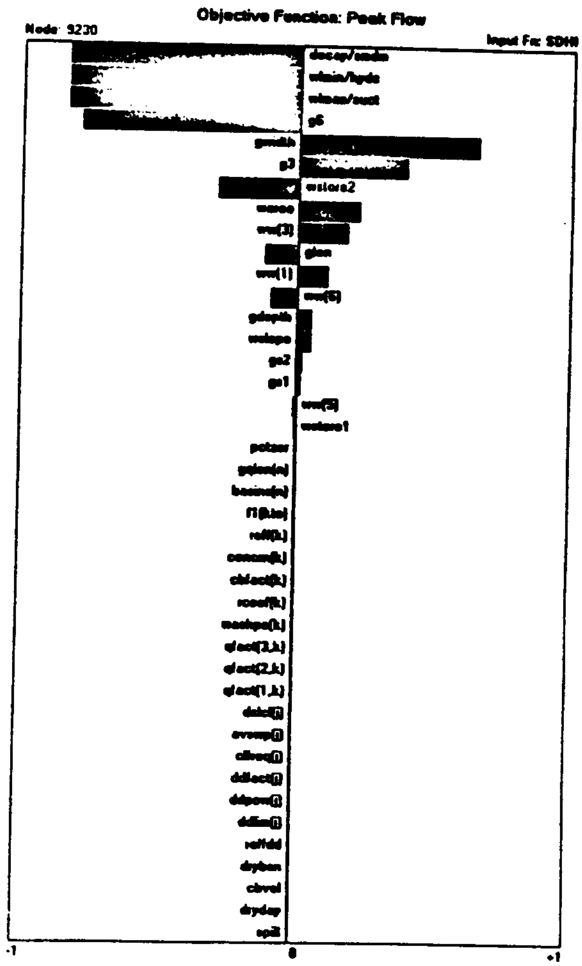

Figure 3: Ranked sensitivity for peak flows, SDHI rain

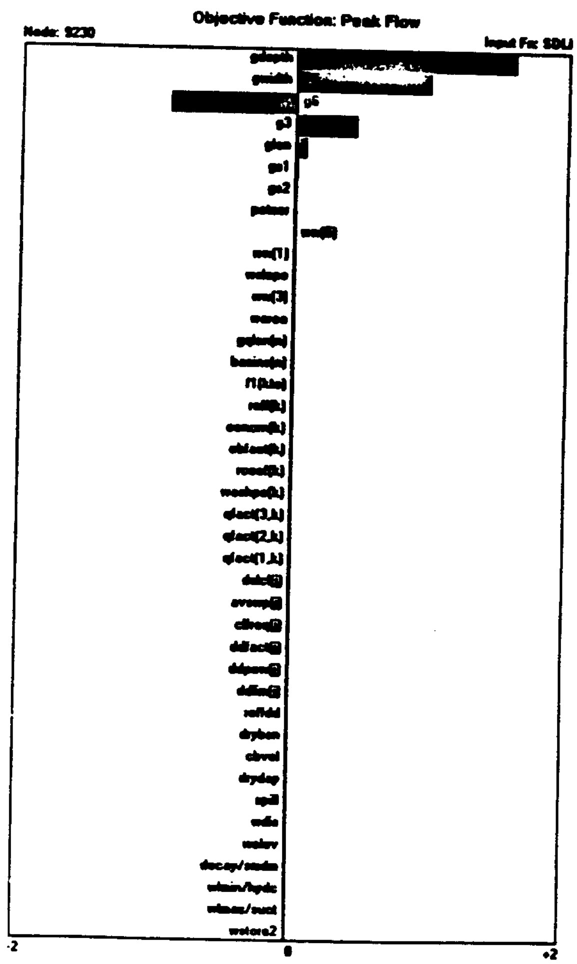

Figure 4: Ranked sensitivity for peak flows, SDLI rain

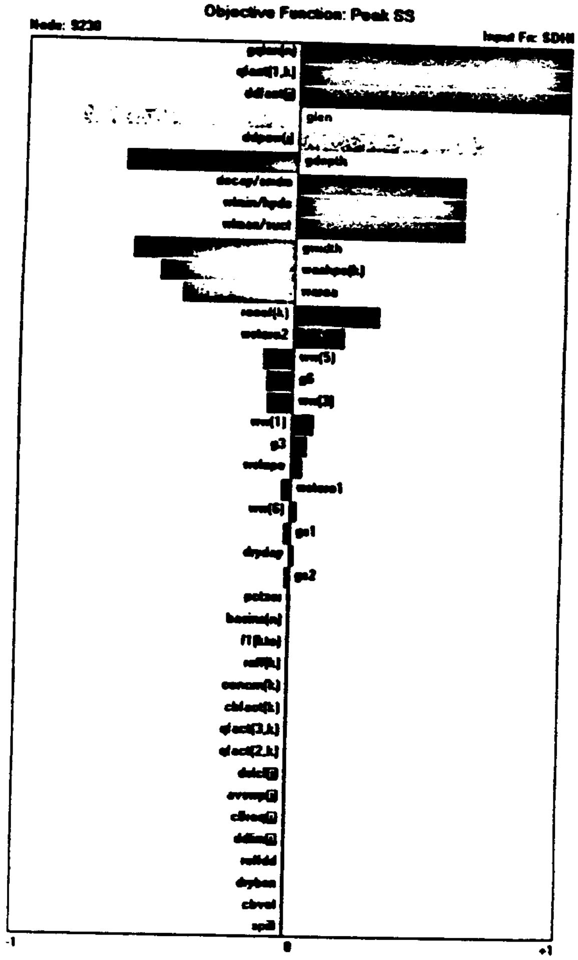

Figure 5: Ranked sensitivity for peak SS concentration, SDHI rain

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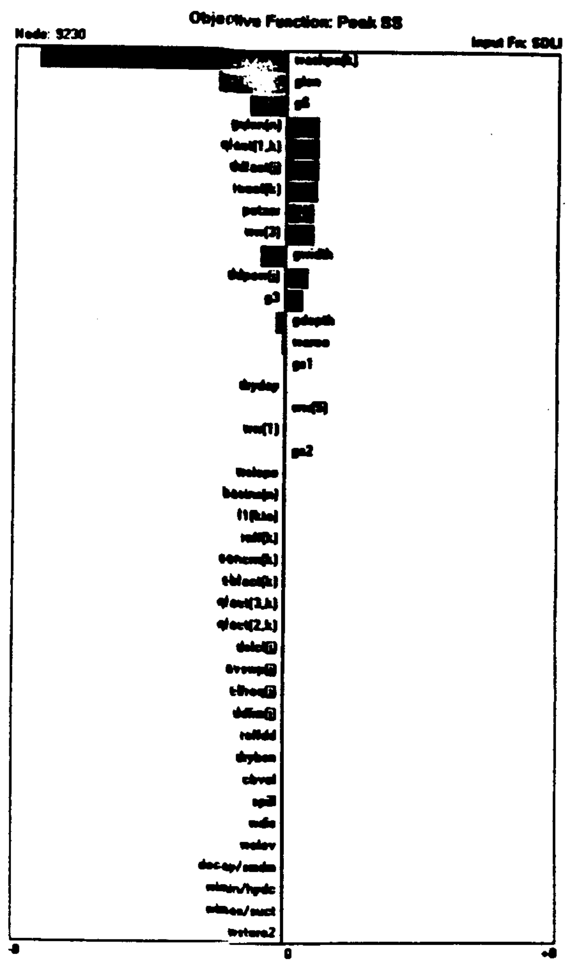

Figure 6: Ranked sensitivity for peak SS concentration, SDLI rain

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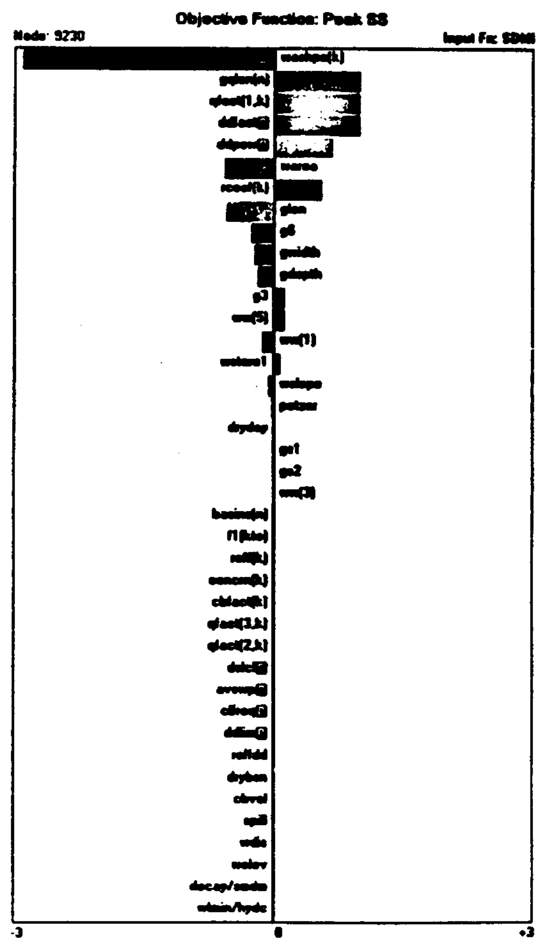

Figure 7: Ranked sensitivity for peak SS concentration, SDMI rain

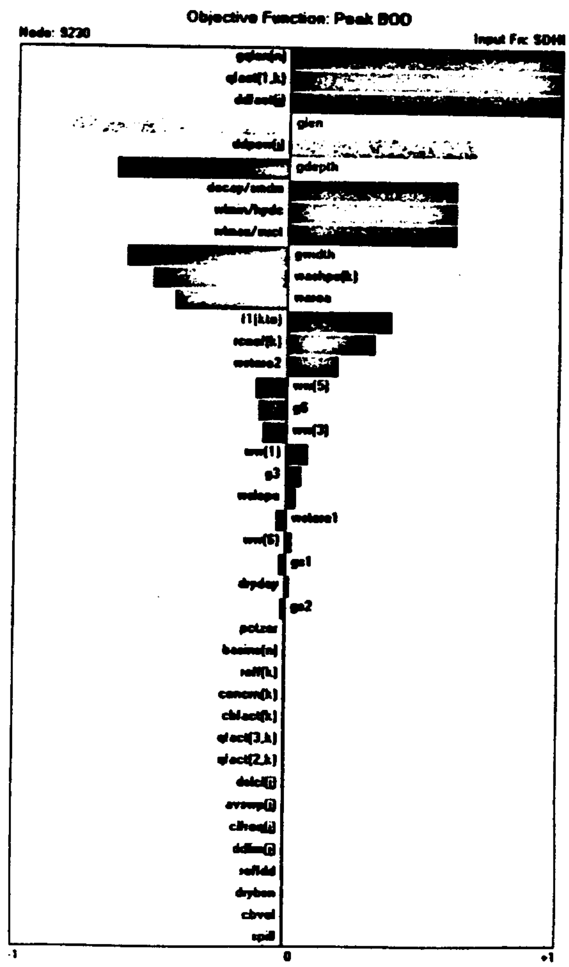

Figure 8: Ranked sensitivity for peak BOD concentration, SDHI rain

RESULTS AND CONCLUSIONS

Figures 3 to 8 rank the variables and thus implicitly the processes in descending order of importance. Large numbers of insensitive processes are revealed, and the dominant processes are few in number. Monitoring effort should be limited to only those fourteen variables that will help calibrate the dominant processes - about 80 parameters are insensitive in this application, and may be ignored.

Figure 3 when compared to Figure 4 illustrates that, for peak flow computations, infiltration parameters are important for SDHI, but not for SDLI rains. Thus good infiltration data are required for flood computations in areas with low imperviousness.

Similarly, when computing peak concentrations of settleable solids and BOD, the input rainfall intensity for short durations has an important influence on the ranking of dominant parameters, as shown by the disparity between Figures 5, 6 and 7 respectively. This should lay to rest the position so often seen in the literature, viz. that the sensitive parameters may be identified for a program, independent of its application.

For example, some surcharging was computed to occur in these Redhill Creek datafile runs, and the rankings show that conduit geometries are important for these cases. When surcharging occurs, computed peak flows are insensitive to all other variables.

For conditions likely to produce high sediment concentrations (high rain rates after prolonged dry weather), data on pollutant build-up are important. Further, according to Figure 8, for peak BOD concentration computed by SWMM-RUNOFF, the only additional parameter of importance, is the fraction that it constitutes of the other pollutant. This is why the other Figures for BOD were not plotted here.

Computational time averaged approximately 11 minutes per run. In other words, the full sensitivity analysis required about 33 minutes on 486-66 microcomputer. The writer considers this to be an insignificant amount of time, considering the value of the information obtained. Even so, these run times were longer than normal, because of the surcharging.

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ACKNOWLEDGMENTS

The shell *PCSWMM4 for Windows* described in this paper was written by Rob James, who also conducted the computer runs. Former graduate students of W. James who worked on similar codes are: Al Dunn (a sensitivity analysis framework for SWMM); Mark Robinson (PCSWMM3 - a user interface); Taymour El-Hossieny (who worked on intelligent database interfaces); and Tony Kuch (PCTOOLS - a sensitivity analysis shell). Co-operation with numerous engineers who have tested the code has been fundamental, and is gratefully acknowledged. Assistance from Mark Stirrup in providing data is acknowledged.

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Robinson, M.A., and James, W. 1984. Continuous SWMM modelling of summer stormwater quality in the Redhill Creek. CHI Report 111. ca. 120 pp. Available from Computational Hydraulics Int., 36 Stuart St, Guelph, ON, Canada N1E 4S5.

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SESSION I: Overview of Stormwater Monitoring Needs

DISCUSSION

Trends in Monitoring for Stormwater
Michael Cook

Tulsa, Oklahoma is the first city issued a Stormwater permit by EPA.

EPA has just undertaken a program to deal with storm sewer overflows - focus over last 20 years has been on wastewater treatment; Agency now hopes to devote more energy to dealing with other forms of pollution. The next increment of control will occur at the local level on a watershed basis.

EPA's Office of Water programs will give more emphasis to NPS, with emphasis on agriculture and mining.

Anecdotal data has been the basis for evaluating the quality of the nation's waters - EPA now looking for a more scientific way to measure the state of water quality.

Groundwater has been a very difficult medium to deal with due to very localized variations in water quality. Current emphasis is on the quality of groundwater used for drinking water supply.

Stormwater Issues

EPA is looking for ways to actually measure improvement in water quality as a result of stormwater pollution control programs. They would like monitoring programs that allow EPA to say "our policy has resulted in a change in water quality." EPA is now holding meetings to identify selected indicators that can be measured. EPA will then give grants to a number of agencies to test their validity.

- Shift from emphasis on water quality monitoring to biological monitoring
- Looking for biological indicators - bioassay, biodiversity, etc.

Questions/Comments

Question: What about funding to continue on-going biomonitoring work?
Answer: Agency needs to look at external research programs that can be used to support EPA efforts. Agency does have some demonstration monies set aside for programs that would look at

biological indicators.

Comment: Reconciliation of use of wetlands for treatment is still an issue - problems tend to be site-specific. Some experts say wetland treatment does not work.

Question: What is "required treatment" for Stormwater?
Answer: Response seemed to be that it was essentially not a problem.

Comment: Regarding mining - EPA is discussing a provision in the Clean Water Act to allow mining industries to assume only partial liability for existing/historic pollution sources.

Comment: Bringing all the different sources of pollution back together under the watershed analysis approach, as proposed in the CWA reauthorization, is difficult, given the history of the CWA in separating sources and dealing with them individually.

American Public Works Point of View
Christine Andersen

We lack the ability to prove clearly the benefits of stormwater management. Therefore, accountability and credibility of municipal agencies and their constituents is a big issue, particularly with respect to environmental programs, i.e. that monies spent on stormwater quality management produce tangible results in terms of improvement of urban waters. This is a particularly acute problem given the reduced levels of state and federal funding.

Concerns of 20 years ago regarding stormwater management are still with us today and not a lot better explained. Not just an engineering problem - requires biological/ecological input as well.

Must come to agreement on how we are going to move forward with storm water management issues. Time is running out and there is no level of agreement. It is imperative that various environmental forces in the community get together in a unified approach.

Review of papers being presented here raises more questions than answers. Still don't know how to interpret data to determine whether or not we are meeting goals.

Pushing those controls that simply meet water quality standards is very expensive, and there is no indication that these actions will meet the community goals for their receiving waters.

Questions/Comments

Question: If you had opportunity, how would you change our approach to monitoring?

Answer: Would change the timing - I would delay it until we had sufficient data to be able to determine with some certainty that the programs we are implementing have some expectation of success.

Question: What about monitoring costs?

Answer: Eugene, Oregon's costs for stormwater management bear no relationship to EPA estimates. Poor quality of these estimates has damaged EPA credibility. Others have had same experience with these estimates.

Answer: Mike Cook - EPA is revisiting requirements for next round of permits (smaller municipalities).

Question: Will current monitoring requirements give us information that will be useful to assess environmental health?

Answer: No. There are many variables, and these are difficult to track.

Overview of Stormwater Monitoring Needs
Kelly A. Cave

CDM is characterizing and comparing (doing statistical analyses on) NPDES data collected for the 30 municipalities for which the firm prepared Stormwater Permits under the EPA Level I program. Results of their study will be made generally available.

Monitoring Program should support watershed management program.

Program should achieve a reasonable level of statistical significance. Continued use of end-of-pipe (EOP) monitoring is not warranted.

Questions/Comments

Comment: CDM's comprehensive analysis of the NURP, USGS, City of Austin, and CDM NPDES studies, will, in effect, redo the NURP statistical analysis.

Comment: We find that Region VI is reluctant to move away from EOP monitoring for land use characterization of stormwater.

Comment: Wisconsin is being blackmailed by cities which have already

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invested a lot of money in establishing EOP stations (as a result of having decided to do monitoring). State is somewhat successful in turning them around.

Comment: Oregon is still focusing on EOP monitoring, but trying to move away. Woodward Clyde is currently monitoring some BMPs in Portland (Editor's note - see paper by Eric Strecker in these Proceedings). Oregon does an annual review of data and BMP effectiveness.

Comment: Austin, Texas is still oriented to EOP because of their non-degradation policy. Feels need to enforce pollution reduction from urban runoff.

Comment: In the Rouge River Study (Detroit, Michigan) they are monitoring atmospheric deposition of pollutants.

How to Monitor Only the Important Parameters
William James

We must report model simulations along with uncertainty, rather than as single valued functions, i.e. must show level of significance and confidence intervals associated with predictions. If we fail to do this, we are being "dishonest and unethical."

There is an optimum size for model complexity in view of our ability to accurately simulate processes, and of the uncertainty in the input data we have for planning.

Questions/Comments

Comment: Monitoring and modeling must be coordinated.

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Locating Inappropriate Discharges to Storm Drains

Melinda Lalor[1], Robert Pitt[2], Richard Field[3], Edward Thackston[4]

Abstract

This article describes the results of a series of research tasks to develop a procedure to investigate non-stormwater (dry-weather) entries into storm drainage systems (Pitt et al. 1993a, Pitt et al. 1993b). Dry-weather flows discharging from storm drainage systems contribute significant pollutant loadings to receiving waters and although they can originate from many sources, the most significant include sanitary wastewater, industrial and commercial pollutant entries, failing septic tank systems, and vehicle maintenance activities. Protocols are discussed to: characterize the drainage area; locate and identify polluted outfalls; estimate the magnitudes of non-stormwater entries; and locate and correct the non-stormwater entries into the storm drainage system. If these loadings are ignored (e.g., by only considering wet-weather stormwater runoff), only limited improvement in receiving water conditions may occur with stormwater pollution control programs.

Introduction

Current interest in illicit or inappropriate connections to storm drainage systems is an outgrowth of investigations into the larger problem of determining the role urban stormwater runoff plays as a contributor to receiving water

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[4]Professor and Chairman, Department of Civil and Environmental Engineering, Vanderbilt University, Nashville, TN 37235.

quality problems. The EPA's Storm & Combined Sewer Overflow Pollution Control Research and Nationwide Urban Runoff Programs, respectively helped highlight the problem with data confirming pollution found in urban storm drainage systems. Regulatory requirements such as the National Pollution Discharge Elimination System (NPDES) require certain classes of stormwater discharges to be permitted. Presently, the NPDES requires certain industries (*Federal* 1990) and municipalities with populations of 100,000 or more to conduct investigations to determine the locations of inappropriate dry-weather entries into storm drainage systems.

Waters discharged from stormwater drainage systems often include waters from many non-stormwater sources. A study in Sacramento, California (Montoya 1987) found that slightly less than half the volume of water discharged from a stormwater drainage system was not directly attributable to runoff. Illicit and/or inappropriate entries to the storm drainage system are likely sources of this discharge and can account for a significant amount of the pollutants discharged from storm drainage systems.

The methods described in this paper were developed specifically for detection of pollution sources in dry-weather flow, but are applicable to wet-weather flows as well. It must be noted that during wet-weather flow conditions there will be additional pollutant sources (e.g., roads, roofs, exposed materials storage, etc.).

Origins of Contamination

Common non-stormwater entries include: sanitary wastewater; automobile maintenance and operation waste products; laundry wastewater; household toxic substances and pollutants; accident and spill waste streams; runoff from excessive irrigation; and industrial cooling water, rinse water, and other process wastewater. Although these sources can enter the storm drainage system a variety of ways, they generally result from: (1) direct connections, such as wastewater piping either mistakenly or deliberately connected to the storm drains; or (2) indirect connections, which include infiltration into the storm drainage system and spills received by drain inlets (Pitt et al. 1993a).

Direct connections may be defined as physical connections of sanitary, commercial, or industrial piping that carry untreated or partially treated wastewaters to a separate storm drainage system. Usually unauthorized, whether mistaken or intentional, they represent the most common source of entries to storm drains by industry.

Indirect connections may be defined as infiltration into storm drainage systems and non-storm related discharges to storm catchbasins and inlets. Infiltration most commonly occurs through leaking pipe joints and connections to manholes and catchbasins, as well as pipes damaged by overburden and subsidence. Groundwater and percolating waters may or may not be

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contaminated and will be variable in nature since their levels and amounts can be dependent upon rainfall events.

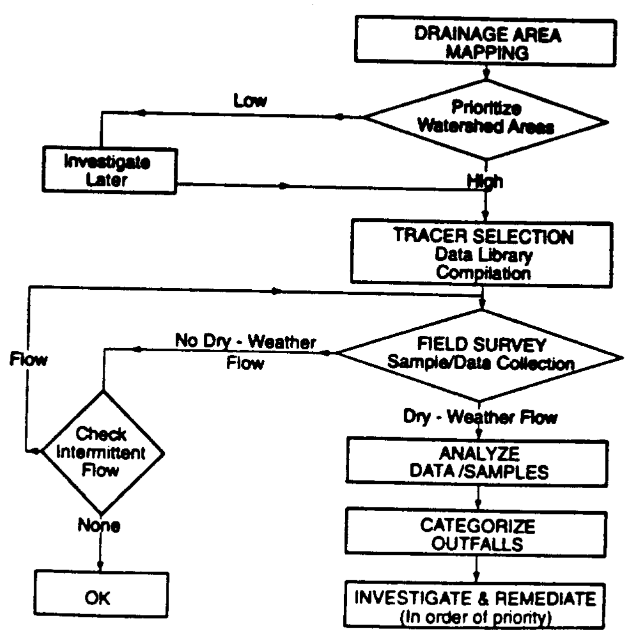
The procedures described in this paper provide an investigative procedure that will allow a user to first determine whether significant non-stormwater entries are present in a storm drain, and then identify the potential source category as an aid to ultimately locating the source.

It is important to emphasize that the removal of inappropriate entries is only one aspect of a comprehensive pollution prevention program required for an effective improvement in receiving water quality.

Procedures

The sequence of "Typical Investigation Steps" is illustrated in Figure 1 and briefly described below.

Figure 1: Typical Investigation Steps



A) Drainage Area Mapping

The mapping exercise is carried out as a desktop operation using existing data/information and field visits to collect additional data/information and/or confirm existing information. It must contain complete descriptions of the drainage areas including: outfall locations, drainage system layout, subcatchment boundaries for each outfall, critical land-use areas, permitted discharges to the storm drainage system, city limits, major streets, streams, etc. Possible sources of information include:

- City records and drainage maps.
- Previous surveys, e.g., sanitary sewer infiltration/inflow and sewer evaluation survey studies.
- Topographic maps.
- Existing GIS (Geographic Information System) data.
- Pre-development stream locations.
- Pre-development site investigations indicating groundwater and water table information.
- Drainage department personnel with knowledge of the area.
- Aerial surveys.

From mapping activities, possible pollutant sources are identified (e.g., industries, landfill sites, areas with septic tank systems, vehicle service stations, industrial sites, etc.) and drainage areas with the highest potential for non-stormwater entry sources are determined. This can assist in setting priorities for field investigation of the outfalls (Pitt et al. 1993a). However, all outfalls will require investigation eventually.

B) Tracer Selection

To detect and identify non-stormwater entries, the dry-weather outfall discharge is analyzed for selected tracers. An ideal tracer should exhibit the following properties:

- Significant difference in concentrations between polluting and non-polluting sources;
- Small variations in concentrations within each likely pollutant source category;
- A conservative behavior (i.e., no significant concentration change due to physical, chemical, and/or biological processes); and
- Ease of measurement with adequate detection limits, good sensitivity and repeatability.

A review of case studies and literature characterizing potential inappropriate entries (e.g., sanitary wastewater, septic tank effluent, laundry wastewater, vehicle wash wastewater, irrigation runoff, etc.) led to the following recommended tracers to identify common pollutant sources in

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residential/commercial land use areas :

- Specific conductivity;
- Fluoride and/or hardness;
- Ammonia and/or potassium;
- Detergents and/or fluorescence; and
- Temperature, chlorine, and pH.

The last three parameters do not fit the previously stated criteria, but can indicate extreme instances of pollution. Further details on the recommended tracers are given in Appendix II. If specific chemicals used by industries in the watershed are known, it may be possible to include them as tracers also.

In addition to the parameters described above, relative toxicity can be an important outfall screening parameter. Short-term toxicity tests, (e.g., the Microtox™ test from Microbics, Inc.), are valuable for quickly and cheaply assessing the relative toxicity (to a selected test organism) of different dry-weather flows. These tests can be used to identify outfalls that contain toxic flows which may warrant immediate investigation.

Potential sources of dry weather flows commonly identified within commercial and residential land use areas include spring water, infiltrating shallow ground water, tap water, irrigation runoff from landscaped areas and golf courses, sewage, septic tank discharge, commercial laundry waters, commercial carwash waters, radiator flushing wastes and metal plating bath waters. Obviously, some of these sources would contribute to pollution problems, and some would not. However, all have the potential for showing up in dry-weather flows. Therefore a chemical understanding of each, with respect to the selected tracers, is needed to build a "library" to which outfall dry-weather flows can be compared. To obtain the background information needed to construct such a library, samples are collected directly from the potential sources identified. To the extent possible, samples should come from sources within the study area. For each tracer, the concentration means and standard deviations for all the potential source flows, is calculated. Without this information the likelihood of identifying the pollutant sources is greatly reduced. The selection of a suitable analytical method is discussed later under the "Analysis of Data/Samples" section.

C) Field Survey

Field investigations are used to locate and record all outfalls, and involve physically wadding, boating, etc. the receiving waters in search of all known and unknown outfalls. At each outfall the inspection and sampling should at least include:

- Accurate location of outfall and assignment of ID number;
- Photographs of outfall;
- Outfall discharge flow rate estimate (and note whether continuous or

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intermittent discharge);
- Physical inspection and record of outfall characteristics including odor, color, turbidity, floatable matter (fecal matter, sanitary discards, solids, oil sheen, etc.), deposits, stains, vegetation effected by pollutants, damage to outfall structure, and discharge water temperature; and
- Collection of dry-weather discharge samples for tracer analyses in the laboratory (specific conductivity and temperature can be field measured).

Intermittent flows will be more difficult to confirm and sample. Additional field visits, use of automatic samplers, and/or flow damming or screening techniques must be utilized for detecting and obtaining samples of intermittent flows.

D) Analyses of Data/Samples

The recommended analytical procedures and associated equipment in Appendix III have been selected based on laboratory and field testing of analytical methods using the following criteria:
- Appropriate detection limits;
- Freedom from interferences;
- Good analytical precision (repeatability);
- Low cost and good durability; and
- Minimal operator training.

For consistent results the analyses should be carried out in the laboratory and not in the field, except for temperature and specific conductivity. Field analyses may be conducted for pH by using portable pH meters or litmus paper depending upon the degree of accuracy required and time constraints. Note that pH is a support tracer and not a primary parameter (see Appendix II for further detail).

The analysis methods selected must provide adequate detection limits (i.e., measurement of the lowest required concentration) and precision (i.e., consistent results). Methods found suitable for residential/commercial land use areas are recommended in Appendix III. These, methods should be checked for suitability at the proposed study site. In order to estimate the required detection limit, it is necessary to know or estimate the tracer mean concentration and standard deviation. The median multiplier values given below, when used in conjunction with the median and coefficient of variation (COV = standard deviation/mean) of the tracer in the more dilute flow, provide a quick and conservative estimate of the detection limit required. These median multipliers were derived from the assessment of a large number of probability calculations. This method is illustrated below:

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COV Value	Median Multiplier For Detection Limit
Low (<0.5)	0.80
Medium (0.5 to 1.25)	0.23
High (>1.25)	0.12

Example: COV <0.5
median concentration = 0.5 mg/L
detection limit required = 0.5 x 0.8 = 0.4 mg/L

The analytical precision, defined as the repeatability of the analytical method, is also an important consideration. It is determined by repeated analyses of a stable standard, conducting replicate analyses on the samples, or by analyzing known standard additions to samples. Precision is expressed as the standard deviation of the multiple analysis results.

E) Categorize Outfalls

Outfalls must be categorized and subsequently prioritized so that a plan of action can be developed. Naturally, the most toxic and dangerous outfalls need to be eliminated first, especially considering the limited availability of funds in today's strained economic climate. The above analysis of the dry-weather flows provides data to help categorize the outfalls into three groups: 1) pathogenic or toxic pollution, 2) nuisance or aquatic life threatening pollution, 3) unpolluted.

The pathogenic and toxic pollutants can cause illness upon water contact or consumption and significant water treatment problems for downstream consumers, especially if the pollutants are soluble metal and organic toxicants. These pollutants may originate from sanitary, commercial, and/or industrial wastewater non-stormwater entries. Additional residential area activities with a pollution potential include, household toxicant disposal, automobile engine de-greasing and oil disposal, and excessive use of chemical pesticides.

Nuisance and aquatic life threatening pollutants include laundry wastewaters, irrigation runoff carrying heavy loads of fertilizers, vehicle washwaters, construction site dewatering, washing of concrete ready-mix trucks, etc. These pollutants can cause: excessive algal growths; tastes and odors in downstream water supplies; offensive coarse solids and floatables; and noticeably colored, turbid, or odorous waters.

Unpolluted discharge from stormwater outfalls can originate from natural springs feeding urban creeks that have been converted to storm drains, infiltrating groundwater, infiltrating domestic waterline leakage, etc.

Outfalls must be visited, observations made, and all dry-weather flows sampled and tested in order to correlate flows with potential sources. Five methods for analyzing outfall dry-weather flow data/observations have been tested. These methods range from relatively simple reviews of physical

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indicators for outfall contamination, to more sophisticated methods requiring computer modeling for evaluation. Methods 1 and 2 attempt only to distinguish between contaminated and uncontaminated flows, while methods 3 through 5 are useful in identifying the likely sources from which dry-weather flows are originating.

Physical Indicators of Contamination

Indicators of contamination (negative indicators) are clearly apparent visual or physical parameters indicating obvious problems that are readily observable at the outfall during the field screening activities. The direct examination of outfall characteristics for unusual conditions of flow, odor, color, turbidity, floatables, deposits/stains, vegetation conditions, and damage to drainage structures is the simplest method of identifying grossly contaminated dry-weather outfall flows. While this procedure doesn't necessarily identify the flow source, some sources may be identifiable based on recognizable odors or floatables, for example. Pearson Correlation results indicated that high turbidity (lack of clarity) and odors appeared to be the most useful physical indicators of contamination when contamination was defined by toxicity and the presence of detergents. Observable parameters cannot be relied upon as a sole method for the evaluation of outfalls. A contaminated discharge may not be visible and can only be determined by other methods (Lalor 1993, Pitt et al. 1993a).

Detergents as Indicators of Contamination

Results from Mann-Whitney U tests during method development indicated that pure streams from any of the dry-weather flow sources investigated in this research could be correctly classified as clean or contaminated based only on the measured value of any one of the following parameters: detergents, color, or conductivity. Color and conductivity were present in samples from clean sources as well as contaminated sources, but their levels of occurrence were significantly different between the two groups (Lalor 1993). If pure streams from only one source were expected to make up outfall flows, the level of color or conductivity measured could be used to distinguish contaminated form clean outfalls. However, since this is commonly not the case, measured levels in outfalls with multiple sources could fall within acceptable levels even though a contaminating source was contributing to the flow. etergents, on the other hand, can be used to distinguish between clean and contaminated outfalls simply by their presence or absence. "Presence" translates to the lower limit of detection for the HACH detergent test kit, which is 3.29 times the standard deviation, or 0.06 mg/L of detergents. This reduces the probability of a false nondetection or a false detection to 5% (Standard Methods 1989).

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Flow Chart for Most Significant Flow Component Identification

Figure 2 is a flow chart describing an analysis strategy which may be used to identify the major component of dry-weather flow samples in residential and commercial areas. This method does not attempt to distinguish among all potential sources of dry-weather flow identified earlier, but rather the following four groups of flow are identified: (1) tap waters (tap water, irrigation water and rinse water), (2) natural waters (spring water and shallow ground water), (3) sanitary wastewaters (sanitary sewage and septic tank discharge), and (4) wash waters (commercial laundry waters, commercial car wash waters, radiator flushing wastes, and plating bath wastewaters).

The use of this method would not only allow outfall flows to be categorized as contaminated or uncontaminated, but would allow outfalls carrying sanitary wastewaters to be identified as such. These outfalls could then receive highest priority for further investigation leading to source control.

This flow chart was designed for use in residential and /or commercial areas only. Investigations in industrial or industrial/commercial land use areas must be approached in an entirely different manner (EPA 1993).

In residential and/or commercial areas, all outfalls should be located and examined. The first indicator is the presence or absence of dry-weather flow. If no dry-weather flow exists at an outfall, then indications of intermittent flows must be investigated. Specifically, stains, deposits, odors, unusual stream-side vegetation conditions, and damage to outfall structures can all indicate intermittent non-stormwater flows. However, frequent visits to outfalls over long time periods, or the use of other monitoring techniques, may be needed to confirm that only stormwater flows occur (Pitt et al. 1993a). If intermittent flow is not indicated, then the outfall probably does no have a contaminated non-stormwater source. The other points on the flow chart serve to indicate if a major contaminating source is present, or if the water is uncontaminated (Lalor 1993). Component contributions cannot be quantified using this method, and only the "most contaminated" type of source present will be identified. Sources are ranked from lowest to highest based on their contamination potential in the following way: (1) Natural water sources, (2) Tap water sources, (3) Wash water sources, (4) Sanitary wastewater sources. Numerical values presented in the flow chart were developed from source flow data collected during method development in Birmingham, Alabama (Lalor 1993). Values should be verified for other locales.

If more specific source information is desired, a more complex approach is necessary. Algorithms based on the simultaneous solution of a series of chemical mass balance equations have been developed to predict the most likely flow source, or sources, making up an outfall sample, and are discussed in the following paragraphs. The degree of accuracy achievable will depend greatly

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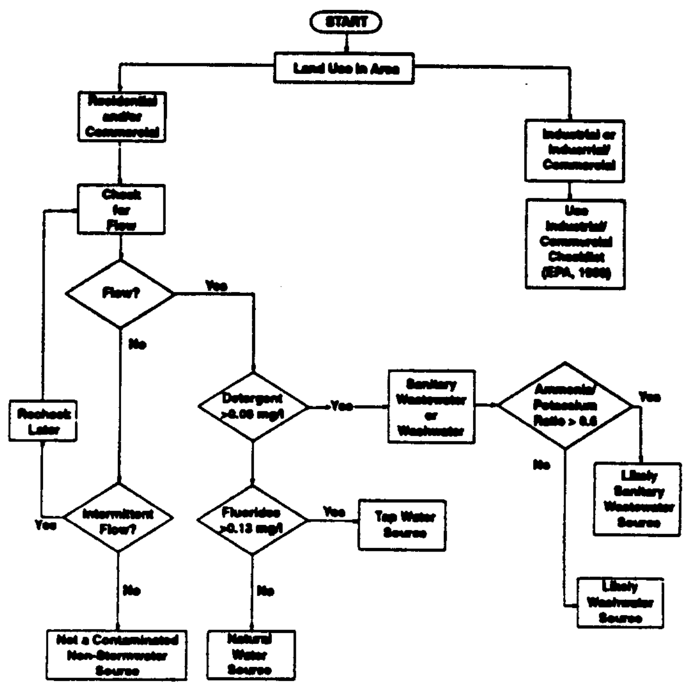
Figure 2: Flow Chart for Most Significant Flow Component Identification



upon the extent of local tracer data gathered to describe potential source flows.

Chemical Mass Balance at Outfalls: Matrix Algebra Solution

Flow contributions from various sources may be estimated by using a 'receptor model' based on a set of chemical mass balance equation. Such models, which assess the contributions from various sources based on observations at sampling sites (the 'receptors'), have been applied to the investigation of air pollution sources for over 20 years. The characteristic "signatures" of the different types of sources, as identified in the library of source flow data developed in the study area, allows the development of a set of mass balance equations. These equations describe the measured concentrations in an outfall's flow as a linear combination of the contributions from the different potential sources. A major requirement for this method is the physical and chemical characterization of waters collected directly from potential sources of dry-weather flow. This allows concentration patterns for the parameters of interest to be established for each type of source. If these patterns are different for each source, the observed concentrations at the outfall will be a linear combination of the concentration patterns from the different component sources, each weighted by a source strength term (m_n). This source strength term would indicate the fraction of outfall flow originating from each likely source. By measuring a number of parameters equal to, or greater than, the number of potential source types, the source strength term could be obtained by solving a set of chemical mass balance equations of the type:

$$C_p = \sum_n m_n x_{pn}$$

where C_p is the concentration of parameter p in the outfall flow and x_{pn} is the concentration of parameter p in source type n. As noted above, the m_n term represents the fraction contribution of flow from source type n affecting the outfall dry weather flow. The selection of parameters for measurement should reflect evaluated parameter usefulness.

Chemical Mass Balance at Outfalls with Monte Carlo Sampling

The Monte Carlo method goes one step further than the matrix algebra solution by allowing the variation within the library values for each source type to be considered. Instead of using a single value (i.e. mean value) to represent the parameter concentration (C_p) for each likely type of source flow, a Monte Carlo simulation is used to randomly select values from a statistical distribution. Monte Carlo sampling is a traditional method of sampling randomly across an entire input variable distribution. Any value across the range of the distribution is possible, although the sampling is influenced by the relative probability assigned to each value. The more probable values will have a greater chance of

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being selected. (Lalor 1993).

Based on samples collected from known sources, probability distributions are calculated, for each parameter (conductivity, fluoride, hardness, etc.), within each potential source flow. Distributions considered in this procedure include normal, log-normal, and uniform. Local source flow quality monitoring is necessary to obtain this information, as discussed previously.

Monte Carlo simulation generates sets of concentration values based on the mean, coefficient of variation, and distribution of each parameter within each source. A set of equations is established for each set of sampled concentration values generated by the Monte Carlo simulation. The fraction of flow from each potential source is calculated by solving each set of equations. These flow values are then stored. Multiple trials are used to calculate the most probable sources of contaminants for each outfall.

F. Investigation and Remediation

The investigation of pollutant sources involves upstream surveys to progressively narrow the drainage area(s) of concern and locate the pollutant source(s). Upstream surveys can take a number of forms including:

1) Analysis of dry-weather flow at strategically designated upstream manholes and/or access points which includes all or some of the methods and parameters measured at the outfall;
2) In-depth watershed evaluation of potential sources, achieved by developing on information gained during mapping and tracer data collection; and
3) Localized surveys by visual inspection, TV camera survey, and smoke and dye tests.

In some of the case studies investigated, correcting problems only at the most contaminated outfalls resulted in insufficient receiving water quality improvements. Therefore after the contaminated outfalls have been identified, most of them are likely to require correction if receiving water quality recovery is to be affected. However, categorizing the outfalls allows the most serious outfalls to be recognized and corrective action to be initially concentrated in the most cost-effective manner.

For an effective improvement in receiving water quality (assuming a problem exists), the investigation and correction of only illicit stormwater entries is unlikely to solve the problem. Dry-weather flows are only one source of pollutants and an effective improvement may require a comprehensive investigation and remediation program covering wet-weather induced flows as well.

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Discussion and Conclusions

The main purpose of the research from which this paper emanated was to develop and test an effective screening methodology to identify storm sewer outfalls which are contaminated by illicit discharges in residential and commercial land use areas. Stormwater outfall screening methods presented here were tested in residential and commercial land use areas only. Techniques appropriate for industrial land use areas are discussed in *Investigation of Inappropriate Pollutant Entries Into Storm Drainage Systems* (EPA 1993).

Each of the screening methodologies evaluated is based on the location and investigation of stormwater outfalls with dry-weather flows. Consideration must be given to the potential of outfalls to carry intermittent discharges. Intermittent discharges are not inconsequential, and are likely to be missed during infrequent outfall screening visits. Care should be taken to note evidence of intermittent discharges, such as unusual sediments, stains, odors, or abnormal vegetative growth around outfalls.

Additionally, field work associated with this research confirms the importance of investigating all storm water outfalls and direct discharge pipes encountered, not just those within a specific size range. Some of the most contaminated flows encountered were issuing from small pipes (Lalor 1993).

The use of negative physical indicators of contamination alone, such as color, odor, lack of clarity, and the presence of floatables or deposits, resulted in a high false negative rate of 20%, and a false positive rate of 10%. Examination of outfalls for negative indicators of contamination identified only the most grossly contaminated commercial outfalls. Outfalls carrying sanitary wastewaters in mixtures with uncontaminated waters, one of the most serious concerns, were frequently missed using this method.

Testing dry-weather flows in residential and commercial areas for only the parameters identified by EPA as minimum requirements, (pH, chlorine, copper, phenols and detergents), can be used to accurately categorize outfalls as contaminated or uncontaminated. This determination in fact can be based simply on the presence or absence of detergents (lower limit of detection 0.06 mg/L as MBAS). During this research effort in Birmingham, Alabama, all flows from contaminated outfalls contained detergents, while all flows from uncontaminated outfalls did not. No false positives or false negatives resulted from the use of this method. No further prioritization of outfalls was possible using only the parameters identified by EPA. However, in residential and commercial areas, pH, total chlorine, total copper, and total phenols could be useful in identifying industrial discharges not previously known to exist within the drainage area (EPA 1993).

Testing for fluoride, ammonia, and potassium, in addition to detergents, allowed for further prioritization of outfalls, by identifying the outfalls most likely to be contaminated by sanitary wastewaters, wash waters, or relatively clean tap water sources. Using the flow chart presented in Figure 2, the most serious contaminating source can usually be identified for each outfall, whether or not the flow is a mixture originating from several sources. In flows issuing from a single source, the sole flow component can be identified. n multiple source flows which include at least one contaminating source, a contaminated source can be identified as long as it comprises at least approximately 10% of the flow. In mixed flows, contaminating sanitary wastewaters may be incorrectly identified as wash water when they contribute less than about 25% of the flow. This depends on the ratio of ammonia to potassium in both the sanitary wastewater and the other flow sources. The use of the flow chart in this research resulted in no false negatives, no false positives, and further, the correct identification of the most contaminated source contributing to each outfall analyzed (Lalor 1993).

The use of chemical mass balance equations as a means of identifying all sources contributing to flow at a given outfall is appealing in theory. However, this research indicated that the amount of variation present within potential sources of dry-weather flow, as well as the likelihood of unexpected and thus uncharacterized flows, especially in commercial areas, made this method ineffective for use in this application. Possible additional modification to the chemical masss balance program, such as allowing for the inclusion of more equations than unknowns, variable weighting, and the linking of variables with relatively high correlation coefficients, could improve its effectiveness (Wilson 1958). However, these modifications are not likely to fully compensate for the highly variable character of many of the potential dry-weather flows which will be encountered in this application. The amount of time and effort required to adequately identify and characterize potential sources also decreases the economic advantage of this method over wide-scales dye testing. Use of the chemical mass balance method in this research, with no threshold for program noise, resulted in a false positive rate of 40%, and no false negatives. Further, the most contaminated contributor to flow was incorrectly identified 70% of the time.

Defining a threshold level, based on analysis of many samples from known sources, and disregarding identified flow contributors below this level, reduced the false positive rate to zero while maintaining a false negatives rate of zero. However, the most contaminated contributor to flow was still incorrectly identified 50% of the time, making this method less useful for prioritizing outfalls than the simpler flow chart approach.

In summary, the following screening methodology is suggested. All stormwater outfalls and direct discharge pipes should be located. All dry-weather flows should be sampled, regardless of the size of the pipe. Evidence of intermittent flows should be noted, and the affected outfalls should be visited again. The flow chart in Figure 2 should be used as a guide for interpreting screening data. It is extremely important to determine the fluoride, ammonia,

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and potassium values for ground, surface, and tap waters in the local study area, if outfall screening data is to be interpreted with confidence. Outfall samples collected should be tested first for detergents. If desired, samples testing negative for detergents could be tested for fluoride, to identify flows from relatively clean tap water sources. Samples testing positive for detergents should be tested for ammonia and potassium. A high ammonia-to-potassium ratio indicates those outfalls most likely to carry flows from sanitary wastewater sources. These outfalls sources receive the highest priority for source correction measures.

Appendix I: References

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Appendix II: Recommended Tracer Parameters

Specific Conductivity- Specific conductivity can be used as an indicator of dissolved solids (i.e., ions). The variation between water and wastewater sources can be substantial enough to indicate the source of a dry-weather flow, and because the measurement is easy, quick, and cheap it is a suggested tracer.

Fluoride- Fluoride concentration should be a reliable indicator of potable water where fluoride levels in the raw water supply are adjusted to consistent levels and where groundwater has low natural fluoride levels.

Hardness- Hardness may be useful in distinguishing between natural and treated waters (like fluoride), as well as between clean treated waters and waters that have been subjected to domestic use. It should be noted that hardness of waters varies considerably from place to place, with groundwaters generally being harder than surface waters.

Ammonia/Ammonium- The presence or absence of ammonia (NH_3), or ammonium ion (NH_4+), has been commonly used as a chemical indicator for prioritizing sanitary wastewater cross-connection drainage problems. Ammonia should be useful in identifying sanitary wastes and distinguishing them from commercial water sources.

Potassium- Greater potassium concentrations have been noted for sanitary wastewater compared to potable water during studies reviewed. These potassium increases following domestic water usage reveal its potential as a tracer parameter.

Surfactants and Fluorescence- Surfactants from detergents used in household and industrial laundering and other cleaning operations results in high concentrations in wastewater. Anionic surfactants account for approximately two thirds of the total surfactants used in detergents in the U.S., and are commonly measured as Methylene Blue Active Substances (MBAS).

Water fluorescence is also an indicator of detergent residue in waters. Most detergents contain fabric whiteners which cause substantial fluorescence.

pH- The pH of most dry-weather flow sources is close to neutral (pH = 7). However, pH values may be extreme (below 6 and above 9) in certain inappropriate commercial and industrial flows or where groundwaters contain dissolved minerals. If unusual pH values are observed, then the drainage system needs to be carefully evaluated. Note that pH values are a power function and

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therefore flow contributions cannot be proportioned in the same way concentration values can.

Temperature- An elevated temperature of a receiving water can indicate contamination, particularly in cold weather. Sanitary wastewater and cooling water are examples of sources in which temperature elevation may be noted.

Total Available Chlorine- Chlorine is not stable in water, especially in the presence of organic compounds. The chlorine demand of contaminated water can be very large, with chlorine concentrations decreasing to very small values after short periods of time. The presence of chlorine in dry-weather flow could indicate a significant and very close potable water flow source or industrial discharges. (Pitt et al. 1993a).

Appendix III: Recommended Tracer Analysis Methods

Specific Conductivity and Temperature- Field measure using a multi-parameter SCT meter from YSI. Both specific conductivity and temperature must be calibrated against standard specific conductivity solutions and a standard thermometer.

Fluoride- Lab. analysis using a field spectrophotometer and evacuated reagent and sample vessels (HACH DR/2000™ and AccuVac™ ampules using SPADNS reagent, without distillation). The samples should be filtered through a 0.45 μ membrane filter (e.g., Millipore™ filter) before analysis to minimize color interference.

Hardness- Lab. analysis using a field-titrimetric kit (HACH Digital Titrator Model 16900). Filter as for Fluoride.

Ammonia- Lab. analysis using a direct Nesslerization procedure and spectrophotometer (HACH DR/2000™ Nessler method, but without sample distillation). Filter as for Fluoride.

Potassium- Lab. analysis using either a spectrophotometer (HACH DR/2000™ Tetraphenylborate method), or a flame atomic absorption spectrophotometer (if available). Filter as for Fluoride.

Surfactants- Lab. analysis using a simple comparative colormetric (color wheel) method (from the HACH Company). Filter as for Fluoride. This procedure to be conducted under a laboratory fume hood.

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Fluorescence- Lab. analysis fluorometer (Turner model 111). The fluorometer has general purpose filters and lamps and should be operated at the most sensitive setting (number one aperture).

pH- Lab. measurement using a standard laboratory pH meter after accurate calibration using at least two buffer solutions bracketing the expected sample pH value. Field measurements can be made utilizing pH meters or litmus paper depending upon degree of accuracy required and time constraints.

Chlorine- Total available chlorine was determined with the DPD method using a HACH DR/2000™ spectrometer with AccuVac™ ampules.

Water color- Lab. measurement using a simple comparative colormetric (color wheel) field test kit from the HACH Company. Apparent color (unfiltered samples), expressed in HACH color units.

Turbidity- Lab. measurement using a HACH Nephelometer.

Toxicity screening- Microtox™ (from Microbics) toxicity screening for relative toxicity values. The 100 percent screening test was most commonly used. If the light output decrease after 25 minutes (the I_{25} value) was greater than 50 percent, then the standard Microtox test was used to determine the sample dilution required for a 50 percent light decrease (the EC_{50} value). (Field et al. 1993a).

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FINDING ILLICIT CONNECTIONS & DISCHARGES WITH P³IL

John D. Minor[1], B.Sc.,M.Sc.

Abstract

The City of Scarborough is a lower tier (area) municipality of 172 square kilometres, population of about 550,000 and borders on the north shore of Lake Ontario. About 85% of the area is fully developed with 7 distinct areas zoned as Industrial Districts (16% of total area). About 400 known ICI sites have stormwater discharges (70% are in Industrial Districts). The City is drained by three watercourses which receive stormwater from 826 outfalls. Thirty-two large outfalls discharge directly to Lake Ontario. Storm outfall and up-pipe pollution prevention efforts utilize aproximately 6,000 manhours per year. Analytic laboratory costs average $35,000 CDN per year. Equipment costs average $15,000 CDN per year. First year start up costs approximate $200,000 CDN for 70% of total area. No stormwater discharge permits are issued in Scarborough except for "once-thru cooling water" to storm. All storm water quality is specified by a Sewer Use Bylaw on a concentration basis, not load. All outfalls, drainage areas and pipes have been digitally mapped. Watercourses are monitored at select locations during dry and wet weather, and on a seasonal basis. Specific storm drainage areas receive intensive investigation. Outfall problems are identified by chemical, biological and visual criteria. Problem outfall (storm sewerage) investigative techniques include visual, biological degradation, chemical and physical assessment. Discharge characterization techniques using flow meters, non-intrusive sensors, video cameras, absorbent sticks/pads (for petroleum), dye testing, smoke testing and pressure testing assist in problem verification. Finding illicit connections and discharges requires dedicated Programs with Procedures that may be executed with Intuition and occasionally Luck (P³IL).

Introduction

Storm water issues in the Province of Ontario have received increased profile and priority since the early 1980's. The Ontario Ministry of Environment and Energy

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(MOEE) and the Ontario Ministry of Natural Resources (MNR) regulate all issues on a province-wide basis. Provincial agencies, such as Conservation Authorities, regulate some water issues on specific watershed bases.

The MOEE regulates predominantly water quality issues, and permits the taking of water from surface and groundwater sources. The MNR regulates water as a habitat and resource issue. Conservation Authorities focus on water quantity control, flood and erosion issues. Legislative authority over storm water related issues rests predominantly in the:

- Ontario Water Resources Act (enforced by MOEE)
- Environmental Protection Act (enforced by MOEE)
- Federal Fisheries Act (as enforced by Provincial MNR)

However, other legislative acts have impact on water discharge (quantity and quality) issues. The Building Code Act (1990) includes regulations pertaining to plumbing and drainage specifications for private lots and some industrial activities.

As environmental concerns and public awareness increased in the mid 1980's, the specific legislation and regulations of the late 1970's and early 1980's have been "enhanced" (with many well intentioned Interim Guidelines.... and Draft Interim Guidelines .....) without amending the legislation. The bottom line of all regulations pertaining to discharges of storm water to the environment is that the owner (or controlling party) of the discharge is deemed to be responsible.

The City of Scarborough (172 square kilometres, population 550,000) owns and operates all sewer conveyances. The City does not own or operate sewage treatment services; treatment is provided by the upper tier Metropolitan Toronto Regional government. All storm sewer conveyances discharge at outfalls or ditches (approximately 825 in Scarborough) into the local waterway (environment). Hence, the City of Scarborough is responsible for local discharge quality issues. Currently no storm water discharge permit or approval process at the municipal level (other than to allow once-thru cooling water on a site by site basis) is practiced. No specific revenues are generated on storm water; general "sewage rates" are calculated on potable water consumption .

The MOEE proposed program of Municipal Industrial Strategy for Abatement (MISA, 1986) includes detailed specifications for quantity and quality of discharge to the environment from seven industrial sectors and the municipal sector. Many of the "direct" discharge sectors (industrial) have been phased in by 1994. The final sector (municipal with "indirect" dischargers) has yet to be brought forward.

Some Regional and Area municipalities, in preparation for MISA and other proposed by-law enhancements, have undertaken waterway and outfall evaluations. The MOEE has provided varying levels of financial assistance through subsidy programs.

Municipalities within the Great Lakes Basin area of Ontario have been provided

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with yet another challenge by the Canada-U.S. Great Lakes Water Quality Agreement under the International Joint Commission (IJC). Forty-three specific "Areas of Concern" were identified in the Great Lakes Basin. The Metropolitan Toronto and Region (which includes the City of Scarborough as an area municipality) was specifically identified and a Remedial Action Plan (Metro RAP, 1994) has been created. Action plans proposed in the RAP include specific Trace and Disconnect Programs for cross connections in both Residential and Industrial/Commercial/Institutional (ICI) locations.

Clearly, the intent to improve storm water discharges in Ontario has now been conveyed to public and political audiences, as well as to the municipal and private ICI corporations.
In response to this intent and scrutiny, the owner of a discharge (outfall) must carefully provide a blended response to:

- public expectation
- political promises
- regulatory requirements/due-diligence
- budgetary constraints

Such a blended response must carefully compare the benefits between short term projects and long term programs.

The City of Scarborough has developed a series of programs dedicated to pollution control and storm water issues. Finding and correcting illicit connections is a major component of these programs. These programs have specific procedures that, on occasion, may be augmented with intuition and luck.

Experience supports the premise that the most successful ventures into storm water issues should start with the creation of a long term program having specific descriptions of:

- intent (including long term environmental benefit, corporate due-diligence and regulatory compliance)
- objectives that are open to public and regulatory scrutiny, endorsement and support
- goals (measurable actions or parameters used for determining program progress)
- budgetary and staffing requirements

<u>Program Creation</u>

Short term ventures, seasonal projects and site specific actions all have immediate political and public appeal because dollars are quickly spent and visible action is taken. The long term success of these ventures, however, may not be readily appreciated, achieved or even verified. A program for finding and correcting illicit connections should be part of a larger, and well promoted and managed, outfall and watercourse management strategy.

At the municipal government level, the long term success and survival of the program requires a complete understanding, clear documentation and disclosure of the true intent and goals of the program. Specifically, the ideal program should;

i) be created and considered as a long term program and not as a project of a few years duration.

ii) clearly state the obvious environmental problem(s) and associated human health risks so that officials and the public have (and continue to have) a high level of comfort with budgetary and staffing issues.

iii) state realistic goals, with realistic schedules that will be reported on annually.

iv) have annual review procedures for staffing and budgetary requirements, and actively seek funding from existing or new senior government subsidies.

The City of Scarborough currently enjoys strong political and public support for its programs. This is very important to program longevity and funding as no discharge permit or approval process (and associated revenues) currently exists. All program funding is achieved through tax based annual budgets.

Program Components

A successful investigation program should be carefully and completely planned before field efforts begin; field implementation should be phased in over two years. Implementation schedules should be carefully scrutinized and reassessed throughout the second year.

Phase I

To avoid lost time, effort and incorrect assessments, the first phase should be primarily administrative with minimal fieldwork. Specifically;

i) Watershed areas should be mapped with associated overlays of street grid and sewer layout (including both sanitary and storm). A Geographic Information System (GIS) with digitized mapping facilities can provide an ideal format.

ii) Each watershed area should be mapped with locations and identification codes of all storm discharge locations (outfalls, ditches, infiltration pits/lagoons, significant overland flow routes).

iii) A drainage map for each storm drainage area, serviced by an individual discharge outfall, should be constructed with site specific identification of:
- all manholes (maintenance holes) and catchbasins
- combined sewer areas
- combined sewer overflow (CSO) locations
- sanitary pumping station overflow and forcemain locations
- septic or holding tank sites (areas not serviced by sanitary sewer)

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iv) Each drainage area map can then be enhanced with:
- industrial zones/districts
- specific industrial sites
- once-thru cooling water discharge locations
- major transportation corridors and industrial traffic routes
- individual lateral connections to the sewers may also be identified if historic connection cards and a digitized Sewer Inventory Maintenance System (SIMS) are available

Phase II

Field verification of outfall location, size and construction material should commence at the end of Phase I and continue throughout Phase II. Specifically,

i) attention should focus on access routes, access hazards/restrictions. Instructions to staff for access by gates/grates should be coded.

ii) each outfall should be photographed and coded for specific outfall identification.

iii) all outfalls (and drainage areas) should be ranked by size of pipe (hence approximate size of drainage area) and potential number of lateral connections.

iv) lateral connections can also be ranked by size and/or by code for street catchbasin, residential lot, ICI lot, etc.

Phase III

Field assessments should always be conducted by teams (minimum 2 persons per team) where each person is fully trained and certified (when appropriate) in
- confined space access
- first aid/CPR
- road closure and traffic control procedures
- sampling procedures
- chain of custody procedures
- data logging

Screening procedures should be conducted in progression as follows:
- outfall assessment
- up-pipe investigation
- focus on specific sewer branch and lateral connection
- verification and documentation for correction and/or legal action

Outfall Assessment Procedure

a) Visual assessment for solids, odour, colour, oil and grease "sheen", paper and rags, structural damage and acid erosion, can be enhanced with visual clues of biological degradation/enhancement (loss or proliferation of aquatic vegetation, macrophytes or invertebrates in the immediate area of the receiving water).

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b) sample parameters should include field measurement of
- flow rate (L/sec)
- temperature (°C)
- dissolved oxygen (mg/L)
- pH
- conductivity (μmho's/cm)

c) Grab samples should be taken if flow is greater than a trigger limit (ie. O.1 L/sec). Analysis of samples should include parameters in Fig. 1.

Figure 1: SAMPLE PARAMETERS AND THRESHOLDS USED TO SELECT OUTFALLS FOR UP-PIPE INVESTIGATION

Parameter		Threshold	Units
Escherichia Coli	(EC)	10,000	/100 mL
Faecal Coliforms	(FC)	50,000	/100 mL
Faecal Streptococci	(FS)	50,000	/100 mL
Pseudomonas Aeruginosa	(PA)	100	/100 mL
Total Kjeldahl Nitrogen	(TKN)	5.0	mg/L
Total Phosphorus	(TP)	1.0	mg/L
Copper	(CU)	1.0	mg/L
Zinc	(ZN)	1.0	mg/L
Lead	(PB)	1.0	mg/L
Cadmium	(CD)	1.0	mg/L
Chromium	(CR)	1.0	mg/L
pH	(pH)	6.0>pH>9.5	
Total Solids	(TS)	1000	mg/L
Dissolved oxygen	(DO_2)	<5	mg/L
Temperature	(Temp)	>45	°C
Biochemical Oxygen Demand	(BOD5)	5.0	mg/L

Additional parametres may include:
- Oil/Grease reported as i) animal/vegetable
  ii) mineral/synthetic
- Chemical parameter(s) specifically related to local ICI

Characterization of outfalls is the most labour intensive and costly activity of the program. It is also a very important activity (second only to finding and removing a cross connection) and must be carefully documented for compliance and enforcement issues, long term trend analysis and watershed loading estimates.

Bacterial data should be reported as a geometric mean count per 100 ml sample volume.

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Chemical concentrations should be reported as flow weighted mean concentrations (FWM); this removes some bias associated with extreme variations in flow rates,

$$FWM = \frac{(\Sigma_1^n q_i c_i)/n}{(\Sigma_1^n q_i)/n}$$

where q_i = flow rate during the i^{th} sample
c_i = concentration of parameter in the i^{th} sample
n = number of samples collected for parameter

Load calculations should be expressed as an arithmetic average load (L),

$$L = (\Sigma_1^n q_i c_i)/n$$

All visual data should be summarized and ranked by presence/absence criteria. All chemical and physical data should be summarized and ranked by concentration.

Outfalls having visible problems plus chemical and physical data in exceedance of threshold values should be prioritized for immediate up-pipe testing.
Outfalls having no visible problems may have chemical or physical problems. Ranking by FWM and loadings will assist in prioritizing specific outfalls for up-pipe investigation.

Up-pipe Investigation Procedures

Always use the same investigation team on a prioritized outfall. Personal insight, experience and continuity of field procedures are very important in minimizing time and cost. Intuition should be considered but always verified by sampling.

The goal of up-pipe testing is to determine which leg of sewer (between sequential manholes) is receiving the offending discharge.

Regardless of the residential or ICI nature of the drainage area, visual clues and bacterial testing provide the most effective initial investigation because:

- visual clues of rags, paper, oil/grease and solids are readily seen in flow or on benching in manholes and pipes
- bacterial tests are usually reported in 24 to 36 hours (compared to 2 to 3 weeks for chemical tests)
- residential cross connections are usually whole house or basement washroom in origin; bacterial counts will be high (E.C. $> 10^4$) with only some measurable chemical parameters
- industrial whole building or unit cross connections usually include locker and washroom facilities (industrial sites with multiple sewer connections will require visual and chemical testing after bacterial cross-connects are removed)

In an area which is predominantly ICI or is known to have specific chemical users, chemical tests specific for that area will result in better investigation progress but cost significantly more in analytic costs and extended turn around times.

In areas having mixed residential and ICI, especially in large areas serviced by storm pipes >700 mm, the visual and bacterial tests should always be investigated and solved first. After bacterial sources are removed, chemical testing can proceed without interference from alternate sources.

Sampling Location and Frequency

a) Manhole entry locations and sampling frequencies are best determined by the knowledgeable field team.

In small drainage areas (pipes <700mm dia.), 5 to 7 manhole entries for visual and bacterial testing should provide a good definition of problem area.

In larger drainage areas (pipes >700 mm dia.) the first sampling effort may require 10 to 12 manhole entries to successfully sample major intersections and pipe branches.

b) Based upon the visual and first series of bacterial results, subsequent sample runs should include 3 to 5 sequential manholes in the suspect pipe branch.

Typically, visual clues become more evident as one gets closer to the site. Within 200 to 300 metres of the source, average EC:FC:FS:PA counts are $\geq 10^4:10^4:10^4:10^2$. Typical storm sewers and outfalls having no sanitary sewage input have average EC:FC:FS:PA counts $\leq 10^3:10^3:10^3: 10^1$.

c) When the affected leg of sewer has been identified, it must be verified by visual, bacterial and chemical testing (with flow estimates) in the upstream and downstream manholes.

d) Once verified, the difficult task of identifying the exact point of discharge to the sewer can be undertaken;
   i) Residential areas require house by house dye testing of sanitary facilities. This is laborious and typically <50% of buildings are accessible on any given day of effort. Repeated returns to the area may accomplish up to 85% of building testing but rarely is 100% access acquired without sending registered letters and pre-arranging after-hour/weekend testing.
   ii) ICI areas are significantly easier to dye test because they have

fewer lateral connections and usually have control manholes for direct access. Large individual ICI site cross connections can result from:

- site or building expansion over existing outdoor drains and catchbasins
- outside storage area and loading and receiving bays may not have spill containment facilities

iii) When access problems occur in residential sites or certain ICI sites, alternate tests may be progressively used:

- smoke tests in sanitary sewer
- smoke tests in storm sewer
- video camera (in-pipe) to find and observe offending lateral
- dye testing rain water leaders

Difficult Scenarios

Scenario #1: No definite leg of sewer (between sequential manholes) can be identified after 3 or 4 sample runs. The investigation team should suspect;

i) faulty structure or integrity of sewers which allows contaminants to escape from the sanitary sewer, cross bedding material and infiltrate the storm sewer. Pressure testing the sanitary sewer is a suitable verification test under these circumstances.

ii) more than one source of contaminant exists, however, sources are intermittent because of shiftwork or weekend schedules.

iii) the offending party has observed investigation teams efforts and has altered business schedule to avoid detection.

To deal with issue ii) and iii) the investigation team should leave the area for about a week, then return and install auto samplers that collect discrete hourly samples. These auto samplers may be augmented with flow loggers or pH sensors to help define the timing of discharges into the branch sewer.

Scenario #2: Full investigation and in-pipe video reveals no lot lateral connection (typically a chemical, not bacterial problem). The investigation team should suspect;

i) spills or illegal dumping into roadside catchbasins or utility chambers. Catchbasin sumps and chambers should be checked for evidence. Surveillance of the area using time delay video recordings or unmarked vehicles may prove successful.

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ii) infiltration into storm pipe during rain events or seasonal high groundwater that is moving contaminants from adjacent lands (landfill sites, industrial site, septic beds, etc.) To verify this problem, a series of boreholes and subsequent soil/water testing should be conducted in the immediate vicinity. Positive results may lead to a large scale and costly remedial effort at source and in the utility trench.

Documentation

The initial phases of program creation (mapping, coding locations, etc.) will become the backbone of a successful program. Proper and complete documentation of all efforts, observations and findings must be carefully and securely filed.

Strict supervision of field staff and their documentation is also necessary. The "thrill of the chase" usually expedites the finding of the cross connection. Concurrent poor documentation may inhibit the correction of the alleged problem especially if the owner becomes adversarial; the good luck of quickly finding the source may turn to bad luck.

Outfall characterization data and cross connection efforts will complement other watershed or stormwater management program efforts. Proper documentation and filing of data will help explain variations in local watercourse conditions. This documentation is essential in maintaining a high level of comfort with government officials and the public.

Summary

The Program and Procedures have been created, and are currently used, in the City of Scarborough. They have evolved (and sometimes regressed) over the years, hence the current program contents have been polished with hindsight.

The creation of a similar program must have full and accurate disclosure of financial and staff requirements from its inception. Failure to properly budget and control expenditures, even if many cross connections are found and corrected, will jeopardize the survival of the program.

Start up costs, in the first year, need not be excessive. Scarborough contracted Phase I (without digitizing), Phase II and Phase III (only outfall characterization) for 70% of the City (554 outfalls) in 1986 for about $200,000 CDN (Gartner Lee, 1987). In subsequent years, staff have digitized most of original Phase I, II work and have conducted Phase I, II, III on the remaining 280 outfalls (250 outfalls in the combined sewer area having 72 CSO's).

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Phase III cross connection efforts continue year round utilizing about 6,000 manhours per year. Annual equipment costs, since 1987, have averaged $15,000 CDN per year. Analytic laboratory costs average $35,000 CDN per year.

Phase III outfall characterization is being repeated on a five year schedule with certain outfalls visited more frequently based upon complaints (or spill occurrences) and as verification after a cross connection correction.

Typically, the first and second year of the Phase III effort reveal the greatest number of cross connections per unit effort as gross visual problems (ie. bean sprouts, oil/grease, fish scales/eyes, acid erosion, etc.) are assessed and quickly traced. Subsequent efforts, dealing with clear water chemical problems require significantly more effort and cost. Success per unit effort is maximized by having a dedicated program and specific procedures with allowance for intuition and luck.

Positive reporting to City officials and the public on initial successes and subsequent follow up efforts is very important. It should be stressed that cross connections can appear at any time and place and that only with a long term program can storm water and waterways be maintained to the public and regulatory standards.

Acknowledgements

Commissioner Michael A. Price, P.Eng., FICE, and former commissioner R.K. Brown, P.Eng. of the City of Scarborough Works and Environment Department provided continued support and encouragement for this and other environmental programs. Environmental Services Director, R.T.Quinn, P.Eng. has provided consistent budgetary, staffing and moral support for this program on an annual basis. Funding assistance for start up of the program was provided by the Ontario Ministry of Environment and Energy.

References

Gartner Lee Ltd., *Highland Creek and Rouge River Pollution Study*, for the City of Scarborough, 1987.

Metro RAP, *Clean Waters, Clear Choices*, Metro Toronto and Region Remedial Action Plan, 1994.

MISA, *White Paper on Municipal-Industrial Strategy for Abatement*, Ontario Ministry of Environment, 1986.

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SESSION II: Locating Illicit Connections

DISCUSSION

Locating Inappropriate Discharges to Storm Drains
Melinda Lalor, Robert Pitt, Richard Field and Edward Thackston

No questions or comments.

Finding Illicit Connections and Discharges with P*IL
John Minor

Approach is to sample outlets for a variety of pollutants and then rank them by the percentage of pollutant load contributed by the individual outlet. The municipality then works to remove the illicit connections from the systems that contribute the most pollution.

Do not neglect the smaller pipes, since they often have the worst water quality.

50% of illegal connections require court action to get removed (could this be because they are industrial and commercial?). Need to collect up to a week's worth of data to document sufficiently for court action. Video is becoming increasingly accepted by the court.

Private homes receive 50-100% reimbursement for removal of illegal connections.

Court win ratio is about 50% - therefore about 75% get fixed.

A high percentage of the original illegal connections have been removed. There are still a number remaining, but the pollution from them is small, compared to what was originally there. The real question is "how far do we go in removing illegal connections"?

(No Paper in Proceedings)
John Bingham

Showed the Stonebrook area of Boston, which is a system that has been separated, and which feeds into a combined sewer area. Purpose of the monitoring program was to define the relative contribution of the stormwater system to dry weather pollution load from Stonebrook, i.e. find sanitary connections to stormwater system.

Study was made to identify cross-connections and other sources in the watershed. Analyzed for color, ammonia, fluoride and detergents.

Hach kits were used, and they found that ammonia was the most useful indicator for distinguishing between wastewater and stormwater.

Found about 1 mgd total of raw sewage flowing directly into the Charles River.

Panel Discussion/Questions/Comments

Question: If the storm drain is on private property, it can be difficult to verify and enforce removal of illegal connections.
Answer: Ontario has purchased the right-of-way for all its sewers.

Comment: Contaminated cooling water has chemicals that are not easy to find with simple test kits.

Comment: Pitt also found this - chemicals were generally concentrated tap water, but you have to look for specific tracers, such as rust inhibitors. Cu might be used.

Comment: (Cave) These discharges are falling through the cracks. Region I now has an ordinance, as does California.

Question: Did Bingham filter samples?
Answer: Yes, tested filtered and unfiltered samples, and found no real difference in measured concentrations except for fluoride. However, they recommend filtration of all samples anyway, to remove interferences for colorimetric tests.

Comment: Used Hach kits and got many false negatives on Cl from unfiltered samples. Pitt observed that Cl is not a good indicator for anything.

Question: How do you deal with illegal dumping problems?
Answer: Must collect a sample - which is the largest problem. This may involve building a dam, or setting up some special sampling equipment to collect intermittent flows.

Question: Were criteria developed based on receiving water quality criteria (largest concentration may not have largest environmental impact)?
Answer: Generally, no, but we are trying to move to this.

Comment: For those starting an illicit connections study, do not begin with sampling, but rather gather up as much existing data as possible.

Comment: An EPA User's Manual on detecting illicit connections is available from Richard Field.

Comment: A public information program can be very helpful - public has many eyes (although it may require considerable staff time to check out citizen reports).

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NPDES MONITORING - ATLANTA, GEORGIA REGION

P. Michael Thomas,[1] Scott L McClelland,[2]

INTRODUCTION

The impact of stormwater runoff on urban streams is becoming more significant as urban areas continue to expand and as treated wastewater discharge quality is improving. Urban stormwater runoff can contain significant amounts of various pollutants including bacteria, sediments, nutrients and heavy metals (U.S. EPA, 1983). The urbanization or development of a watershed can have a variety of impacts on the stream, including increased flooding, streambank erosion and pollutant export (Schueler, 1987). As a result, the U.S. Congress affirmed in the 1987 Clean Water Act Amendments, that stormwater pipes are point sources of pollution and must be permitted through the NPDES permit program. This paper describes a regional stormwater monitoring plan developed and implemented in the Atlanta Region to comply with NPDES rules and to characterize local stormwater discharges.

<u>Coordinated Regional Response</u> - After the U.S. Environmental Protection Agency (EPA) issued the final stormwater permit rules in 1990, the Georgia Environmental Protection Division (EPD) announced that they would issue a uniform region-wide permit for a five county Metro-Atlanta area of Clayton, Cobb, DeKalb, Fulton and Gwinnett Counties. EPD defined this area as a large municipality, despite the fact that it contains over 40 governments ranging in population from 2,642 (Palmetto) to 468,000 (unincorporated DeKalb County). The population for the entire five county area was 2,218,600 in 1990. The result of EPD's action meant that small cities who had never heard of the NPDES stormwater program, had six months to prepare their Part I application. EPD's rationale for this action was that all these jurisdictions were contributing to violations of water quality standards in Atlanta area rivers and streams.

The local governments joined together with the regional planning agency, the Atlanta Regional Commission, to form the Atlanta Region Storm Water

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Management Task Force to develop efficient and consistent stormwater permit applications. EPD's strategy was to issue a single permit for the five county area allowing each government to apply independently or as a coapplicant with a larger government. This resulted in 21 independent or lead applicants and 16 coapplicants (Table 1). By coordinating activities and sharing resources, the local governments were able to reduce the resources required in all aspects of the application process including the stormwater characterization work. The Task Force members also worked together to develop a regional approach for a long-term stormwater monitoring plan.

TABLE 1. Independent or lead applicants and coapplicants to the region-wide NPDES stormwater permit for the Metropolitan Atlanta area and their 1990 population.

Independent Applicants		Lead Applicant & Coapplicants	
Government	Population	Government	Population
Cobb County	453,400*	Clayton County	142,000*
Fulton County	156,005*	Forest Park	17,083
Acworth	4,547	Jonesboro	3,661
Alpharetta	13,104	Morrow	5,206
Atlanta	415,200	Riverdale	9,488
Austell	4,201	DeKalb County	467,871*
College Park	20,823	Chamblee	7,860
East Point	34,858	Clarkston	5,483
Fairburn	4,053	Decatur	17,498
Hapeville	5,510	Doraville	7,723
Kennesaw	9,039	Lithonia	2,482
Marietta	46,213	Stone Mountain	6,560
Palmetto	2,642	Gwinnett County	282,752*
Powder Springs	6,970	Buford	8,862
Roswell	48,257	Duluth	9,125
Smyrna	31,328	Lawrenceville	17,054
Snellville	12,137	Lilburn	9,389
Union City	8,483	Norcross	6,034
		Sugar Hill	4,598

*Population listed is for the unincorporated portion of the County

DESIGN OF THE REGIONAL MONITORING PLAN

To comply with the permit application requirements, a regional characterization plan was developed and each major government was assigned appropriate sampling responsibilities. A number of different governments and agencies were involved in instrumenting these sites and collecting information from appropriate storm events. The data collected from each site were compiled and used to develop local stormwater event mean concentrations and pollutant loading estimates for the Region.

NPDES Monitoring - The rules promulgated by the U.S. EPA, required that each permit applicant collect "quantitative data from representative outfalls" of stormwater runoff. The objectives of this sampling work can be summarized as follows:

a) determine the type and magnitude of pollutants in stormwater runoff; and
b) relate the water quality characteristics to land use type.

An important consideration was to collect enough samples to develop statistically valid event mean concentrations for each pollutant by land use (the rules require that three storm events be sampled at each site). Also, it may be important to collect samples during different seasons to determine if there are seasonal fluctuations in stormwater quality.

Sampling Site Selection - One of the first issues addressed by the Task Force was to determine how many sites should be monitored and who would be responsible for instrumenting the sites and collecting and analyzing the samples. The EPA rules required that each applicant select five to 10 representative outfalls for collection of samples for three storm events. It was obvious that five sites for the entire Region was not adequate and that five sites for each of the 21 independent applicants was excessive. The compromise developed by the Task Force was to locate an average of five sites in each county for a minimum of 25 sites. ARC staff developed a method of allocating the responsibility for these sites among the permit applicants based on population and employment as an estimate of the relative amount of stormwater runoff that would be generated by each jurisdiction. The allocation of sites resulted in the five counties and four largest cities being assigned from one to six sampling sites each. The smaller cities, which lack the resources to conduct this type of work, were not assigned a sampling site but were asked to share in the cost of the monitoring work based on the percentage of their population in their respective county.

After the number of sites per government was selected, general site locations were determined based on existing monitoring networks, land use and watershed characteristics. Specific monitoring sites were then located based on size of the drainage area, type and continuity of land use and use of stormwater pipe or stream sites. Existing local government stream monitoring sites were utilized where possible. Sites were then visited and evaluated based on accessibility, safety, security and suitability for flow measurement and sample collection. Hydraulic factors considered for stream sites included open-channel sites with existing stage-discharge relations or sites where adequate stage-discharge relations could be established, stable channel conditions, and adequate distance from major tributaries to allow for complete mixing. Other general site considerations included avoiding sites having steep slopes, poor visibility, and heavy traffic.

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Most of the sites were located in the Chattahoochee River basin because more of the five county area lies within this basin than any other and because this river is of great significance to the region, providing over 70% of our water supplies. Figure 1 shows the general location of the 27 sites. Because land use is the main factor that impacts the quality of stormwater runoff and is often used in models to predict stormwater quality (ARC, 1992c), sampling sites were selected to represent the major land uses in the area (Table 2). Where possible, small drainage areas which represented a single land use were chosen.

FIGURE 1. Stormwater Sampling Locations in the Atlanta Region

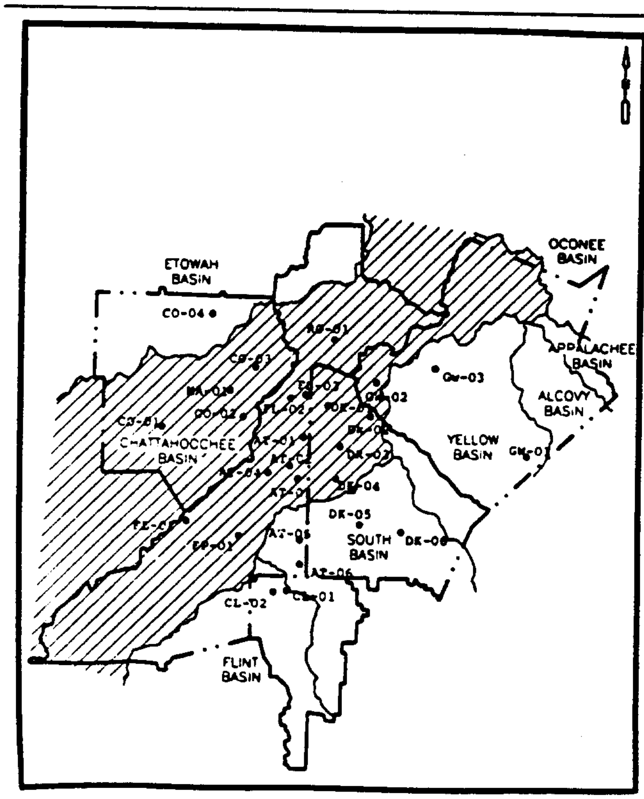

TABLE 2. Sampling Site Description and Land Use Category

Station Number	Site Description	Land Use Category
AT-01	Outfall - Tributary to Nancy Creek - parking lot of large shopping mall, draining commercial land use area.	Commercial
AT-02	Outfall - Tributary to Peachtree Creek - parking lot and roadway, area of commercial and light industrial land use.	Commercial
AT-03	Outfall - Tributary to Clear Creek - draining single family residential area.	Residential
AT-04	Outfall - Tributary to South River - draining a light industrial park.	Industrial
AT-05	Outfall - Tributary to South River - draining an area of industrial land use.	Industrial
AT-06	Outfall - Tributary to Chattahoochee River - draining an area of industrial and transportation land use.	Industrial
CL-01	Junction Box - Tributary to Flint River - draining an area of heavy industry.	Industrial
CL-02	Outfall - Flint River, Clark Howell Highway - draining commercial, business and transportation land use.	Commercial
CO-01	Stream - Olley Creek Tributary to Sweetwater Creek - draining an area of industrial and commercial activity including a closed sanitary landfill.	Commercial
CO-02	Outfall - Unnamed Tributary to Rottenwood Creek - draining a commercial/business park area.	Commercial
CO-03	Outfall - Tributary to Sope Creek - draining moderate density residential area.	Residential
CO-04	Stream - Noonday Creek Tributary to Lake Allatoona - draining an area of residential and commercial land uses.	Residential
DK-01	Stream - Bubbling Creek Tributary to Nancy Creek - draining an area of public parks and residential land uses.	Residential

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TABLE 2. Sampling Site Description and Land Use Category (continued)

DK-02	Stream - Unnamed Tributary to North Fork Peachtree Creek - draining a heavy industrial area.	Industrial
DK-03	Stream - Unnamed Tributary to North Fork Peachtree Creek - draining a residential area.	Residential
DK-04	Stream - Tributary to South Fork Peachtree Creek - drains an area of residential and public land uses.	Residential
DK-05	Stream - Tributary to Shoal Creek - drains an area of residential land use.	Residential
DK-06	Outfall - Tributary to Snapfinger Creek - an area of light industrial land uses.	Industrial
EP-01	Outfall - Tributary to South River - draining an industrial area inside the city.	Industrial
FL-01	Outfall - Tributary to Chattahoochee River - draining area of light/moderate industrial land use.	Industrial
FL-02	Outfall - Tributary to Chattahoochee River - draining area of commercial and transportation land use.	Commercial
FL-03	Outfall - Tributary to Chattahoochee River - area of commercial land use.	Commercial
GW-01	Stream - Tributary to Big Haynes Creek - draining an area of moderate density residential land use.	Residential
GW-02	Junction Box - Tributary to Chattahoochee River - draining an area of industrial land use.	Industrial
GW-03	Junction Box - Tributary to Sweetwater Creek/Yellow River - commercial area around a large shopping mall.	Commercial
MA-01	Outfall - Tributary to Rottenwood Creek - commercial/business park area.	Commercial
RO-01	Outfall - Tributary to Chattahoochee River - draining moderate density residential area.	Residential

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DATA COLLECTION

A regional consultant was selected (Camp, Dresser & McKee, Inc.) by the Task Force to develop standard operating procedures for the monitoring program and to conduct most of the sampling work. The use of the regional consultant allowed the work to be done quickly and consistently. Some of the large local governments were able to use their own staffs to conduct part of the monitoring work. As the local governments move from the permit application phase to the long-term monitoring program, most will conduct the work with their own staff. Table 3 lists who was responsible for conducting the sampling and lab analysis in each jurisdiction. The involvement of many different parties in the sampling program raises a concern over the consistency of the data collected. The use of the standard operating procedures and the use of the same analytical laboratory for 63% of the sample analyses reduced inconsistencies.

TABLE 3. Sampling Program Responsibilities

Participant	No. of Sites	Equipment Procurement	Sample Collection	Sample Analysis
Atlanta	6	City	Reg. Cons.[1]	Reg. Cons.[1]
East Point	1	City	Reg. Cons.	Reg. Cons.
Marietta	1	Reg. Cons.	Reg. Cons.	Reg. Cons.
Roswell	1	City	Reg. Cons.	Reg. Cons.
Clayton County	2	Reg. Cons.	Reg. Cons.	Reg. Cons.
Cobb County	4	County	County	County
DeKalb County	6	County	County/USGS	County/USGS
Fulton County	3	County	Reg. Cons.	Reg. Cons.
Gwinnett County	3	County	County	Reg. Cons.

[1]The Regional Consultant (Reg. Cons.) was Camp Dresser & McKee, Inc. The City of Atlanta utilized a different lead consultant but used the same subconsultants as Camp Dresser & McKee did for sample collection and analysis.

Representative Storm Event Criteria - The EPA rules required that each applicant collect samples of stormwater runoff. The rules recommended that "representative storm events" be sampled which met the following criteria:

- the storm event must be greater than 0.1 inches in magnitude;
- the event must be at least 72 hours from the previously measurable event (>0.1 inches);
- where feasible, the variance of event duration and total rainfall should not exceed 50 percent of the average or median rainfall event; and
- the three storm events must be one month apart.

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These criteria were proposed to insure that "representative" storm events are sampled and that a preceding dry period is provided to allow a normal period of pollutant deposition on land surfaces.

A statistical evaluation of long-term rainfall records for the Atlanta Region conducted by ARC determined that only an average of 6.2 storms per year would meet these criteria (ARC, 1992a). An additional analysis was conducted to determine if expanding the criteria to ±75% of depth and duration would significantly improve the number of acceptable events. The result was an increase to an average of 14 events per year which still was not a practical operating criteria once the actual sampling work began. Seasonal differences in rainfall patterns and the required 30 day period between events made collection of samples from an acceptable storm event very difficult. The Task Force requested a modification of storm event criteria from EPD and received approval to sample any storm event of a depth of 0.1 inches or more with a 72-hour dry period preceding it. No restrictions were placed on duration of the storm event or the time period between sampling events.

Site Instrumentation - All 27 sites were instrumented in a similar manner, although several organizations were responsible for this activity. A typical site instrumented by the U.S. Geological Survey for DeKalb County consisted of a tipping-bucket rain gage, a staff-type gage, and a stream-stage-shaft-encoder, automatic sampler, and datalogger housed in a monitoring shelter. The equipment was purchased by DeKalb County and maintained for operational readiness during the study by the USGS. Repair and replacement costs to structures and equipment were the responsibility of DeKalb County.

A typical site instrumented by the regional consultant included either a tipping bucket or totalizing rain gage, an automatic sampler with integral data logger and a temporary equipment shelter. Both ISCO and American-SIGMA samplers were used, depending on the preference of the local participating agency. Equipment was either purchased by the local agency and operated by the consultant, or leased and operated by the consultant. All maintenance during the program was provided by the consultant.

Sample Collection and Analysis Procedures - At the DeKalb County/USGS sites the datalogger was programmed at each site to record data at 1-min. intervals once a rainfall threshold of 0.1 in. was met or exceeded. A theoretical culvert rating was programmed into the datalogger which converted the recorded stages into discharges. The datalogger then triggered the automatic samplers each time about 10 percent of the estimated storm volume passed the site. Runoff samples were withdrawn from the stream over the storm hydrograph by the automatic samplers and composited into one sample that represented the water quality conditions for the storm event. For a typical rainfall event, procedures were to activate the rainfall and stream-stage recorders at the sites to be sampled prior to the impending storm. The automatic samplers were checked and outfitted with 2.5 gal. containers. When the rainfall amount at each site reached 0.1 in., the datalogger would begin to collect rainfall and stage data at 1-min. intervals. When the stream

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stage reached a preset level (activation level), the volume of water flowing by the site was computed from the recorded stage and accumulated by the datalogger. The datalogger would then trigger the sampler at increments of about 10 percent of storm volume, and the sampler would pump 2 liters of water into the composite bottle. During sampling of the runoff period, ten 2 liter sub-samples were collected in two 2.5 gal. containers. The samples were chilled with ice during the sample collection period and prior to processing. In addition to storm-composite samples, grab samples for measurement of water temperature and pH, and the analysis of cyanide, oil and grease, volatile organic compounds (VOCs), and phenols were collected by hand on the rising side of the storm hydrograph. Water temperature and pH were determined at the site. Grab samples were delivered to DeKalb County Water Quality Lab immediately after collection for the analysis of selected constituents.

Composite samples collected by the automated sampler were processed by the USGS at the District Office. Processing included splitting the composite sample into appropriate bottles using a 16 liter teflon-lined churn splitter, filtering and preserving samples. Processed samples were delivered to DeKalb County Water Quality Lab for inorganic analysis and shipped to the USGS lab in Denver for organic analysis.

Sample collection procedures for the sites administered by the regional consultant were similar to the USGS procedures. Samplers were programmed to collect a sample at equal intervals of flow based on the estimated flow that would be generated from a 0.1 inch rainfall event and the minimum amount of sample required for laboratory analysis. Each sampler was programmed with a theoretical stage-discharge curve and set to initiate sampling when a threshold level was reached.

When a rainfall event alert was issued, each site was visited to check the equipment and activate the battery powered sample. Composite sampling was then initiated automatically when the threshold flow was reached. Grab samples were taken on the rising side of the storm hydrograph. During the grab sample visit, field analysis were made and recorded, the automatic sampler was checked for proper operation, and ice was added to chill the samples of the storm duration. Grab samples were also chilled or fixed in the field. Eventually, composite samples were delivered to the laboratory at the end of the sotrm event. All sample processing including splitting of alloquats, filtering, preserving and analysis was done by the contract laboratory. Typically, all analyses were completed and reported within three weeks.

Several different laboratories were involved in the analysis of the stormwater samples but the majority of the analysis was conducted by a private lab used by the regional consultant. Other labs included the USGS National Water Quality Laboratory, the DeKalb County Water Quality Control Laboratory and the Cobb Water System Laboratory. All laboratories used EPA approved methods for sample analysis. Each sample was analyzed for the full list of over 100 parameters required in the NPDES permit application rules.

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Experience with stormwater runoff sampling in previous studies indicates that about 10 attempts at storm sampling are needed to successfully collect one storm event sample. The USGS found that once equipment problems were solved, such as problems with the datalogger and rainfall recorder, and the criteria for suitable storms were eased, that the success rate for sampling was about 90 percent of the events sampled.

Quality Control of Sampling and Analysis - A quality assurance plan was developed and implemented for this study to ensure that data collected were in accordance with accepted industry standards. The USGS developed a plan to ensure that data were collected in accordance with the U.S. Environmental Protection Agency's program requirements for stormwater sampling and that met the technical standards of the Water Resources Division of the USGS. The USGS plan addressed, in part, quality assurance measures for sample handling procedures, chain-of-custody procedures, and analytical methods that included quality control (QC) samples, and evaluation and reporting of QC data. The quality-control procedures provide a mechanism for control and evaluation of the data quality during the project, and define the data quality for the constituents in terms of precision and accuracy.

The regional consultant and local governments involved in sample collection and analysis used similar QC procedures which are documented in the regional Standard Operating Procedures Manual (ARC, 1992b) prepared by the regional consultant.

SAMPLING RESULTS

For the 81 site events (27 sites sampled three times each), the storm durations ranged from 0.5 hours to 26.4 hours and storm magnitudes ranged from 0.12 inches to 4.22 inches. Table 4 shows information on the storm events sampled during this program.

Impact of Land Use on Stormwater Quality - A review of the sampling results by land use category illustrates some apparent differences among land uses (Table 5). However, the differences may not be statistically significant because of the highly variable nature of stormwater quality. Surprisingly, residential land use appears to have more of an impact on some constituents than commercial and industrial land uses. Residential areas were characterized by much higher concentrations of total suspended solids, copper, fecal coliform and fecal streptococcus bacteria. Industrial areas were characterized by much higher concentrations of dissolved phosphorus and zinc. Commercial areas had much

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TABLE 4. Storm Event Characteristics

Site	Land Use	Duration (hours)	Rainfall (in)	Average Rate (in/hr)	Flow (gal)	Average Rate (gal/hr)
Averages						
	Residential	8.6	1.13	0.14	17,006	4,700
	Commercial	5.4	0.71	0.10	556,087	206,322
	Industrial	5.9	0.70	0.15	293,885	47,881
	TOTAL	6.6	0.85	0.13	335,129	79,868

TABLE 5. Summary of Results for All Land Uses

Constituent[1]	Residential Avg.	Residential S.D.	Commercial Avg.	Commercial S.D.	Industrial Avg.	Industrial S.D.
BOD	15	17	12	16	16	19
COD	68	55	71	91	79	70
TSS	574	1,159	103	114	97	114
TDS	68	54	47	28	57	48
Total P	0.44	0.51	0.18	0.18	0.36	1.04
Dissolved P	0.09	0.06	0.10	0.11	0.24	0.87
TKN	1.35	0.74	2.57	6.93	1.63	1.49
NO2 + NO3	0.69	0.39	0.67	0.57	0.66	0.50
Ammonia	0.22	0.16	0.51	0.43	0.41	0.31
Oil & Grease	4.9	6.2	16.4	40.9	6.3	5.4
Lead	0.036	0.043	0.024	0.005	0.024	0.018
Copper	0.053	0.067	0.020	0.002	0.023	0.020
Zinc	0.116	0.103	0.132	0.063	0.195	0.145
Cadmium	0.010	0.002	0.009	0.003	0.008	0.003
pH	6.6	0.5	6.8	1.0	6.7	0.7
Fecal Coliform	7,653	--	2,460		3,436	
Fecal Streptococcus	28,864	--	6,800		7,805	

S.D. = Standard Deviation
[1]All units are in mg/l except for the fecal coliform and streptococcus which are in MPN/100 ml

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higher concentrations of total kjeldahl nitrogen. Of the 16 parameters detected at each site, average concentrations were higher in residential areas for nine parameters. However, as described below, some of the higher values in residential areas may be explained by the number of sampling locations located in streams rather than direct outfall pipes. Seven of the ten stream sampling sites were in residential areas.

For comparison purposes, the Atlanta Region stormwater quality data are compared to the results of EPA's Nationwide Urban Runoff Program (NURP) studies (1983) and some of the recent sample results from the Florida Part 2 NPDES Stormwater Permit Application wet weather sampling. The Florida data were compiled by Camp, Dresser and McKee, Inc. (CDM) from Jacksonville, Orlando, St. Petersburg, Sarasota County and Palm Beach County.

Residential - Table 6 shows a summary of analytical data collected during three storm events at nine residential sites for classic pollutants and metals (27 data points). Also shown are results from the NURP study for residential land uses. In

TABLE 6. Summary of Analytical Results for Residential Land Uses

Constituent	Units	Atlanta Region Average	NURP Min	NURP Max	Florida* NPDES Average
BOD	mg/l	15	5	28	11
COD	mg/l	68	33	234	64
TSS	mg/l	574	25	2216	43
TDS	mg/l	68			168
Total P	mg/l	0.44	0.22	4.09	0.38
Dissolved P	mg/l	0.09	0.07	0.45	0.23
TKN	mg/l	1.35	0.05	10.80	1.35
NO2 + NO3	mg/l	0.69	0.31	9.54	0.39
Ammonia	mg/l	0.22			
Oil & Grease	mg/l	4.9			
Lead	mg/l	0.036	0.034	2.745	0.0085
Copper	mg/l	0.053	0.006	0.312	0.0014
Zinc	mg/l	0.116	0.054	1.388	0.0550
Cadmium	mg/l	0.010			0.0015
pH		6.6			
Fecal Coliform	MPN/100 ml	7,653			
Fecal Streptococcus	MPN/100 ml	28,864			

Note: Based on data from Jacksonville, Orlando, St. Petersburg, Sarasota County and Palm Beach County NPDES Stormwater Permit Applications (1992-93).

summary, the data are highly variable with the standard deviations (Table 5) frequently approaching or exceeding the means. The minimum observed values for most constituents were at or below the detection limits so that most of the averages shown on the table are slightly high.

Concentrations of constituents measured in samples from residential land uses are very comparable to NURP data: average concentrations for all of the Atlanta Region data fall within the NURP concentration ranges and almost all of the averages are at the low end of the NURP ranges. The only exception is BOD which is about in the middle of the NURP range.

Analytical results for the Atlanta Region and Florida Part 2 studies are similar for the classic pollutants except for TSS. The Atlanta Region data show an average TSS (574 mg/l) which is 10 times higher than the TSS in Florida Part 2 data (54 mg/l). This difference and others, in stormwater quality between the Atlanta Region and Florida data may be due largely to differences in soil characteristics. The Atlanta Region is in the Piedmont physiographic province, which is characterized by highly erodible, clay soils. These soils provide a good substrate for adsorption of pollutants and can be easily transported into nearby streams. The Florida sites, located in the coastal plain, are generally characterized by sandy soils and minimal slopes which minimizes soil erosion and transport into nearby streams. The metal concentrations in the Florida data (Table 6) are considerably less than the concentrations in the Atlanta Region data including concentrations for lead and copper, which are less than the minimum values observed in the Atlanta Region data.

Of the other pollutants detected in samples from the Atlanta Region residential sites, the most frequently occurring was phenol. Phenol was detected in 15 of 27 samples. Chromium was the second most frequently detected (13 of 27), followed by tetrachloroethylene (11 of 27), and toluene, methylchoride, chlordane and diazinon (each 6 of 27). However, of these pollutants, concentrations were generally low with only phenol and chlordane being detected in concentrations in excess of State water quality standards.

Commercial - Table 7 shows the analytical results for the classic pollutants and metals for the commercial land uses. As for the residential land uses, there were 27 events (3 storms at 9 sites). The data were highly variable with large standard deviations and the minimums were generally below the detection limits.

Oxygen demand, solids and nutrient concentrations for, the Atlanta Region data were generally lower that the NURP data although the differences in concentrations are not significant at one standard deviation. Concentrations of lead, copper and zinc for the Atlanta Region data are less than for the NURP data, with lead being 10 times less and copper and zinc about three times less. The lower lead may be attributable to the elimination of lead from gasoline. Since commercial land uses are heavily influenced by parking lots, the lower values for copper and zinc may also be attributed to changes in automotive technology; however, no clear conclusion can be drawn.

In comparison to the Florida Part 2 data, concentrations of parameters in the commercial data, unlike the residential data, are similar for most parameters. The major differences in concentrations are for total nitrogen (TKN plus NO_2+NO_3) and cadmium. Total nitrogen concentrations for the Atlanta Region data is 3.24 mg/l compared to 2.29 mg/l in the Florida data. Average Cadmium concentrations in the Florida data are 10 times less than the Atlanta Region data.

Several other trace metals and organic compounds were detected in individual samples but none of the data sets contained a sufficient number of detections to develop a reliable event mean concentration (EMC).

TABLE 7. Summary of Analytical Results for Commercial Land Uses

Constituent	Units	Atlanta Region Average	NURP Average	Florida* NPDES Average
BOD	mg/l	12	14	7
COD	mg/l	71	92	50
TSS	mg/l	103	186	41
TDS	mg/l	47		114
Total P	mg/l	0.18	0.29	0.15
Dissolved P	mg/l	0.10	0.17	0.08
TKN	mg/l	2.57	1.61	1.24
NO2 + NO3	mg/l	0.67	0.89	1.05
Ammonia	mg/l	0.51		
Oil & Grease	mg/l	16.4		
Lead	mg/l	0.024	0.2350	0.0117
Copper	mg/l	0.020	0.0618	0.0179
Zinc	mg/l	0.132	0.3990	0.0785
Cadmium	mg/l	0.0087		0.0008
pH		6.8		
Fecal Coliform	MPN/100 ml	2,460		
Fecal Streptococcus	MPN/100 ml	6,800		

Note: Based on data from Jacksonville, Orlando, St. Petersburg, Sarasota County and Palm Beach County NPDES Stormwater Permit Applications (1992-93).

Industrial - As with the other land use categories, 27 samples were collected from industrial land use sites. Also, as with the others, the data were highly variable with the standard deviations often approaching or exceeding the means. Table 8 shows mean values for the industrial sites in the Atlanta Region. The Atlanta Region, NURP and Florida Part 2 data are similar except for zinc which was about five times higher in the NURP and Florida NPDES values.

Contrary to the commercial land uses, nutrients are similar in all datasets, and the cadmium concentrations for the Florida data is about seven times smaller than for the Atlanta Region data. In every case, the concentrations of metals in the NURP data are higher than for either the Atlanta Region or Florida Part 2 data.

As with the commercial land use, other constituents were detected in individual samples but too infrequently to compute a reliable EMC. The most frequently detected compounds were phenol and bis(2-ethyl-hexyl)phthalate (seven detects each).

TABLE 8. Summary of Analytical Results for Industrial Land Uses

Constituent	Units	Atlanta Region Average	NURP Average	Florida* NPDES Average
BOD	mg/l	16	10	12
COD	mg/l	79	61	91
TSS	mg/l	97	120	99
TDS	mg/l	57		160
Total P	mg/l	0.36	0.50	0.34
Dissolved P	mg/l	0.24	0.14	0.17
TKN	mg/l	1.63	1.52	1.49
NO2 + NO3	mg/l	0.66	0.80	0.37
Ammonia	mg/l	0.41		
Oil & Grease	mg/l	6.3		
Lead	mg/l	0.024	0.1150	0.0313
Copper	mg/l	0.023	0.0317	0.0228
Zinc	mg/l	0.195	0.9800	0.1602
Cadmium	mg/l	0.008		0.0013
pH		6.7		
Fecal Coliform	MPN/100 ml	3,436		
Fecal Streptococcus	MPN/100 ml	7,805		

Note: Based on data from Jacksonville, Orlando, St. Petersburg, Sarasota County and Palm Beach County NPDES Stormwater Permit Applications (1992-93).

Comparison of Results to State Water Quality Standards - The Georgia EPD has developed instream water quality standards for over 100 different pollutants. These standards apply to all levels of flow, including wet weather flows. The Georgia EPD has also defined State Waters in such a way as to include water in an enclosed stormwater pipe as "waters of the State" for which the instream water quality standards would theoretically apply.

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Table 9 shows the number of times that pollutant concentrations in a storm event sample for this study exceeded water quality standards. The parameter that was most often detected above water quality standards was fecal coliform bacteria. Lead, copper and zinc were also often found in concentrations in excess of water quality standards. Concentrations of pollutants in excess of water quality standards were found across all land use types and in stream and outfall sampling sites. It will be extremely difficult for stormwater runoff to ever achieve compliance with water quality standards developed for low flow periods.

Stream Versus Outfall Sampling Sites - As discussed above, 10 of the 27 sampling sites were in small urban streams rather than on a direct pipe discharge. These sites were utilized because local governments had already established monitoring sites and stage-discharge relationships at these locations for existing trend monitoring programs and because of the existing historical data available at these sites. It can be noted in Table 9 that for lead, copper and fecal coliform, a much greater percentage of the samples from the stream sites exceeded the instream water quality standards. Also a number of organic pollutants were detected in the samples from stream sites that exceeded water quality standards, such as chlordane and phenol (Table 10). Concentrations of chlordane and phenol were not found at these levels in the direct pipe discharges.

The specific reason for the generally higher concentrations in samples from streams compared to samples from direct-pipe discharges is unknown. It could be the result of several factors, including the resuspension of contaminated sediments in the stream bed or in runoff, or saturated soil water flow into the stream channel from residential lawns, industrial or commercial sites.

TABLE 9. Pollutant Concentrations which Exceeded State Water Quality Standards - Inorganic Pollutants and Fecal Coliform

Site Type	# of Samples	Pb	Cu	Zn	Cd	F. Coli	Cyanide
Water Quality Standard***		7.7	21*	190*	2*	4000**	5.2
By Land Use:							
Industrial	27	8	2	9	2	11	
Resid.	27	10	12	4	2	17	1
Comm.	27	4	1	5	1	8	
Site Type:							
Outfall	51	9	4	11	3	20	
Stream	30	13	11	7	2	16	1
Total	81	22	15	18	5	36	1

*For metals, sample results were compared to the highest limit associated with an instream hardness level.
**Single sample maximum for fishing classification.
***all unit in ug/l except Fecal Coliform (MPN/100 ml) and pH (std. units)

TABLE 10. Pollutant Concentrations which Exceeded State Water Quality Standards - Organic Pollutants

Site Type	# of Samp.	BIS 2-E-H phtha-late	Phe-nan-thene	Py-rene	Chlor-dane	Phe-nol	2-4-Di-nitro-toluene	Hepta-chlor Epox-ide	pH
Water Quality Standard***		5.92	0.0311	0.0311	0.0043	300	9.1		6.0-9.0
By Land Use:									
Industrial	27	7	1	2					2
Resid.	27	2			5				1
Comm.	27	6				2	1	1	4
Site Type:									
Outfall	51	11							6
Stream	30	4	1	2	5	2	1	1	1
Total	81	15	1	2	5	2	1	1	7

*For metals, sample results were compared to the highest limit associated with the instream hardness level.
**Single sample maximum for fishing classification.
***all unit in ug/l except Fecal Coliform (MPN/100 ml) and pH (std. units)

Implications for Long-Term Monitoring Programs - The stormwater quality data reported in this paper was collected over a short period of time, primarily to provide information for development of the NPDES permit application. To learn more about the nature of stormwater quality and the impacts of land use and best management practices and to comply with the NPDES permit, long-term monitoring programs should be developed and implemented. This long-term program should be structured to identify water quality trends and evaluate the effectiveness of BMPs, including structural controls.

Additional sampling would provide a large database and hopefully, reduce the statistical variability of the data in order to detect statistical trends or differences between land uses. Although instream sampling sites are useful for detecting general water quality trends and watershed-wide program impacts, continued sampling of direct outfall pipes is needed to better quantify pollutant concentrations and loads coming directly from the municipal storm sewer system.

Development of Pollutant Loadings - The Watershed Management Model developed by Camp, Dresser & McKee (CDM-WMM) was chosen by the Task Force to develop estimates of pollutant loadings. The CDM-WMM model was specifically developed for planning-level estimates of system-wide pollutant loads. The most recent version contains estimates of the 12 pollutants required by the NPDES regulation. Using Lotus 1-2-3 as a model platform, CDM-WMM calculates annual loads and flows based upon land uses, imperviousness, and land use specific event mean concentrations. The model uses 12 land use categories with associated literature-based EMCs and imperviousness. For the purposes of the Atlanta Region, 10 of these land uses were used for the load estimates with Cropland being combined with Agriculture and Wetlands being combined with Water.

The model estimates annual runoff volume from the pervious and impervious areas of each land use category, annual rainfall, and runoff coefficients, as follows:

$$R_L = [C_P + (C_I - C_P)\ IMP_L]I$$

where R_L = annual runoff for land use L (in/yr);
C_P = pervious area runoff coefficient (0.20);
C_I = impervious area runoff coefficient (0.95);
IMP_L = fractional imperviousness of land use L; and,
I = annual rainfall (in/yr).

The total annual runoff for the municipality is the sum of the R_L for all of the 10 land uses. Based upon available information (ARC, 1992a), the annual average runoff-producing rainfall for this area is 46.8 inches using the Atlanta Airport gage.

The load estimates are then calculated using the land use specific EMCs, runoff and area of the land use within the watershed:

$$M_L = 0.2266\ EMC_L\ R_L\ A_L$$

where M_L = the annual load from land use L (lb/yr);
0.2266 = a conversion factor;
EMC_L = the EMC for land use L (mg/l); and,
A_L = the area of land use L (acres).

As above, the total annual load for the watershed is the sum of the M_L for all of the 10 land uses. It can be seen that this model can easily be used for seasonal estimates as long as seasonal rainfall and justifiable seasonal EMCs are available.

As an added feature in the CDM-WMM model, for future assessments, the model can estimate the change in load resulting from the use of regional best management practices (BMP), such as wet or dry detention ponds, retention ponds, etc. The model can adjust the pollutant load for a BMP as follows:

$$M_L' = M_L\ \left(1 - \frac{A_{BMP}}{A_L}\ REM\right)\ A_L$$

where M_L' = the BMP-reduced load from land use L (lb/yr);
A_{BMP} = the area of land use L draining to the BMP (acres); and,

REM = the removal efficiency of the BMP for the pollutant.

This feature can be used to estimate the effectiveness of watershed pollution control plans as well as test various strategic pollution reduction alternatives.

Comparison of the EMCs measured as part of the Atlanta Region study and the EMCs from the CDM-WMM model shows that for the oxygen demanding substances, sediment, and nutrients, the EMCs are comparable. The CDM-WMM EMC for TDS is high and the model EMCs for lead and zinc are considerably higher than the measured ones. On the other hand, the model EMCs for cadmium are low compared to the measured results. This is a result of the availability of EMC data for the development of the CDM-WMM model. Only limited EMC studies were available and the literature basis of the data focused primarily on the NURP studies. It should be noted that due to the lack of timely storms, the estimate of pollutant loads had to be completed before the Atlanta Region sampling work was complete. For this reason, and because the CDM-WMM EMCs are generally high, the predicted loads from the municipal storm sewer system probably represent an upper limit of pollutant discharges. The estimated pollutant loads also represent loads from the entire political jurisdiction rather than just the area draining to the municipal system because these drainage areas have not been adequately identified.

SUMMARY

The Atlanta Region governments were successful in implementing a regional stormwater sampling program. These same governments are now involved in implementing a regionally-coordinated long-term monitoring program. During the NPDES permit application sampling program, we were successful in determining the type and magnitude of pollutants in stormwater and how to measure them, however, there is still more to learn about their relationship to land use. With regard to stormwater quality, the following is apparent:

- stormwater runoff often contains pollutants in concentrations in excess of Georgia's instream water quality standards;
- stormwater runoff quality in the Metro-Atlanta area is comparable to national stormwater quality statistics;
- stormwater characteristics vary by land use but the variability of stormwater quality is so great that it will require much more data from drainage areas composed of a single land use type to statistically validate those differences.

With regard to stormwater sampling procedures, we learned the following:

- the EPA recommended "representative storm event" criteria were not practical for this region;
- once new equipment problems are resolved and reasonable storm event criteria are established, sampling success can reach 90% of all attempts.

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This information will be valuable in implementing the long-term stormwater sampling program but because of the inherent difficulties involved in wet weather sampling and the variability of stormwater quality, it will require a longer sampling history to confidently make conclusions about stormwater quality that can be used with confidence in developing potentially expensive stormwater management programs. Also, sites with a single land use type should be selected; Some of the drainage areas for the sites sampled in this study did not contain a single predominant land use type.

It is recommended that EPA continue to be flexible in the implementation of stormwater monitoring and management programs as we continue to learn more about this problem. It also evident that even though local stormwater quality data may be comparable to national averages, strong regional differences may occur based on natural factors such as rainfall patterns and soil characteristics. Therefore, programs that work well in one region may be impractical or ineffective in others due to these differences.

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NPDES Monitoring - Dallas- Fort Worth, Texas Area

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INTRODUCTION

Cities in the Dallas-Ft Worth, Texas (DFW) area, as have approximately 250 cities and urban counties in the United States, have been responding to the November 16, 1990 final rule regarding stormwater permitting on a system-wide basis for municipal separate storm sewer systems, sometimes referred to as MS4 permitting. The permits, when accepted by a U.S. Environmental Protection Agency (USEPA) Region or a delegated state agency, will be processed in the National Pollution Discharge Elimination System (NPDES). Hence, the permitting effort, is frequently referred to as NPDES permitting for MS4 cities. The published rule is found in USEPA (1990) and the guidance information for the stormwater aspect of the rule is available USEPA (1992).

SCOPE OF NPDES MONITORING, NATIONWIDE AND DFW AREA

The NPDES permitting effort is a very significant national effort that seeks to define and control urban stormwater and dry-weather water quality in cities of 100,000 population or more. It is estimated that the scope of the national effort involves:

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- About 250 municipal entities, including cities and urban counties
- About 1250 NPDES monitoring sites
- About 3750 monitored events, each analyzed for more than 140 chemical or other constituents
- About 670,000 laboratory analyses (about 34,000 analyses were obtained in the DFW area
- About $35 to $50M in cost to cities

The NPDES monitoring and related activities during the period 1990 to present have largely been involved with data characterization, building upon previous USEPA-mandated monitoring efforts. By late 1994, most MS4 cities will commence a five-year compliance monitoring program which may require 2-3 times the cost and effort expended in the data characterization phase above. In addition, USEPA will, after 1997, most likely extend the NPDES permitting obligation to cities with populations less than 100,000.

Because of the significance of NPDES permitting in the DFW area, the North Central Texas Council of Governments, like many other councils of government in the nation, organized a Regional Urban Storm Water Management Task Force (RUSWMTF) to unify the many technical, policy, and fiscal aspects of NPDES permitting. To directly oversee technical aspects of NPDES monitoring, RUSWMTF established a Storm Water Quality Subcommittee, with membership from the cities, the Trinity River Authority (TRA), and the Texas Department of Transportation (TXDOT). Cities subject to the regulations in the DFW area include Dallas and Ft. Worth, with populations over 250,000 and Arlington, Garland, Irving, Mesquite, and Plano with populations of 100,000 or more.

This paper describes the work to date of the DFW Regional Urban Stormwater Management Task Force, with the assistance of NCTCOG, in meeting the requirements of NPDES permitting. Unique among Texas cities and perhaps the nation, is the concept of a *regional NPDES monitoring network* for the DFW area. The *regional concept* has been approved by USEPA Region 6 because the MS4 permitting authority for NPDES has not yet been delegated to the state of Texas.

STUDY AREA

The Dallas-Fort Worth, Texas area is located in north-central Texas and has a population of 3.3 million according to the 1990 census. The region is hydrologically part of the upper Trinity River basin including major tributaries of the West Fork Trinity, Elm Fork Trinity and East Fork Trinity all of which meet in the DFW metroplex. The average annual discharge of the USGS streamflow station, Trinity River near Rosser, downstream of the DFW metroplex, is about 2,900 cubic feet per second. Mean annual precipitation at the long term weather station in Fort Worth is 30.6 inches for the period 1961-1990 while the comparable mean annual precipitation at Dallas is 33.6 inches. The study area is located primarily within Collin, Tarrant, and Dallas counties and includes an urban watershed network of 95 sub-basins.

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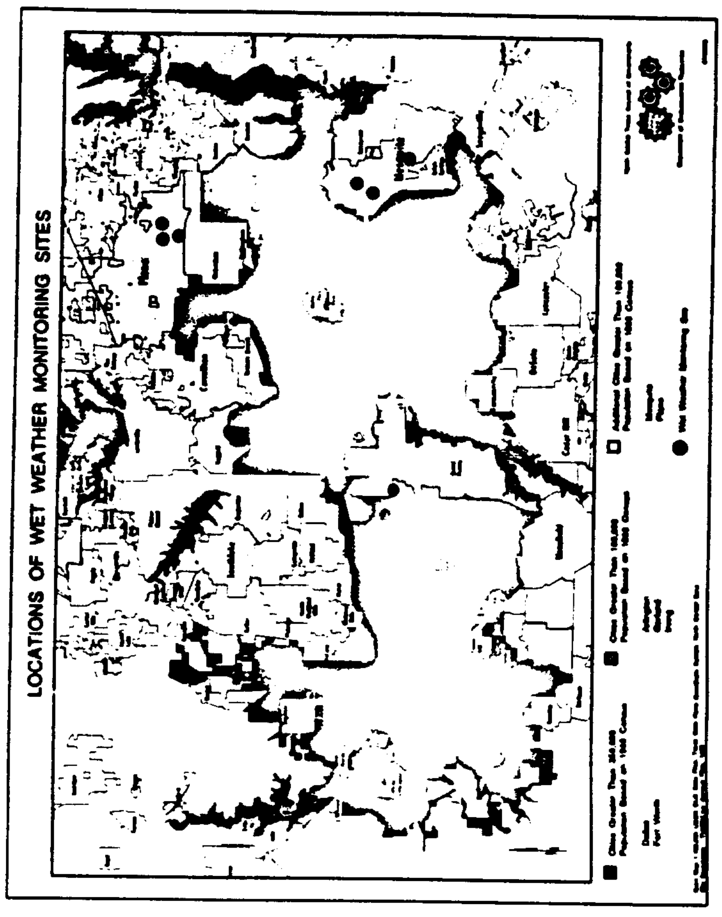

Figure 1 – Study area for DFW Regional NPDES monitoring network, NCTCOG (1993)

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Figure 1 shows the DFW study area and the cities subject to the NPDES permitting regulations. Also shown are smaller communities in the metroplex and the locations of the 26 municipal NPDES monitoring locations. Four TXDOT monitoring locations, now in operation, are not shown.

PREVIOUS DFW AREA STUDIES

Urban storm water studies have been undertaken in the DFW area since the late 1940's when urban gaging began on the 8-square mile Turtle Creek watershed in Dallas. Early urban hydrology studies were concerned with urban flooding and flood-plain management. Through the years, a significant data base on urban watershed rainfall and runoff has accrued. See for example, USGS (1976). With increasing concern by local agencies and the State of Texas over water quality problems in the Trinity River, the emphasis was expanded to include urban stormwater-quality, e.g. Trinity River Authority (1978), Alan Plummer and Associates et. al. (1978) in section 208 studies. The DFW area was not included in the Nationwide Urban Runoff Program (NURP) studies.

The report by Alan Plummer and Associates (1994) reviews historical perspectives and sources of urban stormwater data in the DFW area. For example, in the Trinity River Authority (1978) study, eight urban watersheds varying in drainage area from 30 to 300 acres were sampled for four storm events for a range of chemical constituents. In addition, eight nonurban watersheds varying from 3 to 12 acres in drainage area were sampled for about two storm events each. Twelve metals were measured in urban watersheds and ten pesticides were measured at both urban and nonurban sites. The mean values for all sites are shown in Table 1, taken from Alan Plummer and Associates (1994). As seen in Table 1, urban sites tend to have higher mean values for BOD, solids, phosphorus and fecal coliform. The nonurban sites had a mean value for nitrogen that is 60 percent higher than that for urban sites.

The U.S. Geological Survey, in cooperation with local agencies, has collected water-quality data on urban streams in the DFW area for many years. Records are collected at continuous streamgaging stations and at partial record stations. At 11 sites, on larger urban streams in the DFW area, USGS operates sites equipped with continuous (hourly) measurement of pH, temperature, specific conductance and dissolved oxygen. These records, originally established for receiving water monitoring of wastewater enhancement programs, began as early as 1976 and are expected to provide a benefit in documenting impact of urban stormwater in the DFW area in future years. Alan Plummer and Associates (1994) used five USGS monitoring sites with data available from 1986-1990 that have no effects of wastewater discharges or upstream reservoir releases. These data , summarized in Table 2, are from watersheds with drainage areas ranging from 16,000 to 190,000 acres and are characterized by low density urban and nonurban land use. These data may provide "background" information for some constituents when compared with the NPDES monitoring data.

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Parameter ALL (mg/l)	Residential MEAN	Commercial MEAN	Industrial MEAN	Nonurban (OPEN) MEAN	ALL SITES (URBAN) MEAN	ALL SITES (TOTAL) MEAN
BOD	7.1	-	12.7	5	12	9.5
COD	116	52	100	-	106	-
TSS	707	-	505	305	663	527
TDS	169	218	848	473	490	487
NITROGEN	3.2	-	2.4	4.4	2.7	3.7
ORGANIC-N	2.0	2.4	1.6	1.4	1.9	1.8
PHOSPHORUS	0.69	-	0.89	0.29	0.78	0.55
OIL/GREASE	9.5	3.6	4.6	-	6.5	-
FECAL COLI	108400	19717	45113	4900	64500	59000
COPPER	0.040	0.02	0.02	-	0.04	-
LEAD	0.40	0.21	0.44	-	0.33	-
ZINC	0.87	0.47	0.23	-	0.54	-
BARIUM	21.7	17.3	12.0	-	17.0	-
CADMIUM	0.014	0.02	0.05	-	0.03	-
CHROMIUM	0.035	0.03	0.015	-	0.03	-
IRON	12.5	4.8	8.0	-	8.1	-
MANGANESE	0.034	0.17	0.22	-	0.14	-
MERCURY	0.007	0.02	0.009	-	0.013	-
NICKEL	0.02	0.02	0.02	-	0.02	-
SELENIUM	0.0035	0.005	0.003	-	0.004	-
SILVER	0.004	0.003	0.003	-	0.003	-
CHLORDANE	-	-	-	0.0343	0.198	-
DIELDRIN	-	-	-	ND	ND	-
2,4-D	-	-	-	0.00154	0.0034	-
DDT	-	-	-	ND	ND	-
DDE	-	-	-	ND	ND	-
ENDRIN	-	-	-	ND	ND	-
HEPTACHLOR	-	-	-	ND	0.017	-
LINDANE	-	-	-	0.0048	0.015	-
TOXAPHENE	-	-	-	ND	ND	-
PCB	-	-	-	ND	ND	-
Conventional						
# Stations	3	3	2	8	8	16
# Values (max)	5	3	8	17	14	30
Metals						
# Stations	2	3	2		7	-
# Values (max)	16	21	16		53	

All metals values are "Total" metal fractions; "ND" is for parameter "not detected" in samples.

Table 1 – Mean storm water quality values of all Trinity River Authority sites by land-use catagory, Alan Plummer and Associates, Inc. (1994)

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PARAMETER	1988 - 1990 DATA SUMMARY		
ALL (mg/L)	MEAN	RANGE	NO. OF VALUES IN MEAN CALCULATION
BOD	1.7	0.3-3.8	32
TSS	118	1-880	52
NITROGEN	2.1	0.3-12.5	86
TKN	1.3	0.2-4.2	86
NH3-N	0.07	0.01-0.44	68
NO2+NO3-N	0.85	0.1-11	86
TOTAL P	0.17	0.01-0.83	86
SOLUBLE P	0.09	0.04-0.17	11
CHLORIDE	42	4.3-320	61
SULFATE	87	10-550	61
ARSENIC*	0.0023	0.001-0.008	32
CADMIUM*	-	ALL<0.001	32
CHROMIUM*	0.0078	0.001-0.080	32
COPPER*	0.0045	0.001-0.010	32
LEAD*	0.0054	0.001-0.010	32
MERCURY*	<0.00010	<0.0001-0.0002	29
NICKEL*	-	ALL<0.010	6
SELENIUM*	-	ALL<0.010	30
SILVER*	-	ALL<0.010	32
ZINC	0.0134	0.003-0.044	32

*Metals values are for dissolved portion in sample.

Table 2 -- Mean storm water quality values, USGS Trinity River Basin monitoring stations, Alan Plummer and Associates, Inc. (1994)

The Texas Natural Resource Conservation Commission (TNRCC) has operated 13 monitoring stations in the DFW area on urban streams. However, few of these data were collected during stormwater periods and thus are of limited benefit for comparison with older data bases and the NPDES monitoring results for the DFW area.

Of special concern in the DFW area, is the occurrence of toxic constituents, some of which occur as urban nonpoint sources. According to Alan Plummer and Associates (1994) many of these toxins are known to occur in Trinity River water and sediments and include cadmium, chlordane, chromium, copper, dieldrin, endrin, heptachlor, lead, lindane, and PCB's. Diazinon, apparently occurring due to use for pest control in residential areas, has frequently been found in storm water and in wastewater effluents.

Previous water-quality monitoring in the DFW area for urban storm water quality can be of substantial benefit to current NPDES monitoring programs. The report by Alan Plummer and Associates, Inc. (1994) has set the stage for future analyses. However, it is clear that much needs to be learned about urban stormwater-quality processes in the DFW area and the role that urban stormwater plays in overall water quality in the 95 DFW urban watersheds and the Trinity River.

DFW NPDES MONITORING NETWORK FOR REGIONAL CHARACTERIZATION

According to USEPA guidelines, stormwater events are to be monitored at 5 to 10 sites in each city, three storms per site, each site representing a predominant land use of residential, commercial or industrial land use. The number and kind of each monitored watershed is to be proportional to all typical watersheds draining to stormwater outfalls within the municipal area. The monitored sites must be free of problems associated with illicit connections to sanitary sewers or industrial discharges. A rain-free period of at least 72 hours must precede storm-event sampling in order to allow urban stormwater loads to accumulate on urban surfaces. Special sites will be required to document highway stormwater runoff-quality.

DRY WEATHER FIELD SCREENING

Part 1 of the storm water permit application process required the cities to complete an initial field screening of storm drainage systems during dry weather in order to detect illicit or improper connections to a cities MS4 system. Using a 1/4 mile grid cell system captured in NCTCOG's regional geographic information system, staffs of the seven cities visited at least 500 outfall sites for the two larger cities and at least 250 outfall sites for the five smaller cities. A field screening system developed by the City of Fort Worth, Rattan and McDaniel (1992), was used and two grab samples were collected within 24 hours at each site. For each site, a narrative description of color, odor, turbidity, presence of oil sheen or surface scum and other observations was made. In addition, a field analysis for the estimation of pH, total chlorine, total copper, total phenol, detergents and discharge flow rate were made. A scoring system assigned a numeric value of unity for each parameter detected was then summed into a final score (maximum score was 28)for each outfall site.

Figure 2 shows the dry weather field screen scores for the City of Fort Worth. Overall, the DFW cities found that about 10 percent of outfalls sampled during dry weather conditions produced significant contaminant discharges (scored 7 or more of 28 possible points).

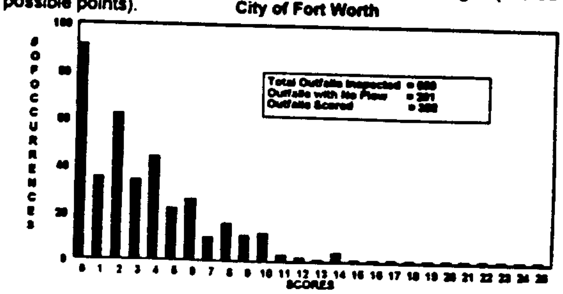

Figure 2 -- Dry weather field screen scores for City of Fort Worth, NCTCOG (1993)

The results of the dry weather field screening have some important implications on storm water quality in the DFW area and for the required wet weather monitoring sites. However, the evidence suggests that illicit *connections* are not prevalent in the DFW area, with sanitary sewage being reported on very few occasions. Illicit *discharges* seem to be a more widespread occurrence, with pollutants probably being generated on land and flowing during both dry and wet periods into MS4 systems. The widespread occurrence of detergents and/or surfactants, NCTCOG (1993), suggests that these constituents may be a major contributor to storm water impacts and therefore represent a challenge for control, due to their spontaneous and erratic appearance. A program of wet weather screening is currently being planned for the DFW area.

Based on the results of the dry weather field screening and the above considerations, RUSWMTF moved forward with the design of the wet weather monitoring network for storm water quality characterization. Assisting RUSWMTF in the design was a regional consultant, Camp Dresser & McKee, Inc. /Alan Plummer and Associates, Inc. (CDM/APAI) and the Texas District, U.S. Geological Survey. The argument was made that the DFW cities, because of their close proximity, lie within a homogeneous hydrologic and climatologic area. This being the case, a cost-effective, regional NPDES monitoring network made more sense than individual city networks. Agreement was reached among the cities and with USEPA Region 6 in Dallas to form a regional network of 30 monitoring sites for the DFW area.

As specified by USEPA, the network must monitor 210 sampled events, the number of events required by USEPA (1990) for 7 cities, each with 10 sites collecting 3 storm events each. However, in recognition of the regional concept, USEPA would allow less than 70 monitoring sites. The USGS suggested that 7 storm events per site would allow an adequate statistical characterization of NPDES monitored data, so the network was designed with 30 monitoring sites each collecting 7 storm events. Of the 30 NPDES monitoring sites, 26 sites were municipal monitoring sites and 4 sites were highway monitoring sites, provided by the Texas Department of Transportation. NPDES monitoring for data characterization, including 182 monitored events, was completed at the 26 municipal sites by June, 1993. Data collection and analysis at the 4 highway monitoring sites is still underway and will not be discussed in this paper.

Following a visit to hundreds of prospective wet-weather monitoring outfall sites across the DFW region and a careful balancing of land-use to be sampled and the ability to obtain good runoff measurements, a tentative DFW NPDES monitoring network was presented and accepted by the RUSWMTF and USEPA Region 6. Figure 3 shows a map of one of the selected monitoring sites, station 08047100 Clear Fork Trinity River Outfall at Oak Hill Circle, Fort Worth, Texas, NCTCOG (1993).

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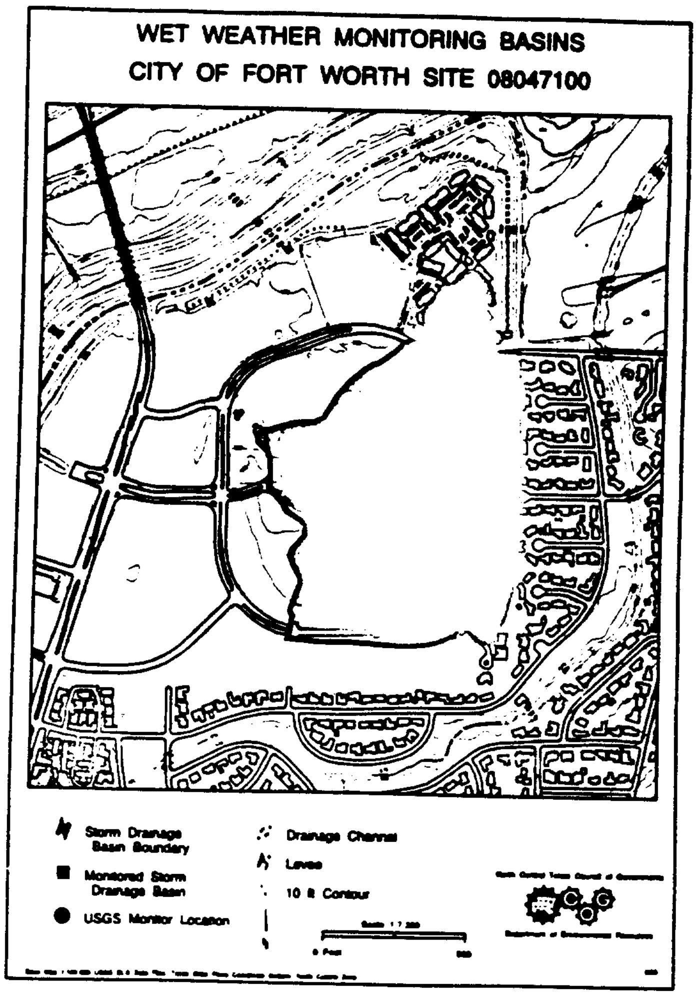

Figure 3 – Map of monitoring site 08047100 Clear Fork Trinity River Outfall at Oak Hill Circle, Fort Worth, Texas, NCTCOG (1993)

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DESCRIPTION OF SITES

As described above, a major goal of the wet-weather monitoring in the data characterization phase of the Part 2 application required by the NPDES permitting rule, was to characterize typical runoff from three broad land use classifications – residential, commercial and industrial. Much study went into the specific site selection, including catchment characteristics, hydraulic factors, accessibility during all hours, and safety. An attempt was made to include a predominance of the single land use sought as well as to include a drainage area of between 10 and 500 acres. Storm-sewer pipe diameters were sought in the range from 4-6 feet or if a box culvert, a size of no more than 8 by 8 feet. A fairly straight and uniform pipe slope was sought for at least 6 pipe diameters upstream from the flow measuring device and an adequate distance was maintained from upstream inflows to allow for complete mixing conditions. Only sites where no problems of substantial backwater conditions, or of unauthorized connections, as determined from the dry-weather screening effort, were considered. In addition, sites with a proximity to sanitary sewers subject to surcharging, were avoided.

WET WEATHER MONITORING

Because the monitoring staff would be collecting samples at any time during the day or night during storm water conditions, sites were selected to minimize high-velocity flow conditions, sewer gases, vehicular traffic, poor visibility lighting and vandalism or crime. Various other considerations were studied before a site was selected, Baldys, et. al (1994).

The final set of wet-weather monitoring sites included 11 residential, 6 commercial, 9 industrial, and 4 highway drainage catchments. Most sites were located at outfall locations while a few were accessible by access to a manhole. The twenty-six monitoring sites were located within the jurisdictional boundaries of the seven cities as follows: Five sites were located in Dallas, five sites in Fort Worth, four sites in Arlington, three sites in Garland, three sites in Irving, three sites in Mesquite, and three sites in Plano. Four additional sites were located along highway right-of-ways, two each in Dallas and Fort Worth. All sites were located and captured in the NCTCOG regional GIS coverages. Figure 1 shows the general locations of the twenty-six municipal monitoring sites in the regional DFW area NPDES network.

Table 3 shows a table of selected watershed characteristics of the municipal NPDES monitoring sites, including impervious area, in percent. Monitoring commenced at these sites in February 1992 with storms having precipitation from 0.2 to 0.9 inches (later raised to 1.5 inches in October 1992 with permission of RUSWMTF and USEPA Region 6) being sampled.

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Table 3 – Selected watershed characteristics of the DFW area municipal monitoring stations, Baldys et. al. (1994)

Site ID	Station name	Drainage basin	Drainage area (acres)	Impervious area, (percent)	Residential land use, (acres)	Commercial land use, (acres)	Industrial land use, (acres)	Non-urban, (acres)
Fort Worth								
8047100	Clear Fork Trinity River Outfall at Oak Hill Circle	Residential	61.7	21.9	13.2	2.7	0.0	45.8
8048505	Pylon Street Outfall at Meacham Blvd	Industrial	151.0	27.7	0.0	4.8	33.6	113.0
8048510	West Fork Trinity River Outfall at Highway 121	Commercial	136.0	66.5	50.7	60.6	0.0	7.9
8048545	Dry Branch Outfall at 33rd Street	Industrial	73.7	79.3	0.0	0.0	72.9	0.8
8048700	Eastern Hills High School Outfall at Weller Drive	Residential	151.0	61.4	97.2	44.8	0.0	8.7
Dallas								
8055590	Joe's Creek Outfall at Denton Drive	Industrial	9.0	80.0	0.0	0.0	9.0	0.0
8056390	Bastille Street Outfall at La Reunion Parkway	Industrial	49.5	80.0	0.0	0.2	49.3	0.0
8057135	White Rock Creek Outfall at Preston Road	Commercial	50.1	84.5	0.9	50.2	0.0	0.0
8057310	Ash Creek Outfall at Whitller Street	Residential	71.3	50.0	71.3	0.0	0.0	0.0
8057441	Newton Creek Outfall at Tioga Street	Residential	38.9	44.9	33.9	0.0	0.0	5.0
Arlington								
8049220	The Parks Mall Outfall at I-2 West,	Commercial	38.8	76.2	0.0	38.3	0.0	0.5
8049320	River Legacy Park Outfall at Green Oaks Boulevard	Residential	180.0	47.4	130.0	3.6	0.0	17.5
8049360	Tributary to West Fork Trinity River at Baird's Farm Road	Residential	77.0	60.0	79.5	8.5	0.0	0.0
8049470	Tributary to Johnson Creek Outfall at I-30 East	Industrial	85.5	80.9	0.0	7.7	77.9	0.0
Irving								
8049590	Bear Creek Outfall at Shady Grove Road	Residential	65.3	41.9	50.4	0.8	0.0	14.1
8055570	Hereford Road Outfall at Walnut Hill Road	Industrial	43.4	77.3	0.0	16.8	26.5	0.1
8056100	Tributary to Elm Fork Trinity Riverat Cascade Street	Industrial	43.9	77.8	0.0	7.7	35.8	0.4
Garland								
8061635	Tributary to Duck Creek Outfall at Jupiter Road	Industrial	33.9	67.3	0.0	0.0	27.8	0.1
8061660	Sleepy Hollow Street Outfall at Northwest Highway	Residential	67.3	56.1	58.7	8.6	0.0	0.0
8061690	I-635 Outfall at Centerville Road	Commercial	36.2	84.6	11.3	24.9	0.0	0.0
Plano								
8061510	Rowlett Creek Outfall at Willow Creek Park	Residential	51.4	54.3	44.7	5.9	0.0	0.8
8061525	Spring Creek Outfall at Park Boulevard	Commercial	22.7	73.5	0.0	18.6	0.0	4.1
8061530	Spring Creek Outfall at Avenue F	Industrial	49.0	81.5	5.1	32.0	11.9	0.0
Mesquite								
8061910	South Mesquite Creek Outfall at I-635	Commercial	45.9	89.4	0.0	45.5	0.0	0.4
8061915	South Mesquite Creek Outfall at South Parkway	Residential	45.4	49.9	44.8	0.2	0.0	0.4
8061940	South Mesquite Creek Outfall at Bruton Road	Residential	49.2	45.9	46.1	0.0	0.0	0.1

INSTRUMENTATION

The instrumentation for wet weather monitoring, described in Jennings et. al. (1992), is typical of urban storm water instrumentation in use by USGS is other localities. However, USGS urban storm water monitors are significantly different from a normal USGS streamflow monitoring station. Much of this difference is due to rapidity of urban stormwater runoff and due to the fact that small pipes and open channels are typically being monitored in an urban storm water situation. Figure 4 shows a schematic of a typical USGS urban storm water monitoring site with its instrumentation. In the DFW area, the monitoring equipment was located in a sheet metal structure and resembles a utility box familiar to urban areas. Because of the unobtrusive nature of the DFW monitoring structures, little or no vandalism has been experienced during operation of the network.

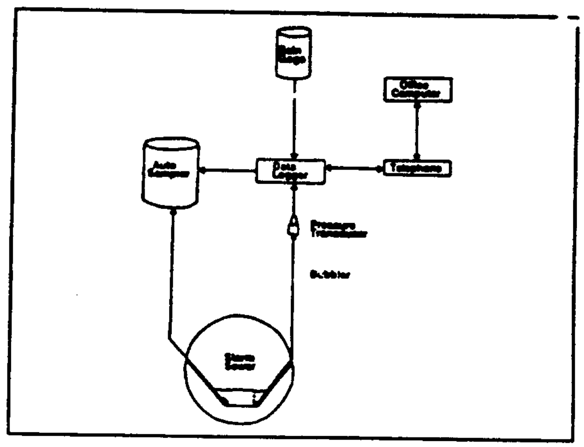

Figure 4 - Schematic of DFW urban stormwater monitoring instrumentation

Equipment for a typical site costs about $15,000 and includes:

- automatic water quality sampler for organic sampling
- controller and datalogger programmed for 1-minute sampling of precipitation and flow
- telephone modem and connected wired or cellular telephone
- 2 or 3 nonsubmersible pressure transducers and gas lines, regulators and sight feeds
- Palmer-Bowlus flume (circular pipes) or V-notch weir (square pipes and open channels)
- tipping bucket raingage
- solar panels, batteries, voltage regulators for AC power

- communication and analysis software
- shelter

Telephone communications with "beeper" alert systems were vital to successful operation due to the fact that the monitoring sites were located over a large area. Not only could a given monitoring station be called to find out if a storm water event was occurring (the stations also called an assigned "storm chief" at all hours when precipitation or flow "triggers" were exceeded), but stormwater data could be efficiently retrieved over the phone line for analysis. This proved useful as an analyst could be graphing rainfall and flow hydrographs soon after samples were retrieved but before a decision was made to process the laboratory samples. Because of the cost of laboratory analyses, quick analysis of the adequacy of the storm data for the event was extremely helpful in deciding whether or not to process the samples.

The automatic sampler contained four one-gallon sample bottles and these were cleaned using the protocols outlined in 40 CFR 136, Part D (USEPA, 1992). The automatic sampler was powered by a 60 amp/hour battery and the sampling line consisted of a stainless steel intake and teflon coated tubing, according to Baldys et. al. , (1994). The sampler intake was typically located just below the flume or weir flow measuring device.

Stage-sensing at the sites included up to three sensing locations per site. In general, for weir sites, only one stage sensor was used. For sites equipped with a Palmer-Bowlus flume as described in Kilpatrick et. al. (1985), typical sites included a stage sensor in the flume approach, and one in the in the throat of the flume. A third stage sensor was located downstream to detect possible flume submergence. The stage sensors were pressure transducers calibrated in the laboratory at temperatures up to 55 degrees Celsius.

Flow measurement was based on laboratory calibrated flumes or known weir flow formula. The flume calibrations and other specifications can be found in Kilpatrick et. al. (1985). The DFW flow measurement conditions fell within the range of the laboratory calibrated flumes and good definition of flow hydrographs at 1-minute time intervals were obtained for all storm events measured. Because the automatic sampler was "pulsed" by the datalogger device, flow volume calculations were continuously made during the storm water event thus allowing flow-weighted sampling by sub-sampling over the hydrograph. Sub samples were taken after a known volume of flow passed the monitoring site. After the storm (sometimes additional bottles were added during longer storm events), a quick assessment was made to see if sampling had adequately occurred over the flow hydrograph and the samples were then processed.

Maintenance was essential to successful operation of each monitoring site and steps were taken to check battery voltage, clean raingages, check communications and data storage devices and software, and make ready all water quality sampling equipment as storm events approached the DFW area.

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LABORATORY ANALYSES

When sampling is complete at the DFW NPDES network, more than 34,000 laboratory analyses will have been performed. While the final rule required monitoring for 138 parameters, by use of USGS laboratory schedules at the USGS Central Laboratory in Denver, the actual number of parameters reported is 189. The laboratory analyses performed by USGS fall into seven categories:

- Metals (e.g. arsenic, cadmium, chromium, lead, zinc)
- Volatiles (e.g. benzene, carbon tetrachloride, chloroform, toluene)
- Pesticides (e.g. dieldrin, PCBs, toxaphene, diazinon)
- Acid/Base/neutral organic compounds (e.g. chlorophenol, naphthalene, pyrene)
- Conventional pollutants (e.g. BOD, COD, fecal coliform, oil and grease, phosphorus)
- Additional constituents (e.g. pH, temperature, alkalinity, specific conductance)
- Other (e.g. other organics, not required, but included in a given laboratory schedule)

Water-quality samples were collected using grab sampling methods for 71 constituents while automatic samplers were used for flow-weighted composite samples for 118 other constituents. Water quality samples were processed, packaged and shipped from the USGS office in Fort Worth to the USGS National Water Quality Laboratory (NWQL) in Arvada, CO where most of the laboratory analyses were performed. Total concentrations for thallium, silver, antimony, and cyanide were determined by contract with Rocky Mountain Analytical Laboratory in Denver, CO. Alkalinity, biochemical oxygen demand, fecal coliform and streptococci constituent concentrations were determined locally at the USGS Fort Worth laboratory. Temperature, pH, specific conductance, and the presence of residual chlorine were determined in the field at the time of grab sampling.

According to Baldys et. al. (1994), strict quality control and quality assurance procedures were followed throughout the study. Chain-of-custody procedures, as prescribed by USEPA, were followed with each sample. Equipment blanks for organic constituents as well as matrix spikes were used in the local lab and repeated at NWQL. Trip blanks, used to determine if contamination of the volatile organic samples occurred during transit, and laboratory blanks, used to determine if contamination of the organic samples occurred in the field office during compositing procedures were followed at USGS Fort Worth and at the NWQL, as standard procedure.

PARTNERSHIP FOR FIELD WORK

Because of limited field staff, USGS could operate only about 10 monitoring sites during any particular storm water event. Field staff of the various cities were asked to help with sample retrieval and general monitoring station operation. For safety reasons, at least two people visited monitoring stations and some times three people assisted during night hours. This partnership paid off as shown on Figure 5 which shows a timeline of all storms occurring during 1992 and those storms which were actually sampled.

STORM WATER ANALYSES AND RESULTS

Because storm water was sampled by both grab sampling and by automatic sampler, it is convenient to discuss storm water analyses and results by method of sampling. This is the method of presentation adopted by Baldys et. al. (1994). Brief comments are made concerning unusual occurrences of specific constituents. More details are found in Alan Plummer and Associates, Inc. (1994), NCTCOG (1993) and Baldys et. al. (1994). Alan Plummer and Associates, Inc. (1994) also includes information on the dBase III Plus data base and report generation procedures for the DFW area data.

GRAB SAMPLE CONSTITUENTS

Grab samples were collected primarily by hand dipping at the monitoring station outfall. An attempt was made to collect grab samples early in the storm event. For practical reasons, this was not always possible.

Water Temperature -- Water temperature values varied from 6.5 to 30.0 degrees C. In general water temperatures during storm events did not vary more than 1-2 degrees C.

pH -- Values of pH varied from 6.2 to 9.9. The maximum value occurred at a station with roadbuilding activities in progress.

Cyanide -- Generally below detection limits.

Total phenol -- From below detection limits to a maximum of 58 mg/l at an industrial site.

Oil and grease -- Generally near or below detection limits.

Bacteria -- Fecal streptococcus bacteria concentrations were equal to or greater than those of fecal coliform bacteria. Lowest bacterial concentrations were from industrial land use while median concentrations were highest for residential land use

Volatile-organic compounds (VOC) -- Samples from industrial land use, especially during the first 25 percent of the storm runoff, were more often detected than samples from other land use sites. The most frequently detected VOC was toluene, the 27th largest volume of chemical substance produced in the United States. Benzene and related derivatives were the next most often detected VOC.

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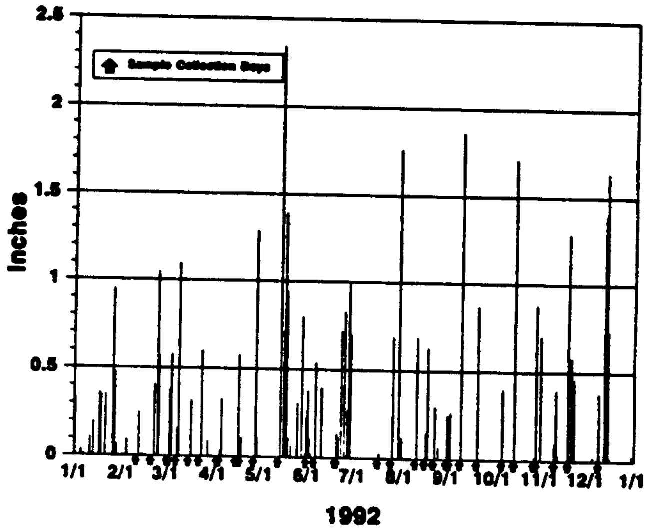

Figure 5 – 1992 storm precipitation in DFW area with indicated sampled events, Alan Plummer and Associates, Inc. (1994)

FLOW-WEIGHTED CONSTITUENTS

Flow-weighted constituents were collected by automatic sampler, generally within the first three hours of the storm water event. There were seven groups of such constituents:

Nutrients – Median concentrations of total nitrogen and total ammonia plus organic nitrogen in samples from residential land uses were significantly greater than for other land uses. Phosphorus concentrations were also higher for residential land use. Lawn care practices are probably responsible for higher nutrient concentrations.

Biochemical and Chemical Oxygen Demand – Samples from industrial land use had the greater median concentration of oxygen demand than for other land uses. Samples from residential land use had the higher median chemical oxygen demand.

Inorganic Compounds – Median suspended sediment concentrations and median dissolved solid concentrations from industrial land use were higher than for other land uses.

Trace metals -- Trace metal concentrations from industrial land use were generally higher. High total arsenic concentrations were detected at one residential site 11 to 35 ug/l with a mean of 22.6 ug/l. One industrial site had very high mean values of total copper (732 ug/l), total lead (133 ug/l), and total zinc (296 ug/l).

Base-Neutral Acid Semi-Volatile Compounds -- Fifty-seven organic constituents for each composite sample were analyzed. The greatest number of detections (96) were from industrial land uses and the fewest number (37) were from residential land uses.

Pesticides -- Diazinon was detected in 92 percent of residential samples, 67 percent of commercial samples and 33 percent of industrial samples. Chlordane and dieldrin were the next most frequently detected pesticide constituent.

Table 4 shows a comparison of the most frequently detected organic constituents for the Nationwide Urban Runoff Program (NURP) of 1978-84 and the DFW area NPDES analyses. Metals such as zinc, lead and copper appear with high frequency of detection in both lists. A paper by Young and others (1994) compares NPDES analyses among several Texas cities.

SPATIAL AND TEMPORAL VARIABILITY OF CONSTITUENTS

Based on a selection of detected constituents in the DFW area, Raines and Baldys (1994) evaluated spatial and temporal characteristics of the monitored data base. The constituents selected were:

chemical oxygen demand
suspended solids
total nitrogen
total phosphorus
total arsenic
total lead
bis (2-ethyljexyl) phthalate
xylene
benzene
chloroform
mesitylene (1,2,4-trimethylbenzene)
biochemical oxygen demand
dissolved solids
total kjeldahl nitrogen
dissolved phosphorus
total copper
total zinc
toluene
pyrene
diazinon
chlordane
fecal coliform
fecal streptococcus

Graphical and statistical analyses were performed designed to explore differences for the constituents between land uses, within land uses, and the effect of seasonality. Techniques found in Helsel and Hirsch (1992), with emphasis on nonparametric statistics, were utilized in the comparisons. For example, figure 6 shows the Kruskal-Wallis results indicating that for many constituents, the seasonal medians are not significantly different for each land use type. Many other tests are given in Raines and Baldys (1994) and are being used in the design of the 5-year DFW compliance monitoring network.

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COMPARISON OF MOST FREQUENTLY DETECTED TOXIC PARAMETERS FROM NURP AND USGS-NPDES PART II SAMPLING		
Percentage of Samples	NURP Priority Pollutant Study Parameter (%)	USGS Current NPDES Part II Regional Study Parameter (%)
75 Percent or more	Zinc (94) Lead (94) Copper (91)	Zinc (100) Lead (98) Copper (98) Phenols (98) Nickel (97) Chromium (90) Arsenic (87)
50 to 74 Percent	Chromium (58) Arsenic (52)	Diazinon (66)
20 to 49 Percent	Cadmium (48) Nickel (43) Cyanides (23) BIS(2-Ethylhexyl)Phthalate (22)	BIS(2-Ethylhexyl)Phthalate (45)
10 to 19 Percent	Pentachlorophenol (19) Chlordane (17) Fluoranthene (16) Lindane (15) Pyrene (15) Phenol (14) Antimony (13) Beryllium (12) Phenanthrene (12) Selenium (11) 4-Nitrophenol (10) Chrysene (10)	Toluene (18) Chlordane (18) Xylene (17) Fluoranthene (15) 1,2,4-Trimethylbenzene (15) Cadmium (14) Pyrene (14) Chloroform (13) Phenanthrene (10)

Table 4 – Detected toxic parameters (metals and organics), Alan Plummer and Associates, Inc. (1994)

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Ho: The medians of the three seasons are not significantly different for each land use type.

Reject Ho if $Hadj > \chi^2$

$\alpha = 0.05$
$\chi^2 = 5.99$

	Residential	Industrial	Commercial
		Kruskal-Wallis	
	Hadj	Hadj	Hadj
COD	1.97	1.07	2.59
BOD	5.75	1.19	10.24
SS	2.45	1.85	5.56
DS	2.67	8.35	3.18
TN	17.63	1.70	4.27
TKN	20.10	0.86	9.86
TP	6.17	0.71	7.05
DP	3.94	0.79	13.13
As	4.18	0.56	4.67
Cu	3.26	2.90	3.48
Pb	7.85	8.96	8.39
Zn	5.59	8.49	3.45
Bis(2-Ethythexy) phthalate	6.20	3.80	8.85
Pyrene	0.49	10.52	6.83
Diazinon	24.49	1.47	7.50
Chlordane	9.65	1.95	2.85
Toluene	0.81	1.00	3.91
Xylene	2.24	1.84	4.13
Benzene	1.37	0.23	1.51
Chloroform	3.97	3.71	0.62
Mesitylene	7.75	0.22	2.70
Fecal Coliform	18.34	8.31	8.08
Fecal Streptococci	3.87	1.83	1.34

Figure 6 -- Kruskal-Wallis results for median concentrations within each land use by season (after Raines and Baldys, (1994))

CONSTITUENTS FOR USEPA LOAD CALCULATIONS

Twelve constituents were selected by USEPA for load calculations including BOD-5, COD, Total Suspended Solids, Total Dissolved Solids, Total Kejldahl Nitrogen, Nitrate+Nitrite, Total Phosphorus, Dissolved Phosphorus, Total Cadmium, Total Copper, Total Lead, and Total Zinc. For the DFW area, it was decided to add Diazinon to this list of constituents. Figures 7 and 8 show box plots of concentrations for Total Dissolved solids and Diazinon grouped by land use and site.

Event-mean concentrations (EMC's) of twelve constituents and diazinon can be calculated in several ways according to Baldys et. al. (1994): volume-weighted mean concentrations, logarithmic mean concentrations, and arithmetic mean concentrations. A volume-weighted mean concentration over all sites of a given land use is computed by summing the concentration times runoff volume for all storms and dividing by the summation of runoff volumes for all storms. The same procedure is followed for logarithmic mean concentrations except that all storm values for a given land use are transformed to base 10 logarithms prior to the computation. The final value is converted back to original units after computation. The arithmetic mean concentration is the summation of EMC's for each storm for a given land use divided by the total number of observations. Finally, the median , or 50th percentile value for all storms of a given land use can be computed. Table 5 shows the various means and the median by land use for the DFW area. For comparison, the NURP median values, if available, are also shown. The median EMC's for the DFW area are significantly less than NURP median values for BOD, total nitrogen and the trace metals of total copper, lead, and zinc. Cadmium was rarely detected above the detection limit of 1 mg/l. Because of the non-normality of distributions of the concentration values, the median or the log-transformed mean are the better estimates of population mean.

STORM WATER LOADS

Based on monitored data, storm water loads for each storm can be calculated as the product of the observed flow-weighted even-mean concentration and runoff volume, with an appropriate units conversion factor. The local regression storm load equations for constituent loads for the twelve constituent (no value for Cd) are shown in Table 6, based on seven sampled storms at each DFW monitoring site.

Storm load calculations were also performed on three study basins using a deterministic urban watershed model called the Simplified Particle Transport Model (SIMPTM) developed by Sutherland and others (1992). SIMPTM was calibrated at each site using data for four storms and verified with data from three additional storms. SIMPTM provided good results, especially for site-specific results. It is expected that deterministic models such as SIMPTM, will play a role in the site-specific stormwater management studies in the DFW area e.g. evaluation of best management practices.

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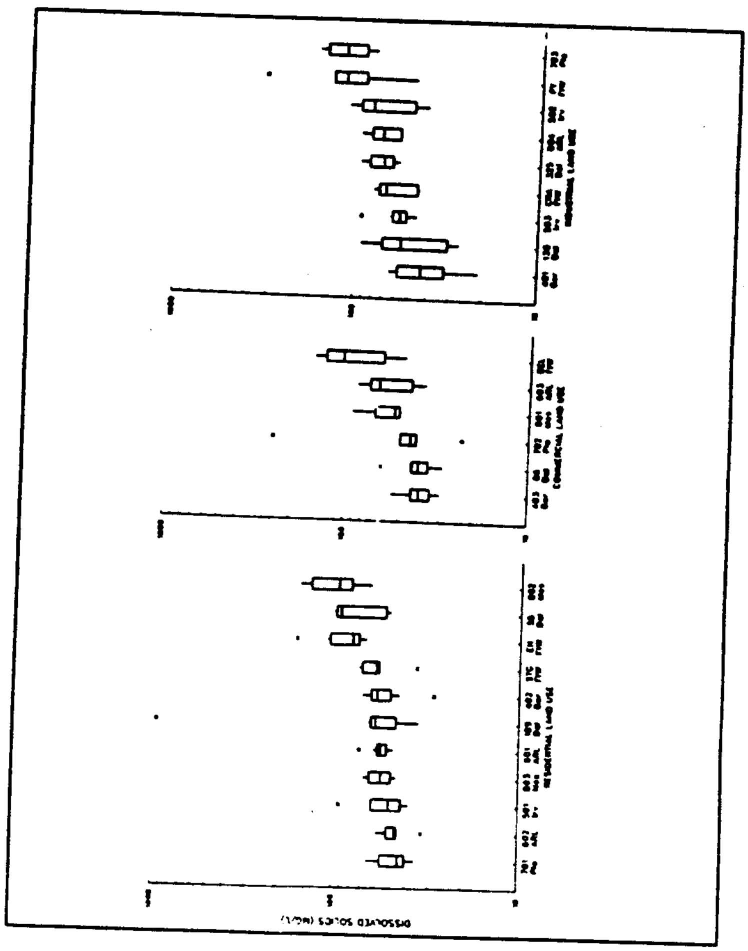

Figure 7 – Concentration of Total Dissolved Solids grouped by land use (after Baldys and Raines (1994))

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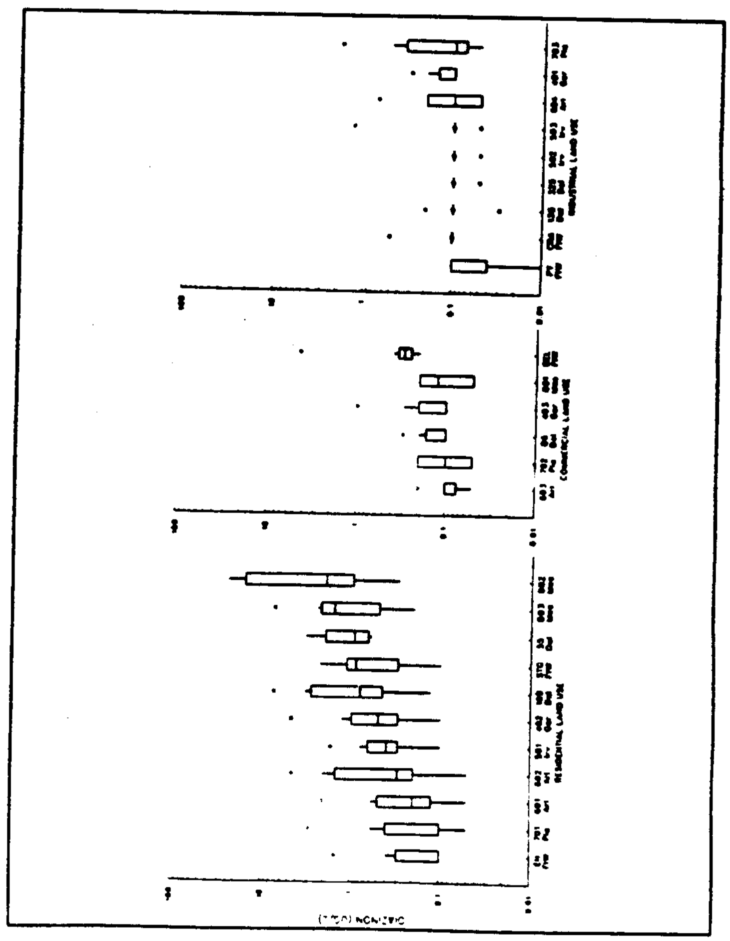

Figure 8 – Concentration of Diazinon grouped by land use (after Baldys and Raines (1994))

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		Residential EMC-11 Sites					
		Volume-Weighted Mean	Log-Transform Mean	Arithmetic Mean	Median	#obs	NURP Median
COD	mg/l	77	71	85	70	78	73
BOD	mg/l	6.7	6.6	7.0	7.3	72	10
SS	mg/l	110	83	127	78	69	101
DS	mg/l	64	62	96	58	70	--
TN	mg/l	2.0	1.9	2.1	1.7	77	--
TKN	mg/l	1.3	1.2	1.5	1.1	77	1.80
TP	mg/l	0.39	0.34	0.38	0.33	77	0.38
DP	mg/l	0.27	0.22	0.25	0.21	77	0.14
Cd	ug/l	--	--	--	<1.0	78	--
Cu	ug/l	8.2	8.0	9.6	8.0	74	33
Pb	ug/l	17	15	21	13	74	144
Zn	ug/l	67	66	78	60	75	135
Diaz	ug/l	1.8	0.54	1.8	0.55	78	--

		Commercial EMC-6 Sites					
		Volume-Weighted Mean	Log-Transform Mean	Arithmetic Mean	Median	#obs	NURP Median
COD	mg/l	65	59	68	56	42	67
BOD	mg/l	7.0	6.2	6.5	6.6	38	9.3
SS	mg/l	61	45	60	52	35	69
DS	mg/l	59	55	64	50	37	--
TN	mg/l	1.6	1.4	1.5	1.2	42	--
TKN	mg/l	0.92	0.83	0.98	0.80	42	1.18
TP	mg/l	0.18	0.14	0.18	0.14	42	0.20
DP	mg/l	0.10	0.08	0.09	0.08	42	0.08
Cd	ug/l	--	--	--	<1.0	40	--
Cu	ug/l	12	8.6	11	8.0	38	29
Pb	ug/l	38	25	33	30	40	104
Zn	ug/l	102	88	103	80	40	228
Diaz	ug/l	0.30	0.12	0.27	0.10	40	--

		Industrial EMC-9 Sites				
		Volume-Weighted Mean	Log-Transform Mean	Arithmetic Mean	Median	#obs
COD	mg/l	77	69	80	67	59
BOD	mg/l	7.1	7.0	7.5	7.5	61
SS	mg/l	259	121	222	104	60
DS	mg/l	73	70	78	69	60
TN	mg/l	1.5	1.5	1.5	1.4	63
TKN	mg/l	0.83	0.80	0.86	0.80	63
TP	mg/l	0.26	0.23	0.28	0.21	63
DP	mg/l	0.12	0.11	0.14	0.09	63
Cd	ug/l	--	--	--	<1.0	78
Cu	ug/l	100	17	95	12	61
Pb	ug/l	64	32	55	29	61
Zn	ug/l	173	139	168	130	59
Diaz	ug/l	0.14	0.07	0.14	0.05	62

Table 5 – Mean and median event mean concentrations by land use (after Raines and Baldys, (1994))

The local storm load regression equations were used with long-term rainfall characteristics based on a technique described by Tasker, Gilroy and Jennings (1990) to estimate average annual loads for the 95 sub basins in the DFW area. Comparative analyses were also made using the Watershed Management Model (WMM) developed by Camp Dresser and KcKee, Inc. (1993). The results of the two methods of obtaining DFW area annual stormwater loads is discussed in NTCOG (1993) and is still being evaluated. WMM, a spread sheet-based approach uses run-off coefficients and observed local loading estimates. In general, WMM and USGS methods are comparable.

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Table 6 – Local regression equation coefficients (after Baldys, et. al, 1994)

y	b0'	b1 TRN	b2 DA	b3 IA+1	b4 LUI+1	b5 LUC+1	b6 LUR+1	b7 LUN+1	BCF	SE %	R^ 2 adj %
COD	10.2	0.711	0.593	0.961	0.176	0.123	0.130	--	1.16	58.5	53.6
BOD	9.01	0.879	0.725	0.656	0.104	0.065	--	--	1.11	48.7	64.0
SS	5.85	0.889	0.544	0.913	0.463	0.170	0.328	--	1.52	115	42.0
DS	104	0.764	0.745	0.568	0.131	0.124	--	--	1.13	52.3	59.2
TN	1.14	0.838	0.597	0.725	0.072	0.056	0.052	--	1.15	57.1	49.9
TKN	0.666	0.878	0.544	0.716	0.045	0. 037	0.077	--	1.19	63.0	45.0
TP	0.955	0.932	0.475	--	0.266	0.176	0.272	--	1.20	66.2	51.6
DP	0.546	1.05	0.477	--	0.281	0.121	0.333	--	1.25	75.7	52.7
Cu	0.0023	0.894	0.623	0.996	0.138	0.057	0.012	--	1.24	72.6	49.2
Pb	0.00000086	1.21	0.500	2.55	0.371	0.210	0.274	0.285	1.41	99.5	58.9
Zn	0.00020	0.905	0.520	1.85	0.363	0.196	0.201	0.288	1.20	65.6	65.3
Diaz	0.0013	1.47	0.305	--	--	--	0.374	--	2.32	210	40.6

COD is chemical oxygen demand, BOD is biochemical oxygen demand, SS is suspended solids, DS is dissolved solids, TN is total nitrogen, TKN is total ammonia plus organic nitrogen, TP is total phosphorous, DP is dissolved phosphorous, Cu is total recoverable copper, Pb is total recoverable lead, Zn is total recoverable zinc, and Diaz is total diazinon in storm-runoff load in pounds, b0' is the intercept in the regression model, b1 is the coefficient for the variable TRN (total storm rainfall in inches), b2 is the coefficient for the variable DA (drainage area in square miles), b3 is the coefficient for the variable IA (impervious area as a percentage of total area), b4 is the coefficient for the variable LUI (industrial land use as a percentage of total land use), b5 is the coefficient for the variable LUC (commercial land use as a percentage of total land use), b6 is the coefficient for the variable LUR (residential land use as a percentage of total land use), b7 is the coefficient for the variable LUN (non-urban land use as a percentage of total land use), BCF is the bias correction factor, SE is the standard error of the regression equation in percent, and R^2 adj is the adjusted coefficient of determination, dashes (- -) indicate that the variable is not included; equation form is:

y=b0' (TRN)^b1*(DA)^b2*(IA+1)^b3(LUI+1)^b4(LUC+1)^b5*(LUR+1)^b6(LUN+1)^b7*BCF)

DESIGN OF COMPLIANCE MONITORING NETWORKS

Special Studies, based on results of the DFW area characterization data base, were undertaken by the consultant team and are still in progress. A goal of these studies is to recommend a cost-effective network for the DFW area MS4 cities for the next five years. Concepts other than water-quality monitoring e.g. rapid bioassessment monitoring are also being considered.

Tasker and Raines (1994) have joined the use of the regional regression method of estimating annual loads for the twelve water-quality constituents with a mathematical programming method. Figure 9 shows results of the network analysis for Total Nitrogen load for three 5-year scenarios -- (1) no new stations allowed but stations are added and dropped optimally, (2) thirteen new sites added optimally to existing 26 sites, and (3) twelve fixed sites with optimal addition of 13 new sites. It was assumed that each station was sampled four times per year. Results are being evaluated, however, it is clear that new stations, in general, are the most effective in adding regional information. The analyses shown for loads can also be performed for concentrations.

Based on the network studies, the study team has suggested a proposed monitoring plan as shown in Table 7 to DFW cities. The cities have accepted scenario 3 as shown on this chart.

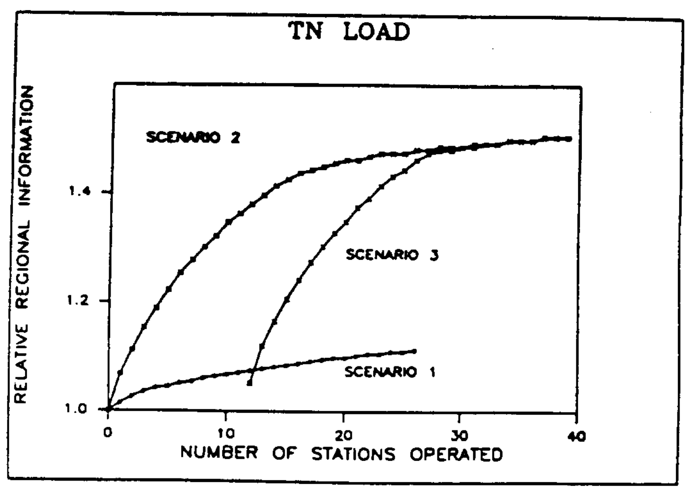

Figure 9 -- Results of network analysis for Total Nitrogen (TN) load (after Tasker and Raines, (1994))

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STATION LOCATION					REGIONAL MONITORING SCENARIOS		
CITY	CITY STATION NAME	USGS STATION NUMBER	ACRES		SCENARIO 1 30 existing sites 5 new sites	SCENARIO 2 14 existing sites 7 new sites	SCENARIO 3 14 existing sites
RESIDENTIAL SITES							
FORT WORTH	STG1	8047100	61.7		X		
FORT WORTH	EH1	8048700	151		X	X	X
DALLAS	55	8057310	71.3		X		
DALLAS	189	8057441	38 9		X	X	X
GARLAND	402	8061660	67 3		X		
IRVING	501	8049530	65.3		X	X	X
ARLINGTON	601	8049300	77		X		
ARLINGTON	602	8049320	160		X	X	X
PLANO	701	8061510	51 4		X		
MESQUITE	802	8061915	45 4		X		
MESQUITE	803	8061940	48 2		X		
COMMERCIAL SITES							
FORT WORTH	BEL1	8048510	136 2		X		
DALLAS	86	8057135	59 1		X	X	X
GARLAND	403	8061650	38 2		X		
ARLINGTON	603	8043220	38 8		X	X	X
PLANO	702	8061525	22 7		X	X	X
MESQUITE	801	8061910	45 9		X	X	X
INDUSTRIAL SITES							
FORT WORTH	PY1	8046505	151		X	X	X
FORT WORTH	CRA1	8048545	73.7		X	X	X
DALLAS	138	8055590	9		X		
DALLAS	325	8056330	49 5		X	X	X
GARLAND	401	8061635	33 9		X	X	X
IRVING	502	8056100	43 9		X		
IRVING	503	8055570	43 4		X		
ARLINGTON	604	8049470	85 5		X		
PLANO	703	8061530	49		X		
TxDOT HIGHWAY SITES							
DALLAS	901	8055630		Bachman outfall at I-635	X	X	X
DALLAS	902	8049060		Mountain Creek outfall at I-20	X		
ARLINGTON	903	8049950		Fish Creek outfall at I-20	X	X	X
FORT WORTH	904	8048920		Deer Creek outfall at I-35W	X		
NEW SITES FOR RELOCATION OF EQUIPMENT							
ARLINGTON	Instream Site—Rush Creek				X	X	
DALLAS	Mixed Land Use Site					X	
FORT WORTH	Instream Site-Sycamore Creek					X	
GARLAND	Background site				X	X	
IRVING	Mixed Land Use Site				X	X	
MESQUITE	Instream Site-Mesquite Creek				X	X	
PLANO	Background Site				X	X	

Table 7 – Companson chart of proposed regional monitoring scenarios (after CDM/APAI, (1994))

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Storm Water NPDES Monitoring in Santa Clara Valley

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Abstract

Results from stormwater monitoring conducted in Santa Clara Valley from 1987 through 1994 are presented. During this period, hydrologic, water quality, and toxicity data have been obtained from a variety of small and large catchments and within storm drains and in streams and rivers. Approximately 200 station-events have been monitored for water quality, primarily focused on heavy metals. Both flow composite and manual grab samples have been obtained. Data presented address water quality characterization, effects of land use on water quality, compliance with water quality objectives, urban versus natural erosional sources of metals, water quality correlations with flow, equilibrium partitioning between dissolved and particulate forms of metals, spatial and temporal differences based on analysis of variance (ANOVA) and analysis of covariance (ANACOVA), power analysis for designing monitoring programs to measure long term trends, and toxicity testing.

Introduction

The Santa Clara Valley is located at the southern end of San Francisco Bay, encompasses about 1800 square kilometers (700 square miles) of which about 50% is urbanized, and has a population of 1.4 million people (Figure 1). The valley contains major cities such as San Jose, as well as "Silicon Valley". The valley is semi-arid with mean annual precipitation on the valley floor of 355 mm (14 in) per year.

In 1986 the San Francisco Regional Water Quality Control Board revised their Basin Plan to require that storm water discharges into the southern portion of San Francisco Bay be characterized and controlled. In response to this requirement, thirteen cities, Santa Clara County, and the Santa Clara Valley Water District

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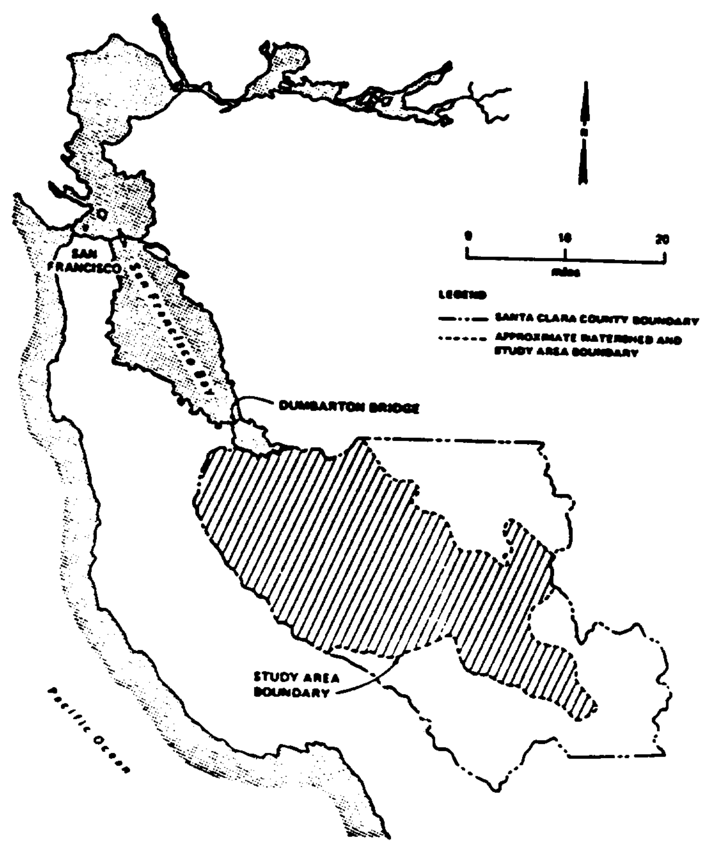

Figure 1 STUDY AREA LOCATION

(SCVWD) formed the Santa Clara Valley Nonpoint Source Pollution Control Program (Program). In 1989 the State Water Resources Control Board listed the south Bay as an "impaired water body" as required under Clean Water Act Section 304(L) because water quality standards for heavy metals were frequently exceeded. The Program applied for and received an early NPDES stormwater permit in June 1990.

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This paper summarizes findings from the extensive monitoring conducted by this program. The first two fiscal years (FY 87-88 and FY 88-89) of monitoring prior to the first permit period included wet weather monitoring at 7 stations that drained different land use areas and wet and dry weather monitoring at 4 waterway stations. These data were used to characterize storm water runoff water quality and to estimate the distribution of annual metals loads to the Bay.

In FY 89-90, monitoring was continued at the four waterway stations to evaluate long term compliance with water quality objectives and at one industrial land use station which was being used as a pilot demonstration project for evaluating the effectiveness of an intense industrial inspection program.

The monitoring activities during the first 5 year permit period (starting in FY 1990) included automatic flow-composite sampling at the four waterway stations. Because the permit required that sampling be conducted at locations which were representative of the discharge, two of these locations were in the largest watersheds in Santa Clara Valley, Guadalupe River and Coyote Creek. For comparison, one sampling station was in a relatively small watershed with a predominantly natural channel, Calabazas Creek, and a fourth was in a constructed channel, Sunnyvale East. The data from these stations are being used to meet the objectives of evaluating water quality trends, and to determine if storm water discharges are in compliance with applicable water quality and toxicity objectives.

To meet other objectives of the monitoring program, monitoring was conducted during the first permit period at two industrial land use stations to characterize storm water quality and to evaluate storm water quality improvements due to the implementation of pollution prevention actions resulting from a pilot inspection program conducted in one of the areas. To characterize storm water quality from transportation corridors, two stations were installed and operated for three years on an eight lane freeway and on a local 4 lane expressway. The Program also evaluated the use of automated flow-composite sampling equipment compared to grab sampling, to ensure that representative samples were being obtained. As part of the grab sampling effort, the Program conducted studies to evaluate how pollutant concentrations vary over the course of a storm event, the duration of water quality exceedences for pollutants during storm events, and whether or not pollutants persist after the event concludes and flows return to pre-storm levels. Toxicity testing was conducted at the land use and transportation stations for two years, and at the waterway stations all five years of the first permit period.

Monitoring Stations

Monitoring stations consisted of two types: stations located in relatively small catchments (typically 10-1,000 hectares) containing predominantly one land use; and stations that drained relatively large watersheds (1,000-30,000 hectares) which contained a mixed land use. The former stations are referred to as "land use" stations and are commonly located in small streams or municipal storm drain pipes. Data from these stations are indicative of urban runoff water quality from urban and non-urban sources and were used to characterize water quality and as input to loading estimates. The latter type of stations, referred to as "waterway or stream stations" were located in larger streams and rivers near the Bay and represented local receiving waters. Data

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from these stations were used for compliance and reflect the effects of upstream non-urban areas and stream sediment processes. Table 1 describes the various stations.

TABLE 1
STATION DESCRIPTIONS

Station ID	Type of Station	Location	Principal Land Use	Drainage Area hectares (acres)	Conveyance	Remarks
L1	Land Use	Junction Avenue	industrial park	8.9 (22)	0.76m (30") R.C.P.	Manhole station, with weir installed
L2	Land Use	Walsh Avenue	heavy industry	11.3 (28)	0.68m (27") R.C.P.	Manhole station, with weir installed
L3	Land Use	Fremont and Bernardo avenues	commercial	107 (265)	1.06m (42") R.C.P.	Manhole station, with weir installed
L4	Land Use	Hale Creek	low-density single-family residential	661 (1,633)	open channel	SCVWD gaging station No. 33
L5	Land Use	Sunnyvale East Channel	single-family residential (valley)	842 (2,080)	channelized	Highly-erodible channel, rating developed
L6	Land Use	[illegible] and Williams	multi-family residential	34 (85)	0.84m (33") R.C.P.	Manhole station, with weir installed
L7	Land Use	Stevens Creek	open (forest)	3400 (8,410)	natural	Rating developed but not considered reliable because of backwater effects
L8	Land Use	[illegible] Creek	open (rangeland)	2617 (6,464)	natural	SCVWD gaging station No. 57
L9	Land Use	West San Carlos Ave.	industrial	16 (40)	storm drain	Storm drain outfall into Los Gatos Creek
T1	Land Use	Montague Expressway	transportation	4.9 (12)	storm drain	Four lane expressway Average Daily traffic (ADT) about 45,000
T2	Land Use	Interstate 280	transportation	14 (35)	pump station	Eight lane freeway - ADT about 213,000
S1	Waterway	Calabazas Creek	mixed	7731 (9,216)	natural	SCVWD gaging station No. 26A
S2	Waterway	Sunnyvale East Channel	mixed	1391 (3,437)	channelized	SCVWD gaging station No. 34
S3	Waterway	Guadalupe River	mixed	6438 (15,904)	natural	USGS gaging station No. 169000
S4	Waterway	Coyote Creek	mixed	32,207 (79,552)	natural	SCVWD high-flow gaging station No. 2060

Monitoring Methods

Storm water sampling was generally conducted with automatic flow composite samplers. Station designs varied but generally consisted of ISCO Model 2700 or 3700 automatic samplers, a Campbell Scientific CR-10 data logger and controller, a Druck diaphragm-type pressure transducer, and 10 or 20 liter borosilicate glass bottles to contain the composite samples. Each station was flow rated using established or new flow rating curves or where weirs were installed, appropriate weir equations. Based on the anticipated runoff, the controller was programmed to collect twenty 500 ml sub-samples over the course of the runoff event. Initially stations could only be controlled on site, then telemetry was added to allow remote control and monitoring. This change significantly improved the storm coverage and quality of data obtained.

Manual grab samples were collected for volatile organics, bacteria, and total oil and grease. Manual samples sometimes were obtained for other pollutants to define pollutographs.

Analytical Suite

In the early part of the Program, a full suite of analyses was conducted which included 10 metals for total and dissolved fractions (arsenic, cadmium, chromium, copper, lead, mercury, nickel, selenium, silver, and zinc), organics (organochlorine pesticides, organophosphate pesticides, volatile organics, semi-volatile organics, total oil and grease, and total organic carbon), and other parameters (pH, hardness, turbidity, and total suspended solids). Parameters that were consistently not detected were dropped from the full suite to a reduced suite of analyses that has become the routine analytical suite for the past 4 years of monitoring. The reduced suite is shown in Table 2.

Note that in Table 2 the method detection limit for mercury was reduced by modifying the analysis techniques in order to quantify mercury levels. Analysis methods were also modified to lower the method detection limits for selenium and PAHs.

Quality Assurance and Quality Control

Since the start of the Program, stringent field and laboratory QA/QC procedures were developed and implemented to ensure high quality data. Field QA/QC includes following strict sampling protocols as specified in standard operating procedures and evaluation of potential contamination through the analysis of field equipment blanks. Laboratory QA/QC addressed:

- Accuracy (analysis of matrix spike recoveries on each batch of samples and quarterly analysis of certified samples)
- Precision (analysis of matrix spike duplicates)
- Contamination (analysis of method blank, and filter blank)
- Holding Time (specified holding times associated with each chemical method)
- Certified Methods of Analysis (EPA or State certified methods of analysis)

Metals Detected

Figure 2 shows the percent of waterway samples in which metals were detected during storm events from 1988 to 1992. Of the metals detected by the total recoverable methods (total metals), cadmium, chromium, copper, lead, nickel and zinc were consistently detected. Total arsenic was detected in 74% of the samples while total mercury, selenium and silver were detected in approximately half the samples. Of the dissolved metals only chromium, copper and zinc were consistently detected.

Table 2. CHEMICAL ANAYTICAL SUITE AND METHOD DETECTION LIMITS

Parameter	Units	Methodology	EPA Method (a)	Method Detection Limit
Inorganics				
pH	pH	pH electrode	150.1	-
Hardness	mg/L	Titrimetric EDTA	130.2	1
Turbidity	NTU	Nephelometric	180.1	1
TSS	mg/L	Gravimetric	160.2	10
Metals - Total Recoverable				
Arsenic	μg/L	Furnace-AA	206.2	1
Cadmium	μg/L	Furnace-AA	213.2	0.2
Chromium (Total)	μg/L	Furnace-AA	218.2	1
Copper	μg/L	Furnace-AA	220.2	1
Lead	μg/L	Furnace-AA	239.2	1
Mercury	μg/L	Cold Vapor - AA/AF	245.1	0.2/0.001
Nickel	μg/L	Furnace-AA	249.2	2
Selenium	μg/L	Hydride - AA	270.3	0.025
Silver	μg/L	Furnace-AA	272.2	0.2
Zinc	μg/L	Furnace-AA	289.2	1
Metals - Dissolved (< 0.45 μm)				
Cadmium	μg/L	Furnace-AA	213.2	0.2
Copper	μg/L	Furnace-AA	220.2	1
Lead	μg/L	Furnace-AA	239.2	1
Mercury	μg/L	Cold Vapor - AA/AF	245.1	0.2/0.001
Silver	μg/L	Furnace-AA	272.2	0.2
Zinc	μg/L	Furnace-AA	289.2	1
Organics				
PAH	μg/L	GC-MS	8270 (modified)	0.0005
TOC	mg/L	Combustion	9060	1
Total Oil and Grease	mg/L	IR	413.2	0.2

(a) Methods for Chemical Analysis of Water and Wastes (1983) EPA-600/4-79-020

Dissolved nickel was detected in 71% of the samples and dissolved lead was detected in 54% of the samples. Less than half the samples had detectable concentrations of dissolved cadmium, selenium and silver. Dissolved mercury was undetectable using standard EPA methods.

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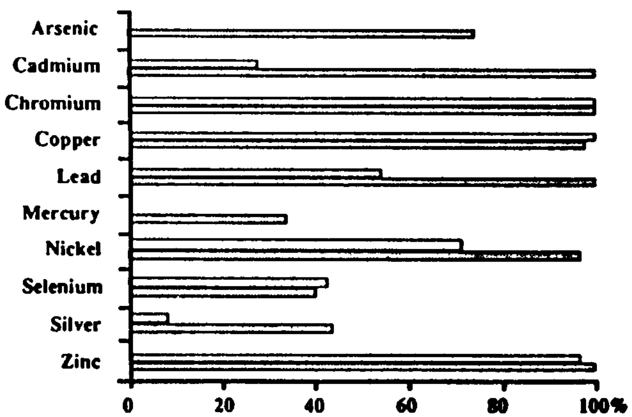

(Total Number of Samples)

Total	Dissolved
62	7
62	39
53	7
62	39
62	39
62	7
62	7
62	7
62	39
62	39

Monitoring Period: 1988 to 1992

Figure 2 PERCENT OF WATERWAY SAMPLES IN WHICH METALS WERE DETECTED DURING STORM EVENTS

<u>Effects of Land Use on Water Quality</u>

During the first two years of the Program (1987-88,1988-89), monitoring data were collected at seven land use stations (Table 1, stations L1-L7) to characterize water quality from open, residential/commercial, and industrial land uses. To characterize water quality from transportation corridors, two stations were installed and operated for three years on an eight lane freeway and on a local 4 lane expressway (Table 1, stations T1, T2). Figure 3 shows the median concentrations of total cadmium, copper, lead, nickel and zinc at the land use stations and at the waterway stations (Table 1, stations S1-S4).

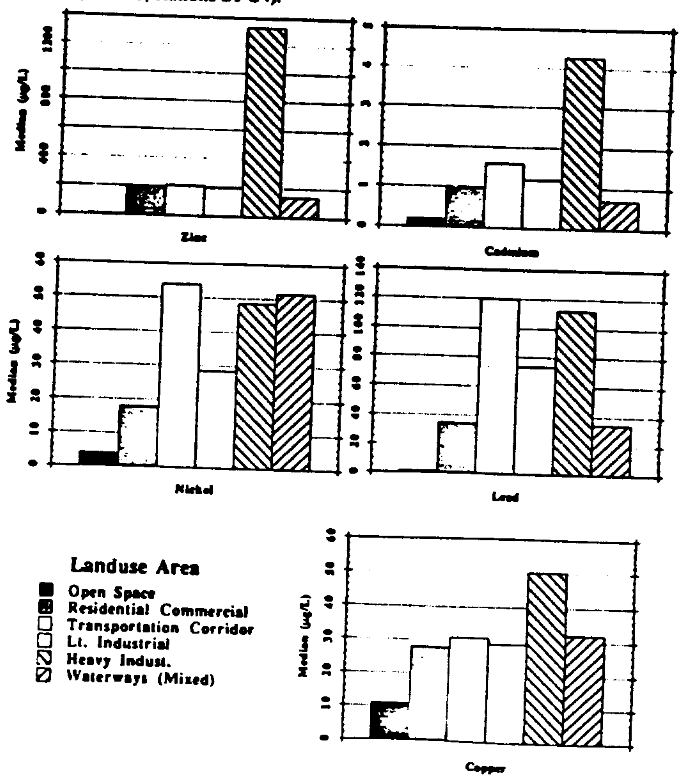

Figure 3 MEDIAN METAL CONCENTRATIONS IN STORM RUNOFF

Total zinc and cadmium at the heavy industrial station were 4 to 6 times higher than concentrations at the other land use areas. (Note: pilot inspection programs implemented in this catchment indicated a source of cadmium and zinc from metal plating operations.) Total cadmium in the other land use areas was only slightly elevated relative to the waterway concentrations. Total lead concentrations were highest at the transportation and heavy industrial stations. Total nickel concentrations were highest at the transportation, heavy industrial, and waterway stations. Total copper concentrations were highest in the heavy industrial station. Total median copper concentrations at the other urbanized land uses are consistently around 30 µg/L/L. Copper concentrations in samples obtained from open space stations were approximately one third of this value suggesting a substantial amount of copper may originate from open space land use areas.

Statistical tests of these data indicate that metals concentrations in samples obtained from open space versus residential/commercial samples versus heavy industrial samples are significantly different. The tests do not show statistically significant differences in concentrations of samples collected in different types of residential areas (eg, single versus multi-family) or between residential and commercial areas (SCVNPS, 1989).

Enrichment of Metals Associated With Suspended Particulates

Metals in storm water runoff are often associated with suspended solids. Metals in these solids may arise from either 'natural' sources (erosion of soils containing minerals) or manmade sources. One measure of the amount of manmade metal in a given sample is the "enrichment factor" defined as the ratio of the suspended metal concentration in a storm water sample collected in an urbanized portion of a watershed to the surficial soils concentrations in upland open areas of that watershed. (The enrichment concept is that if there were no additional input, or "enrichment", of metals from sources other than erosion, the suspended metals concentration would equal upland surficial sediment concentrations and the enrichment factor would be of the order of unity.)

The suspended metal concentration (µg/g) is defined as the ratio of the particulate metal concentration (g/L) to total suspended solids (TSS) concentration (g/L); where the particulate metal concentration (g/L) is the total metal concentration minus the dissolved metal concentration. The suspended metals concentrations are expressed on a dry weight basis (as are TSS values).

Data from Shacklette and Boerngen (1984) for the San Francisco Bay Area were used to characterize upland surficial sediment concentrations. The hills in the

South Bay contains serpentine outcrops as well as other mineral formations which are a source of nickel, copper, chromium, and mercury and metals concentrations in Bay Area soils were in the upper quartile of national data compiled by Shacklette and Boerngen.

Figure 4 shows enrichment factors for a variety of metals and sampling station types. The highest enrichment factors for land use stations are for zinc, lead, and cadmium which have enrichment factors between 10 and 40 for the three urban land use area types. In the waterway stations suspended solids had higher enrichment factors for most metals than bed sediments. Several factors may contribute to the

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observed higher enrichment factors in suspended versus bed sediments including differences in particle size.

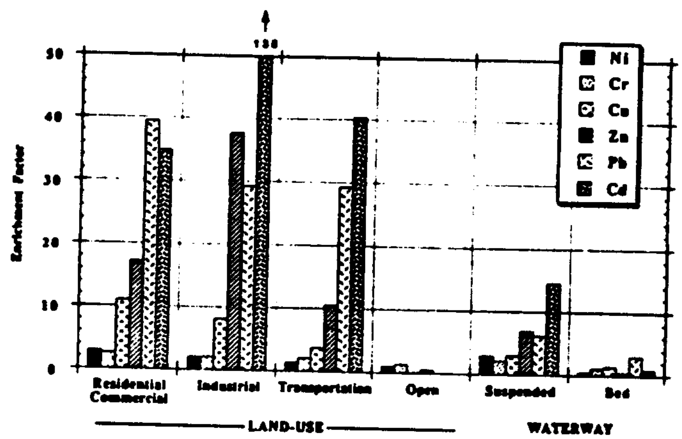

Figure 4 ENRICHMENT FACTORS FOR SUSPENDED SOLIDS

Enrichment analysis is a tool for identifying the relative importance of urban versus upland erosional sources. These results indicate that urban sources for cadmium, lead, and zinc are much larger than upland erosional sources, whereas for copper and nickel both sources are important. Chromium appears to be primarily an erosional source.

Water Quality Flowrate Correlations

There has always been an interest in potential correlations between water quality and flow and efforts at correlation using flow composite data have not been successful. However, grab sampling results for five storm events (28 data points) from the Guadalupe River Station (S3) were successfully correlated with flowrate. Figure 5 shows discrete TSS concentrations versus instantaneous stream flowrate. Linear regression analysis indicated a correlation coefficient of 0.781. The best-fit linear regression equation describing this relationship is:

$$TSS\ (mg/L) = 0.277\ FLOWRATE\ (cfs) + 58.49$$

Because of the high affinity of metals to solids, and since TSS is correlated with flowrate, we tested the relationship between total copper and flowrate.

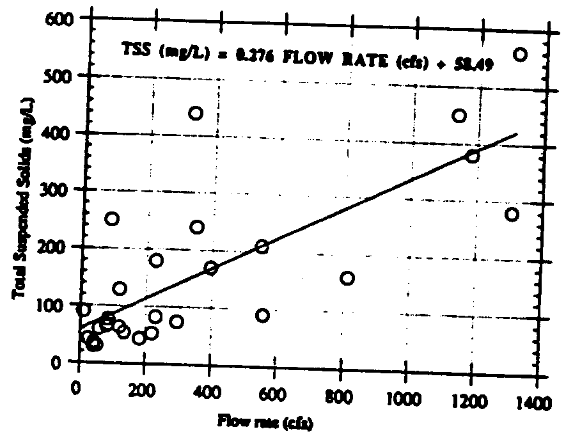

Figure 5 TOTAL SUSPENDED SOLIDS VERSES FLOW RATE IN GUADALUPE RIVER

Figure 6 shows a positive correlation (R^2= 0.820) between total copper concentration (TCu) and flowrate with a best-fit linear regression equation given by:

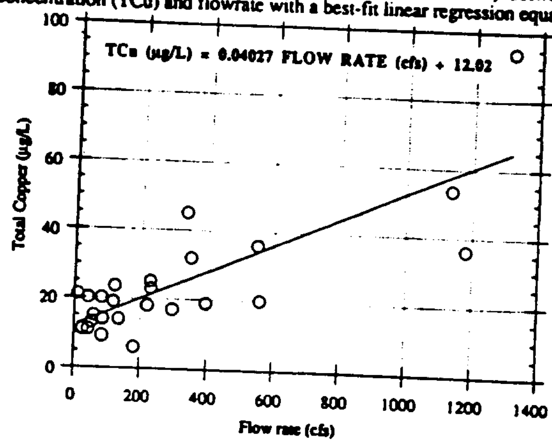

Figure 6 TOTAL COPPER CONCENTRATIONS VERSES FLOW RATE IN GUADALUPE RIVER

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Equilibrium Partitioning

The form (as well as presence) of pollutants is important as the dissolved form of the constituent is more biologically available than the particulate form . In order to be able to characterize dissolved versus particulate partitioning we examined the applicability of equilibrium partitioning theory to storm water. A sorption isotherm describes the partitioning of chemicals between the dissolved phase and the sorbed phase. Assuming a linear isotherm for dilute solutions yields the following equilibrium partitioning equation (Maidment, 1992):

$$F_{dis} = 1/[1 + (K_d\ TSS)]$$

where

F_{dis} = ratio of dissolved to total concentration
K_d = Distribution coefficient (L/Kg)
TSS = Total Suspended Solids Concentration (μg/L)

When the grab sample data for copper were fitted to this theoretical relationship (Figure 7), there was a significant correlation (R^2=0.937). The distribution coefficient which yielded the best-fit regression curve shown in Figure 7 is 29,079 L/kg.

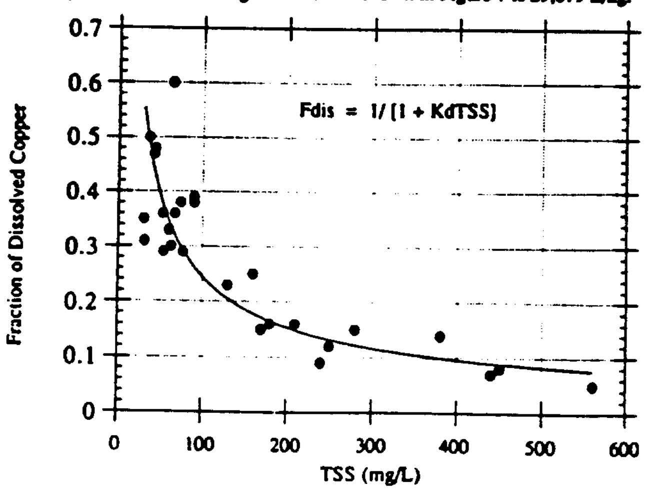

Figure 7 RELATIONSHIP BETWEEN FRACTION DISSOLVED COPPER AND TOTAL SUSPENDED SOLIDS

The distribution coefficient is the ratio of the sorbed concentration (g/Kg) to the dissolved concentration (g/L); therefore the higher the value of K_d, the lower the dissolved fraction. The distribution coefficient for lead is greater than that for zinc

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which is greater than that for copper. This means that in the sorbed phase, there is a higher fraction of lead than zinc than copper.

In conclusion, these storm water data support the linear isotherm equilibrium partitioning theory and this theory may be applied to estimate the dissolved fraction given the TSS and total concentration. Although not shown, this theory also applied reasonably well to data taken in storm drains (SCVNPS, 1993).

Exceedances of Water Quality Objectives

The metals data from four years of monitoring waterway stations have been compared to water quality objectives contained in the April 1991 California Inland Surface Waters Plan. Since the average storm runoff duration at waterway stations is about 36 hours in Santa Clara Valley, comparison of urban runoff water quality to the freshwater aquatic life1-hour and 4-day objectives are used to "bracket" the actual exposure. The 4-day average objective is referred to as the "chronic" objective, and the 1-hour average objective is referred to as the "acute" objective. Given the duration of storm events, exceedance of an acute objective is considered a better indicator of a potential toxicity problem. In addition, exceedances of objectives by dissolved metal concentrations are considered better indicators of potential toxicity problems than exceedances by total metals concentrations because dissolved metals are more bioavailable.

Table 3 summarizes the water quality objective exceedances for various metals at the four waterway stations using dissolved and total metals data collected during the 90-91, 91-92, 92-93, and 93-94 wet weather seasons. Acute and chronic water quality objectives for total copper and total zinc were consistently exceeded in samples collected from Calabazas Creek (station S1) and Sunnyvale East Channel (S2). The objectives for total zinc were only occasionally exceeded in storm water samples from Guadalupe River (S3) and Coyote Creek (S4). The objectives for total copper were less frequently exceeded, and the concentrations were nearer the objectives, in storm water samples from Guadalupe River and Coyote Creek than in samples from Sunnyvale East Channel and Calabazas Creek. The chronic objectives for total nickel and total lead were always exceeded in samples from Sunnyvale East Channel and Calabazas Creek, and frequently exceeded in samples from Guadalupe River and Coyote Creek. Acute objectives for total lead were rarely exceeded, and acute objectives for total nickel have never been exceeded. Total cadmium has not exceeded acute objectives, and exceeded chronic objectives in 8 of 61 storm samples; the most recent observed exceedance was in October 1991.

Dissolved constituents seldom exceed objectives. Dissolved copper exceeded the chronic objectives in 2 of 42 samples, and has not exceeded acute objectives. Dissolved lead was detected in 10 of 43 samples and one of these ten samples exceeded the chronic objectives; no lead samples exceeded the acute objectives.

Those 304(l) metals of concern that have never exceeded water quality objectives include total mercury (acute objectives only, chronic objectives were lower than the MDL), total selenium, dissolved cadmium, and dissolved zinc. Total silver is generally not detected, and dissolved silver and chromium (VI) have never been detected in storm water samples from the four waterway stations.

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Figure 8 compares the total copper data with acute and chronic objectives for the four waterway stations. This figure shows the effect of urbanization on water quality exceedances. Most exceedances occur at the stations (S1 and S2) whose watersheds are smaller and more highly urbanized.

Table 3
SUMMARY OF WATER QUALITY OBJECTIVES EXCEEDANCES FOR WATERWAY STATIONS

Station ID	Cadmium		Chromium	Copper		Lead		Mercury	Nickel	Selenium	Silver		Zinc	
Exceedance of Acute Water Quality Objectives at Waterway Stations (#samples exceeding/total samples) FY 90-91 Through FY 93-94														
	Total	Diss.	Total	Total	Diss.	Total	Diss.	Total	Total	Total	Total	Diss.	Total	Diss.
S1	0/12	0/7	N/A	11/11	0/7	1/12	0/7	0/12	0/12	0/12	0/12	0/7	11/12	0/7
S2	0/12	0/8	N/A	12/12	0/9	2/12	0/7	0/12	0/12	0/12	0/12	0/8	12/12	0/7
S3	0/17	0/12	N/A	0/17	0/12	2/17	0/12	0/17	0/17	0/17	0/17	0/8	3/17	0/12
S4	0/20	0/14	N/A	10/20	0/15	0/20	0/16	0/20	0/20	0/20	0/20	0/9	7/20	0/16
Exceedance of Chronic Water Quality Objectives at Waterway Stations (#samples exceeding/total samples) FY 90-91 Through FY 93-94														
	Total	Diss.	Total	Total	Diss.	Total	Diss.	Total	Total	Total	Total	Diss.	Total	Diss.
S1	2/12	0/7	N/A	11/11	0/7	12/12	0/7	NC	12/12	0/12	N/A	N/A	12/12	0/7
S2	3/12	0/8	N/A	12/12	2/8	12/12	0/7	NC	12/12	0/12	N/A	N/A	12/12	0/7
S3	1/17	0/12	N/A	15/17	0/12	16/17	0/12	NC	13/17	0/17	N/A	N/A	7/17	0/12
S4	2/20	0/16	N/A	14/20	0/15	17/20	1/16	NC	14/20	0/20	N/A	N/A	0/20	0/16

N/A - No Objective For This Metal
NC - Not Comparable (Method Detection Limit > Objective)

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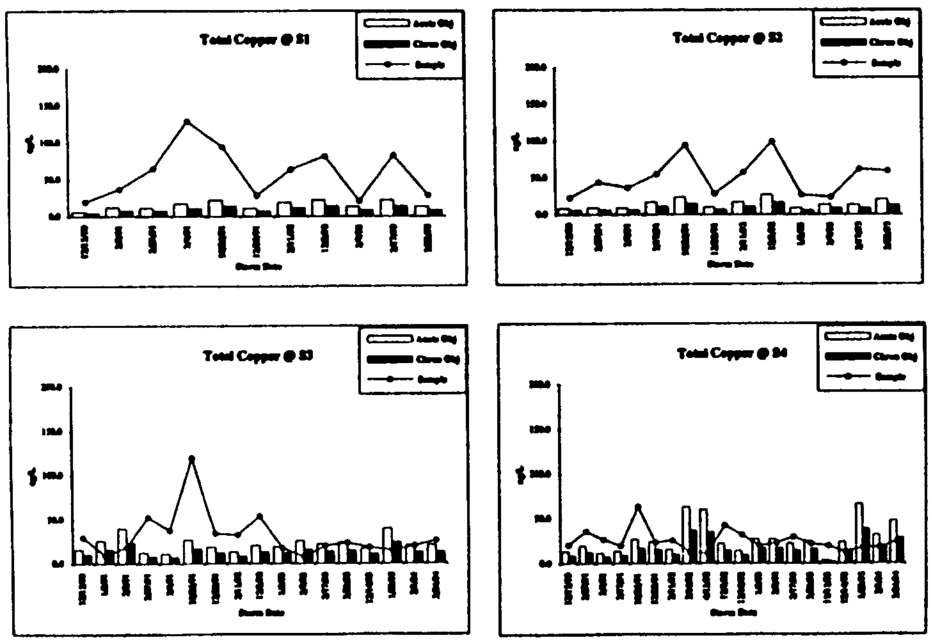

Figure 8 COMPARISON OF TOTAL COPPER CONCENTRATIONS IN STORM WATER SAMPLES TO WATER QUALITY OBJECTIVES AT FOUR WATERWAY STATIONS

Duration Of Water Quality Objective Exceedances

If flow-weighted concentrations exceed the WQOs, it is often assumed that the duration of exceedance equals the duration of the runoff event. In order to test this assumption, the actual duration of exceedance was determined by collecting and analyzing discrete samples during six storm events at the Guadalupe River Station (S3). For each storm event, about six samples were collected over the rising, peak, and receding limb of the hydrograph.

Table 4 shows that the duration of exceedance of acute WQOs for total copper, lead and zinc is always less than the duration of the storm runoff event. The frequency of exceedance varies depending on the metal, and was greatest for copper (5 of 6 events), then zinc (4 of 6), and then lead (2 of 6). For copper, exceedance duration ranged between 8-38 hours or about 20 to 95% of the duration of the storm runoff. For zinc, the exceedance durations ranged between 3-28 hours (8 to 74% of storm runoff duration) and for lead the two exceedances were each 6 hours or 20-25% of the storm runoff duration. For those cases where an exceedance was measured, the average duration of exceedance (expressed as a percent of the storm duration) was approximately 60% for copper, 40% for zinc, and about 20% for lead.

Table 4. Estimated Duration of Exceedance of Acute WQO for Total Copper, Lead, and Zinc

Storm Event	Storm Date	Storm Runoff Duration (Hrs)	COPPER Exceedance Duration of Acute WQO (1)		LEAD Duration of Exceedance of Acute WQO (1)		ZINC Duration of Exceedance of Acute WQO (1)	
			(Hrs)	(%)	(Hrs)	(%)	(Hrs)	(%)
SE11	12/15/90	40	38	95	0	0	28	74
SE13	2/2/91	20	0	0	0	0	0	0
SE14	2/28/91	30	23	77	6	20	10	33
SE23	12/6/92	23	14	61	6	25	10	43
SE24	12/10/92	38	8	21	0	0	3	8
SE25	1/6/93	34	14	41	0	0	0	0

(1) Estimated exceedance duration is based on discrete water quality objectives calculated from discrete hardness data for storm events 11, 13 and 14. For storm events 23, 24 and 25, average composite hardness data were used to estimate WQO.
Percentage is calculated as: (Exceedance Duration/Storm Duration) X 100

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Statistical Analyses

Statistical analysis were used to determine if there were differences in water quality between monitoring stations and between monitoring years. The results were also used to help select future stations for long term monitoring and to determine the number of samples that need be collected to detect a given trend in water quality (power analysis).

Two way analysis of variance (ANOVA) and analysis of covariance (ANACOVA) were used to perform comparisons between stations and years. Parametric procedures (using the actual values of the data) rather than non-parametric procedures (using the ranks of the values) were chosen because they allow the statistical results to be used to determine the number of samples necessary to determine a given difference between years and/or stations (power analysis). Previous data analysis indicated total metals are lognormally distributed and therefore, statistical analyses used log-transformed data.

ANOVA Results - Station Differences

Figure 9 presents total copper box plots for the four waterway stations for samples collected during the permit period. The figure indicates total copper concentrations are highest and more variable in Calabazas Creek (S1) and Sunnyvale East Channel (S2), with lower concentrations and less variability seen in Guadalupe River (S3) and Coyote Creek (S4). The stations with the higher concentrations drain smaller more urbanized watersheds.

The results of the ANOVA statistical analysis (top of Figure 9) indicate Calabazas Creek (S1) had significantly higher total copper concentrations than Guadalupe River (S3) and Coyote Creek (S4) and Sunnyvale East Channel (S2) was significantly higher than Coyote Creek (S4). If the data for the two stations (S1,S2) having the higher concentrations are pooled, these data are significantly higher than the pooled data for stations S3 and S4 ($p=0.002$).

ANACOVA Results - With TSS as Covariant

Much of the total copper in waterways during storms is associated with suspended solids, with the dissolved fraction typically ranging from 15% to 30% of the total concentration (Figure 7). Variations in TSS from event to event may mask apparent station and or year differences. To examine this effect, analysis of covariance (ANACOVA) was used to account for differences in total copper concentrations caused by variations in suspended solid concentrations by including TSS as a covariant. Differences not due to variations in TSS are seen as better indicators of station and year differences.

Station Differences

Figure 10 presents the suspended sediment total copper percentile box plots. The figure indicates the total copper concentrations in suspended sediments are highest in Sunnyvale East Channel, with lower concentrations in Calabazas Creek, Guadalupe River and Coyote Creek. Sunnyvale East Channel is not a natural channel while the other waterways are natural channels with little or no improvements. This suggests that total suspended sediment concentrations are lower in constructed waterways

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(because of minimal or no bottom or bank erosion) which, for a given total metals concentration, results in lower copper concentrations in suspended sediments.

Results of ANOVA Comparison Between Waterway Stations

Parameter: Total Copper

STID i;j	S1	S2	S3	S4
S1		=	>	>
S2			=	>
S3				=
S4				

Confidence level: 0.05 (95%)

> means row is greater than column station
= means row not different than column

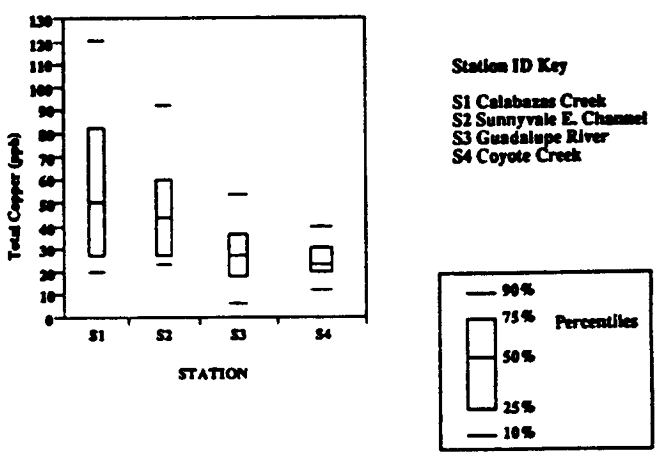

Figure 9 TOTAL COPPER PERCENTILE DISTRIBUTION AT WATERWAY STATIONS

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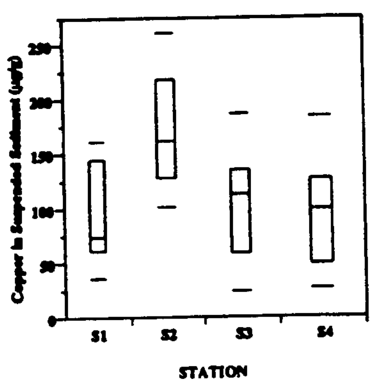
Results of ANACOVA Comparison Between Waterway Stations
TSS used as covarient

Parameter: Total Copper

STID i:j	S1	S2	S3	S4
S1		<	=	=
S2			>	>
S3				=
S4				

Confidence level: 0.05 (95%)

= means row not different than column station
> means row is greater than column station
< means row is less than column station



Station ID Key

S1 Calabazas Cr.
S2 Sunnyvale E. Channel
S3 Guadalupe River
S4 Coyote Creek

Figure 10 TOTAL COPPER IN SUSPENDED SEDIMENT IN SANTA CLARA VALLEY WATERWAY STATIONS

Results of the ANACOVA statistical comparison are presented at the top of Figure 10. The results indicate Sunnyvale East Channel (S2) had significantly higher total copper concentrations than Calabazas Creek, Guadalupe River and Coyote Creek. Total copper concentrations in Calabazas Creek, Guadalupe River, and Coyote Creek are not significantly different after accounting for differences due to TSS.

Annual Differences

Data from the three similar stations (Calabazas, Guadalupe, and Coyote) were used to conduct a two-way ANACOVA using year and stations as the effects to be tested. The results shown in Figure 11 indicate total copper was significantly lower in 1992 as compared to 1991 (p=0.044). No other significant differences between years were observed. These observed differences may be due to increased rainfall in 1992 (19.5 inches total) as compared to 1990 (11 inches) and 1991 (14 inches) or other factors.

In conclusion, these analyses indicate the advantage of conducting ANACOVA statistical testing taking into account the effects of TSS as a covariate. The results indicate that, by taking into account TSS, differences between stations were illuminated which would otherwise have been masked using an ANOVA analysis. The ANACOVA results also showed a statistically valid annual difference which was not evident in the ANOVA analysis.

Power Analysis for Detection of Long-term Trends

There is considerable interest in storm water monitoring to detect long term trends in water quality that may be associated with BMP implementation. The following describes the application of the statistical tool called power analysis to help address this issue.

The ability to distinguish long-term trends in a dataset is influenced by several factors including the magnitude of the difference to be observed, the amount of variability in the data, the number of samples, and the desired confidence intervals for the statistical tests. The probability of observing a given trend increases when sample size is increased and decreases when variability and/or desired statistical confidence intervals are increased. Additionally, the larger the trend to be observed the higher the probability it will be observed, other factors being equal. The main variables which can be controlled are the number of samples and which stations will be monitored.

Results of the ANOVA statistical testing indicated the four monitoring stations could be grouped into subsets based on total copper concentrations. Each of the subsets contained differing degrees of variability with the Calabazas Creek Sunnyvale East Channel subset (S1&S2) having higher variability than the Guadalupe River Coyote Creek subset (S3&S4). As variability is a factor influencing statistical power, separate power analysis was conducted for each station subset.

Figure 12 presents the results of the power analysis for total copper data collected at the Coyote Creek and Guadalupe River monitoring stations. Presented are the number of samples per year (total for both stations) and the power (probability of detecting the trend) for three projected trends. For example, this figure indicates that, at the 80 percent confidence level, it would take about 22 samples per year to confirm a 40% change over a 10 year period. If the trend analysis were to be conducted at the other two waterway stations where the data are more variable, the analysis shows that about 30 samples would be required.

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Results of ANACOVA Comparison Between Monitoring Years
(Calabazas, Guadalupe & Coyote Stations)
TSS used as covarient

Parameter: Total Copper

Year i:j	1990	1991	1992
1990		=	>
1991			=
1992			

Confidence level: 0.05 (95%)

= means row not different than column station
> means row is greater than column station
< means row is less than column station

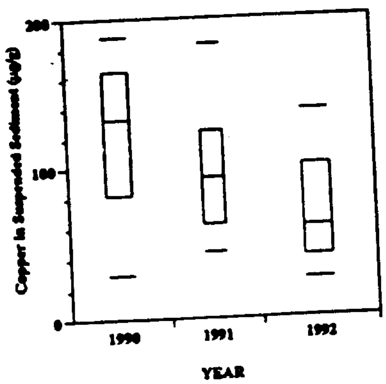

Figure 11 TOTAL COPPER IN SUSPENDED SEDIMENT AT CALABAZAS, GUADALUPE RIVER, AND COYOTE CREEK

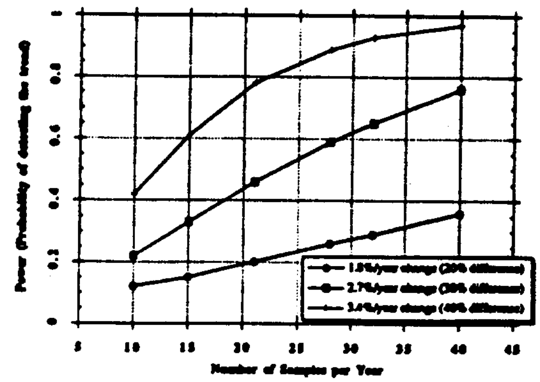

Figure 12 NUMBER OF WATERWAY SAMPLES NEEDED TO DETECT A 10-YEAR TREND IN TOTAL COPPER CONCENTRATIONS IN STORM WATER SAMPLES (Guadalupe and Coyote Stations)

An alternative power analysis was conducted using the ANACOVA statistical results which examines differences in total copper caused by factors other than changes in total suspended solids (Figure 13).

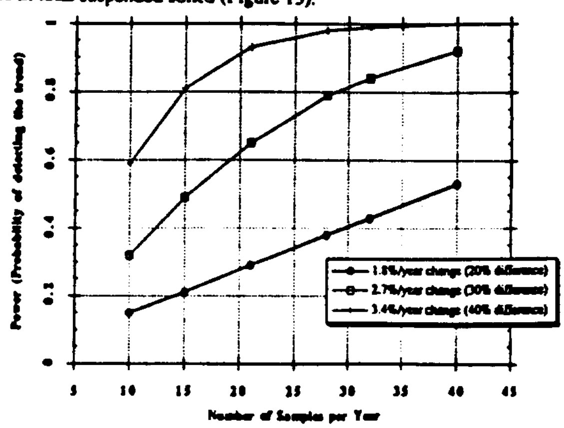

Figure 13 NUMBER OF WATERWAY SAMPLES NEEDED TO DETECT A 10-YEAR TREND IN TOTAL COPPER BASED ON ANACOVA USING TSS (Calabazas, Guadalupe, and Coyote Stations)

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When compared to the previous power analysis presented in Figure 12 it is apparent that changes in TSS-corrected total copper are easier to detect using the ANACOVA model, reflecting the lower unexplained error after changes due to TSS are taken into account. (For example, 15 samples per year are sufficient to detect a 40% change).

The disadvantage to using the ANACOVA model is that it is more difficult to relate the observed differences to actual changes in pollutant concentrations and loads. The advantage of the model is that, by correcting for changes in TSS in individual storms, some of the influence due to changes in stream hydrology during individual storms is taken into account and annual differences due to other factors may become more apparent.

Toxicity Testing

The purpose of toxicity monitoring was to characterize toxicity at different land use stations and to provide a long term assessment of toxicity (frequency and intensity) in waterway stations. Storm water samples were collected in Santa Clara County during several winters. Some of these were used in chronic, 7-day toxicity tests with *Ceriodaphnia dubia* (USEPA,1989), and some were used for further characterization employing toxicity identification evaluations (TIE) phase I protocols (USEPA, 1988).

The results of chronic toxicity tests are presented in Figure 14, arranged by categories of toxicity intensities. The legend lists the categories in ascending order of intensity (F being more intensive than A) and defines each toxicity category. The mortality endpoint is based on how long it took for a sample to cause mortality of 50% of the test organisms, and samples were assigned to one of three groups: extremely toxic (F, less than 24 hours), highly toxic (E, 1-4 days), or moderately toxic (C and D, 4-7 days). Impaired reproduction (or lack of reproductive effect) was assessed for all samples that did not cause mortality within 5-7 days, using the average number of offspring per female per reproductive day (OFRD) as compared to control OFRD. Moderately toxic samples were assigned to category D if they did not impair reproduction and to category C if they did. Samples which did not kill the organisms but caused impaired reproduction were defined as non-lethal (category B), and samples that did not have any deleterious effect were categorized as non-toxic (category A). Generally, the term "acute toxicity" for *C. dubia* refers to toxic effects delineated in categories E and F (mortality within four days), while the term "chronic toxicity" refers to situations encountered in categories B, C, and D.

Samples from various stations revealed distinctly different distribution among toxicity categories (Figure 14). In the heavy industry station (L-2), all of the samples collected during 1991-1993 were extremely toxic (category F). All samples collected at residential and commercial areas in 1989 caused mortality, and half were extremely toxic. The majority (80%) of the waterway stations samples collected during 1989-1994 were lethal to *C. dubia* (categories D, E and F), but only 20% were extremely toxic. It is important to emphasize that moderately toxic and non-lethal samples from residential, commercial, and mixed land use catchments did not inhibit reproduction of *C. dubia*, except for one unusual event (SE-27) in which all samples collected in Santa Clara Valley impaired reproduction. On the other hand, most of the transportation stations samples inhibited reproduction, and were categorized either as moderately toxic (category C) or non-lethal (category B).

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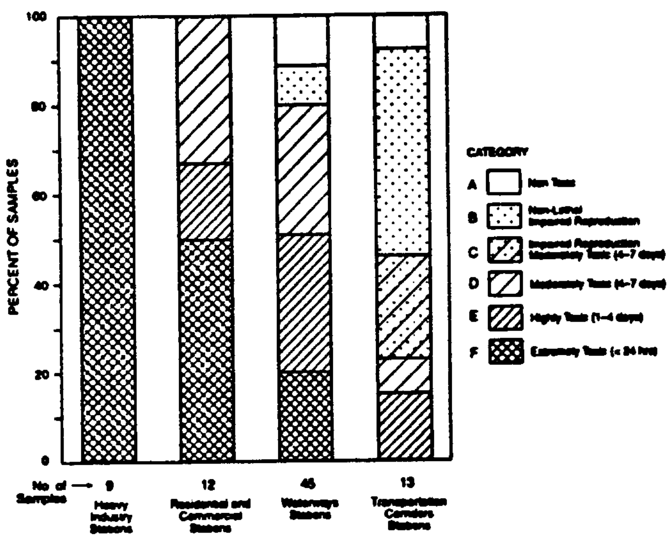

Figure 14. CATEGORIES OF TOXICITY OBSERVED IN DIFFERENT LAND-USE STATIONS IN SANTA CLARA VALLEY

Figure 15 shows the relative intensities of toxicity as measured in Coyote Creek (Station S4, Table 1) during three years of monitoring. The white upper portion of each bar represents the median time to lethality (LT_{50}), which is the duration of exposure that killed 50% of the test animals. The shorter the LT_{50} the higher the toxicity. The duration of the entire test is 7 days (168 hours). To more easily visualize variations in toxicity, we have defined a relative toxicity intensity unit that equals 168 hours minus LT_{50}, shown by the lower darker part of each bar. Taller dark portions mean higher intensity of toxicity, and absence of a dark portion means that toxicity was not detected at all. As can be seen in Figure 15, the variability in toxicity between storm events is very high, and due to this variability it is difficult to see a trend. However, toxicity was detected in autumn and spring storms more often than in mid-winter storms. The environmental significance of laboratory toxicity tests using sensitive non-native organisms is unclear. But the fact that the actual runoff duration in waterway stations is consistently less that the observed LT_{50}s suggests that storm water may not be creating toxic conditions in the tributary streams.

TIE testing has been conducted in a limited way, in part because such tests require highly toxic samples that have not been observed in waterway samples since 1991. TIE tests (3 samples) from industrial stations showed that dissolved metals accounted for a substantial portion of the toxicity observed. This is consistent with the fact that, at industrial stations, dissolved metals also exceeded WQOs and the toxicity intensity correlated with the magnitude of the exceedance.

At waterway stations (5 samples) and transportation stations (1 sample) the major causes of toxicity were non-polar organics (e.g., pesticides or hydrocarbons), or metal-organic complexes. This is consistent with the lack of exceedances of WQOs by dissolved metals and lends support to the appropriateness of dissolved (rather than total) concentrations as the preferred indicator of acute toxicity (Cooke and Lee, 1993). Instead of metals, pesticides, particularly diazinon, have been implicated as a major cause of toxicity in urban runoff samples from residential areas in Alameda County (S.R. Hansen, personal communication) and in the Central Valley (Connor et al, 1994).

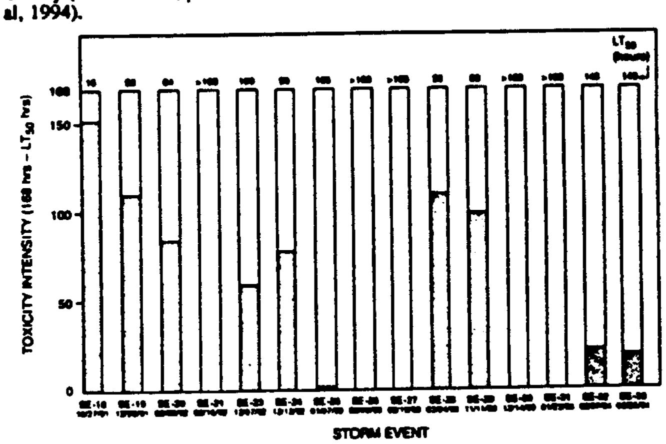

Figure 15. INTENSITY OF TOXICITY AT COYOTE CREEK STATION (S4) DURING THREE YEARS OF MONITORING

<u>Conclusions</u>

(1) The effects of land use on water quality is statistically significant only when data are pooled into the following broad land use categories: open, residential/commercial, and heavy industrial. No statistically significant differences in water quality have been determined for data sets within these broad land use categories.

(2) Enrichment analysis indicates that urban sources of cadmium, lead, and zinc are much larger than upland erosional sources, whereas for copper and nickel both sources are important. Chromium appears to be primarily an erosional source.

(3) Discrete grab sample water quality data correlate with flow whereas past attempts with correlations using flow composite data have been largely unsuccessful.

(4) Linear Isotherm equilibrium partitioning theory applies to storm water samples in alluvial streams and to a lesser extent in storm drains. This theory is very useful in predicting the dissolved versus particulate fraction of metals which is important in evaluating the potential toxicity and treatability of the sample.

(5) Exceedances of acute water quality objectives have not been observed with dissolved metals data and only 2 copper samples (out of 42) exceeded the chronic objectives. Toxicity data indicate that toxicity does not correlate with total concentrations of the metals and that toxicity is not reduced by filtering the sample. These results support the current EPA recommendations (EPA, 1993) that dissolved forms of metals are preferred for evaluating compliance with water quality objectives.

(6) If total metals data is used to evaluate compliance, grab sample data indicate that the duration of exceedance is 20-60 % of the storm event duration depending on the metal.

(7) Evaluating differences between stations and between years appears to be facilitated if one uses ANACOVA analysis using TSS as a covariate. This effectively eliminates hydrologic effects associated with increased TSS (and implicitly increased flows). This analysis indicated that water quality in a watershed where the channels have been significantly improved (e.g., lined with concrete) was statistically different from water quality collected in natural watersheds.

(8) The results of a power analysis to design a monitoring program to detect potential long term trends in water quality shows that accounting for TSS as a covariate could reduce the sampling burden. Nonetheless the number of samples per year required to measure trends are large (eg. 20-40 samples) and it is questionable whether such resources should be applied, especially every year. The authors suggest that monitoring resources should be balanced between compliance and trends analysis versus focused special studies of limited duration.

(9) Toxicity effects have been characterized in six categories depending on the type of effect (mortality and/or reproduction) and time scale of effect. Based on this classification, toxicity testing data indicate that runoff from different land uses exhibit different levels of toxicity to *Ceriodaphnia dubia*. The most toxic samples were found in industrial land use areas, and the least toxic were collected at transportation corridors. However, samples from transportation corridors specifically inhibited reproduction of *C. dubia*.

The cause of toxicity also varied. Data suggest that dissolved metals are the principal cause of observed toxicity at the heavy industrial station whereas at waterway stations the cause appears to be related to non-polar organics or metal-organic complexes. Pesticides, particularly, diazinon, have been implicated in storm water monitoring conducted in other areas of the state.

Future Direction Of Monitoring Program

The two major watersheds, Guadalupe River and Coyote Creek, will continue to be monitored annually for five storm events per year to evaluate long term trends in water quality and to determine if storm water discharges are in compliance with water quality and toxicity objectives. Sunnyvale East Channel and Calabazas Creek will be monitored every other year to meet these objectives, and to provide comparative data. The program will continue to conduct studies to evaluate control measure effectiveness, such as the development of BMPs for the control of pollutants from urban parking lots, scheduled for completion in December 1995. Toxicity testing will continue, but new approaches to evaluating the causes of observed toxicity will be implemented to better understand this complex environmental issue.

In addition to taking a more targeted approach specifically to stormwater quality monitoring, the Program will initiate efforts in the next permit period to expand the scope and purpose of monitoring. New monitoring objectives include greater emphasis on source identification, integrating monitoring into the goals of public education and participation, and expanding the scope of monitoring as a component of watershed management.

The Program recently completed a pilot Citizen Monitoring Project and will be supporting an expansion of this throughout the Santa Clara Valley in an effort to encourage public education and participation and to help prevent illegal dumping through increased community awareness. A pilot watershed-based sediment sampling and analysis project will be conducted in late 1994 to test such an approach to source identification, with particular emphasis on potential erosion and sediment management measures to reducing total copper loads to South San Francisco Bay. Finally, the Program, in cooperation with the Bay Area Stormwater Management Agencies Association and the San Francisco Estuary Institute, will be developing comprehensive watershed monitoring goals, objectives, protocols, and data management and analysis guidelines. A watershed monitoring approach will then be implemented in the Santa Clara Valley during the next permit term as component of watershed management.

Acknowledgements

The authors would like to express their appreciation to the member agencies of the Santa Clara Valley Nonpoint Source Pollution Control Program for supporting this work. We particularly wish to thank Mr. Roger James who, as Chair of the Program Management Committee during the 1st Permit Period, established a proactive program. Kinnetic Laboratories Incorporated (KLI) designed, installed, and maintained the equipment and collected the samples. Special appreciation is given to the field crews who collected these data under often difficult conditions. Marty Stevenson and Richard Mattison of KLI were key players in executing the field program. Toxscan, Inc. Laboratories conducted the chemical analyses and toxicity testing. Josephine Shum of SCVWD assisted in toxicity testing data interpretation. Marco Lobascio of Woodward Clyde assisted in designing and implementing the data management system. Michael Paquet of Woodward Clyde assisted in coordinating the field work and tracking weather.

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SESSION III: System Runoff Characterization

DISCUSSION

NPDES Monitoring - Atlanta, Georgia Region
P. Michael Thomas and Scott McClelland

Finding - Average EMC for any pollutant from any land use is always close to the minimum observed value. Also, there was no statistical difference in the average EMC between land uses for any pollutant.

Finding - 14 parameters exceeded WQS. Fecal coliform in 44%, metals (lead copper, zinc and cadmium), chlordane and bis-2-ethylhexyl-phthalate.

Finding - Standards more frequently violated in stream samples than in end-of-pipe samples. 43% of stream samples exceeded lead standards, while end of pipe samples were much less - possibly due to resuspension of solids (Note: Still comparing measured chemical quality to WQS).

The storm event criteria recommended by EPA were not practical in Atlanta. Atlanta has short intense thunderstorms; can meet volume criteria, but not duration.

Questions/Comments

Question: Why the State designation of storm drains as waters of the state?
Answer: This is just the way it is defined in Georgia state law.

Question: Why are organics so ubiquitous?
Answer: We think it may be from plastic hoses. Chemists also say it is commonly found in laboratories; so possibly laboratory contamination.

Question: Why weren't any of the detention basins sampled?
Answer: They don't do anything for water quality because they are only for peak flow control.

NPDES Monitoring - Dallas/FortWorth, Texas Area

Samuel Brush, Marshall Jennings, P. Jonathan Young and Harry McWreath

Values of median and mean constituent concentrations were lower for all constituents than NURP data.

Level 1 priority pollutants monitored: Arsenic Cadmium, Chromium, Copper, Lead, Zinc, Chlordane, Diazinon, FC, FS, TSS.

Recommendations:

- Limit single land use monitoring.
- Locate some monitors on streams.
- Gather some data on undeveloped land for background.
- Limit the number of parameters to be sampled.

Diazinon found mostly on residential areas. Seasonal variations found in Diazinon, dissolved phosphorus, N, FC concentrations.

5-year objectives:

- Develop cost-effective program
- Consider network analysis of current stations
- Add some new stations requested by participating cities

Issues:

- Must all 7 cities start sampling at the same time?
- Can bioassessment substitute for some of the sampling?
- Can regional approach satisfy EPA's desire for equity among cities?
- Can monitoring results be used to measure effectiveness of management programs?
- How much sampling is enough?
- Are in-stream effects being adequately addressed?

Questions/Comments

Comment: Dallas (NCTCOG) has very good BMP manuals available for residential, industrial, commercial areas. These are available from Alan Plummer and Associates (see address for P. Jonathan Young in Proceedings).

Comment: Some WWTPs have problems with pesticides affecting the treatment process - their experience was that high pesticide concentrations were related to background concentrations, and not just to runoff loads.

Question: What is total cost of monitoring program?
Answer: Including USGS contribution ($1.9 million) the total is about $2.9 million.

Stormwater NPDES Monitoring in Santa Clara Valley

Terry Cooke, David Drury, Revital Katznelson, Chow Lee, Peter Mangarella and Keith Whitman

Santa Clara county is semi-arid - total rainfall about 14 in/yr)

Theme - you have to make monitoring work for you; must be mission driven as opposed to task driven.

Toxicity has been added to the monitoring program.

Telecommunications has made a big difference in the measured values of parameters; we cannot compare pre-telecommunication data with post-telecommunications data , because pre-telecommunications we were not able to get to the stations soon enough to set up sample bottles, etc.. Cannot lump data together for analysis because results are from two different data sets.

<u>Land use</u>

- Lead shows land use variability - found in transportation and heavy industry sectors when compared with background.
- Zinc high in heavy industry, but same in other land uses.
- Copper constant at 30 micrograms/l for all land uses except heavy industry (higher) and open areas (lower). Thus, conclude that the effect of land use on water quality is statistically significant only when data are pooled into gross categories.

Defined enrichment ratios as the relative concentrations in streambed locations versus upland soils. From this analysis, determined that the source of copper can be both urban runoff and soils, whereas lead, cadmium, and zinc are found only in urban runoff.

Correlations - can get good correlation of TSS and copper grab samples to flow (Editor's note: One would expect this because TSS is a function of velocity and the copper is attached to flow).

When looking at acute toxicity, only dissolved fractions are available and they are

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almost never out of compliance.

Trend analysis is not possible using water quality data because of high variability - because high scatter in data requires large number of samples. May be able to do trend analysis in streambank sediments or bioassays.

Recommendations

- Focus on protection of beneficial uses.
- Initiate integrated watershed management approach e.g. it is more cost effective to control copper in runoff than at the WWTP.
- Shift from a task-driven to a mission-driven approach.
- Vehicles are key sources of stormwater pollution.
- A national strategy is needed to address transportation sources (approximately 50% of the copper in Bay area is from brake pads).
- Need different perspectives for streams in the Bay area vs the Bay.
- Use a multi-media approach (runoff, sediments, fish) in defining the monitoring program.

In the future they will:

- Emphasize source identification and targeted monitoring.
- Public participation is really needed and useful - streamkeepers program.
- Develop multi-media watershed-based monitoring strategy.
- Emphasize missions, goals and priorities.
- Use an integrated watershed management approach.
- Use targeted strategies and actions.
- Increase regional and state coordination and collaboration.

Questions/Comments

Question: Is some copper in streams due to copper treatment in upstream reservoirs?
Answer: Yes - probably as copper sulfate applied to the lake as an algicide.

Question: Were dry-weather flows a problem?
Answer: No, they were not a problem, and amounted to only about 1-2% of annual flows.

Panel Discussion

Question: Is the USGS maintaining a centralized data base for all their data?
Answer: Yes.

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Question: Can you say that enrichment is primarily due to channel erosion?
Answer: No - we believe that enrichment is due to urban runoff.

Question: What is the accuracy of the samplers you used?
Answer: About + or - 10%.

Question: Were any samples in the Atlanta study taken both above and below the weir to see if intake location made any difference?
Answer: The USGS did not do this, but the SWFWMD found in their work no difference except in DO and things like that.

Comment: Roesner (supported by Urbonas) thought that correlations of pollutants with flow are probably more related to the sediment (and their relationship to flow and attached pollutants).

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Biological and Chemical Testing in Storm Water

William T. Waller[1], Miguel F. Acevedo[1], Eric L. Morgan[2], Kenneth L. Dickson[1], James H. Kennedy[1], Larry P. Ammann[3], H. Joel Allen[1], and Paul R. Keating[1]

Abstract

Watershed management has long been a goal of individuals interested in quality aquatic ecosystems. The implementation of the National Pollutant Discharge Elimination System has gone a long way toward providing the tools necessary to manage point source discharges from waste water treatment plants. Managing episodic toxicity events associated with storm water events has always been problematic. Understanding and controlling episodic toxicity is necessary if watershed management leading to quality aquatic ecosystems is to be realized. This paper provides some examples of the importance of biological and chemical testing in storm water management and provides a developing approach to help achieve management objectives.

Introduction

The 1972 amendments to the Federal Water Pollution Control Act, referred to as the Clean Water Act (CWA), prohibited the discharge of any pollutant to navigable waters from point sources unless the discharge was authorized by a National Pollutant Discharge Elimination System (NPDES) permit. The principal focus of the NPDES program has traditionally been to reduce pollutants in discharges of waste water treatment plants. This program emphasis developed because many industrial and municipal sources were not controlled or poorly controlled at that time and were easily identified as contributing to water quality impairment. Nonetheless, within the framework of the law, channelled storm water was classified as a point source. The passage of the CWA led to a long and intense debate over storm water regulations.

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[3]University of Texas at Dallas, Richardson, Texas

The Water Quality Act of 1987 added section 402(p) to the Clean Water Act (CWA). Section 5402(p) requires the Environmental Protection Agency (EPA) to establish phased and tiered requirements for storm water discharges under the NPDES program (Federal Register, 1992).

The application for NPDES permits for storm water discharges consists of two parts. Part 1 of the permit application includes a description of legal authority to address separate storm sewer systems; an inventory of outfalls and details about drainage areas; a field screening program to detect illicit discharges; a plan for a representative sampling program to be implemented in Part 2 of the application; and a description of existing storm water controls. Part 2 of the storm water permit application includes a list of industrial dischargers to the municipal separate storm sewer system; quantitative data from the representative sampling program developed in Part 1; and a storm water management plan to be implemented during the term of the permit. An assessment of the effectiveness of the storm water management plan and a fiscal analysis of necessary capital and operations and maintenance expenditures are also included in Part 2 (Oakley and Forrest, 1991).

As part of the response to the Part 2, NPDES storm water permit application requirements, seven major cities in the Dallas-Fort Worth (DFW) metroplex participated in a comprehensive storm water sampling program. Thirty sampling sites representing different land uses (residential, commercial, industrial, and highway) were sampled for seven storm events. Approximately 185 parameters including nutrients, metals, pesticides and organics were analyzed.

Results of the local storm water sampling program are being compared with historical findings of the Nationwide Urban Runoff Program (NURP), as well as historical local data (EPA, 1983). NURP was a five-year program during the period 1978-1983. NURP collected data for ten constituents at 81 sites in 22 cities for over 2300 storm events at acceptable "loading sites" where no devices modifying runoff were upstream. Runoff was characterized by land use and for all urban sites combined. NURP values included biochemical oxygen demand (BOD), chemical oxygen demand (COD), total Kjeldahl nitrogen, nitrite+nitrate, total phosphorus, total suspended solids (TSS), total copper, total lead, and total zinc. In addition to these "standard pollutants", special priority pollutant and metals studies were conducted at many of the sites.

One use of the data collected from the recent Phase 2 sampling program carried out in the Dallas-Fort Worth metroplex is to determine the local event mean concentration (EMC) values for the calculation of the pollutant loads from local watersheds. An EMC value is defined as the flow-weighted mean pollutant concentration for a given or typical storm event. Choosing the correct local EMC value could result in different pollutant loadings than those predicted by the national average NURP EMC values. The regional program is being coordinated by the

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North Central Texas Council of Governments (NCTCOG) (Young, *et al.*, 1993) and has as its objectives:

1) **Satisfy the U.S. EPA requirements for Part 2 NPDES storm water permit applications.**

2) **Determine the constituent loads from representative watersheds in the area.**

3) **Characterize the land use impacts on water quality.**

4) **Provide basic information to develop management alternatives for permit compliance.**

Toxicity

Much of the data collected in storm water sampling programs have focused on chemical constituents and loadings because of the emphasis on the reduction of loadings characteristic of most Best Management Practice (BMP) goals, and concerns over the realism of traditional toxicity tests when used to measure episodic toxicity. Nonetheless, concerns exist about the toxicity of storm water, and toxicity tests are the only adequate method of characterization. Poor correlations between conventional contaminant measures and toxicity indicate that toxicity should be measured directly to assess the biological impacts of storm water runoff instead of inferring toxicity from chemical measurements. With chemical specific measurements you only find what you are looking for; what you do find is not always biologically available; the toxicity of all the chemicals that can be measured is not always known; and our understanding of the interaction of toxicants (synergism, antagonism, and/or addition) is poor at best. The need for the use of toxicity tests to determine toxicity has been stated best by Cairns and Mount (1990);

> "No instrument has yet been devised that can measure toxicity! Chemical concentrations can be measured with an instrument but only living material can be used to measure toxicity."

As a supplement to their participation in the Phase 2 storm water study, the City of Fort Worth, Texas applied for and received a 104(b)(3) grant from EPA to test the practical use of biotoxicity tests as screening tools in storm water programs. The City of Fort Worth contracted with the Aquatic Toxicology Laboratory of the University of North Texas (UNT) to perform acute toxicity tests on selected storm water samples collected in the Phase 2 storm water program. Acute toxicity tests using *Ceriodaphnia dubia* and *Pimephales promelas* were performed on these samples according to EPA methods (EPA, 1991a). City of Fort Worth personnel performed Microtox™, test methods on some of the same samples. In addition, UNT tested selected samples for chronic toxicity and some acutely toxic samples were

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characterized using Phase I, Toxicity Identification Evaluation methodologies (EPA, 1991b).

Acute toxicity tests were performed on thirty-one storm water samples collected from eighteen storm events. Sixteen stations representing industrial, commercial, residential, and mixed landuses were included in the analysis. Of the thirty-one acute toxicity tests performed on storm water samples from the Phase 2 study there was no significant mortality to *P. promelas* in any of the tests. In 12 of the thirty-one tests the no observable effects level (NOEL) for *C. dubia* was 50% or less. There were 23 tests for which both *C. dubia* and Microtox™ tests were performed. In eight of these tests *C. dubia* showed toxicity when Microtox™ did not, while there were three tests for which a 15 minute EC50 could be calculated for Microtox™ for which there was no measurable *C. dubia* response. In 16 tests neither *C. dubia*, Microtox™, or *P. promelas* showed a significant acute response. In one test both *C. dubia* and Microtox™ showed a significant response. These results suggest that *C. dubia* was the most sensitive indicator of toxicity tested, although strictly speaking comparing Microtox™ EC50's with *C. dubia* NOELs is not a good comparison. A better comparison would have been a comparison between percent light loss for Microtox™ and NOELs for *C. dubia*. Not unexpectedly, the finding that *C. dubia* is more sensitive to a broad range of toxicants is consistent with our findings for effluent tests and ambient toxicity tests.

The data from the Phase 2 study that will be focused on in this analysis involves two different but important toxicants, diazinon and zinc. The chemical specific data from all the samples collected during the Phase 2 study are not as yet available. The results for the chemical specific summaries reported in this paper are based on data from 15 stations represented by eight residential sites, seven industrial sites and four commercial sites. The data are not as yet considered final and are subject to revision. We will focus on diazinon and zinc because they were common to most of the samples collected in the Phase 2 study regardless of land use and they were identified through Phase I, Toxicity Identification Evaluation (TIE) procedures as being the likely causative agents responsible for acute toxicity to *C. dubia*, in some of the samples. Fifty-seven percent of the parameters analyzed for, and reported in the Storm Water Discharge Characterization Final Summary Report--Task 2.0 (NCTCOG, 1993) were not found at the analytical detection limits employed in the Phase 2 study.

Toxicity Reduction Evaluations (TRE), of which Phase I, Toxicity Identification Evaluation (TIE) methods are an integral part, are an important part of the Water Quality Based approach to toxics control (EPA, 1984). Facilities which fail the toxicity portion of their NPDES permits are required to determine the causes of toxicity and develop methods to remove the toxicity. Phase I of the TIE procedures involves the physical and chemical manipulation of a toxic sample. The toxic sample is fractionated by seven manipulations; pH adjustment, filtration, aeration, C_{18} solid phase extraction, oxidation reduction, EDTA chelation and graduated pH. The

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filtration, aeration, and C_{18} solid phase extraction steps are all performed on the sample at its initial pH and after the pH has been raised to pH 11 and reduced to pH 3. After the sample is fractionated, each fraction is returned to the initial pH, if necessary, and tested for toxicity. Those fractions which remove and/or reduce toxicity are further tested to determine causative toxicants. The process of fractionation and toxicity testing focuses the search for the toxic components by reducing the number and types of chemicals one has to deal with by only concentrating on those fractions which reduce or remove toxicity. Phase II and III of the TIE procedures involve verifying the causes of toxicity.

Diazinon

Diazinon is an important toxicant in the southern part of the United States. Many municipal wastewater treatment plants in the southern part of the country are failing their NPDES permit requirements for toxicity and frequently the indicated toxicant is diazinon. Diazinon is a very popular broad spectrum pesticide and is used extensively in residential settings. Table 1 shows there is a widespread occurrence of diazinon in storm water samples regardless of the landuse from which the samples were collected. The percentage of events and concentrations of diazinon were highest from residential sites and the median concentration in these samples was greater than the 48-hour LC50 for *C. dubia*.

Landuse	Percentage of Sites with Diazinon	Percentage of Events with Diazinon	Median Concentration of Diazinon μg/L
Residential	100	97	0.55
Commercial	100	85	0.20
Industrial	83	39	0.00

Table 1. The relationship between diazinon and its occurrence in samples collected during the Phase 2 study from residential, commercial and industrial sites in the Dallas and Fort Worth metroplex.

Diazinon is also extremely toxic to aquatic organisms. The 48-hour LC50 of diazinon to *C. dubia* is 0.350 μg/L (Norberg-King, *et al.*, 1989). Arthur, *et al.* (1983) recommended that diazinon in aquatic environments not exceed 0.080 μg/L. The 48-hour LC50 for the midge *Chironomus tentans* has been reported as 0.100 μg/L and development of the larvae of this midge have been inhibited by continuous exposure (80 days) to concentrations as low as 0.0006 μg/L (Morgan, 1976). Diazinon is sold in a variety of formulations by numerous companies. One liquid formulation of diazinon sold in quart containers contains 25% diazinon by weight. It would take 247 football field size containers, exclusive of the endzones, three

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yards deep to dilute the amount of diazinon in a quart container of 25 Diazinon to the 0.080 μg/L concentration recommended by Arthur, *et al.* (1983).

Figure 1 shows the distribution of diazinon concentrations from the 31 samples from residential sites for which diazinon concentrations were available. While the concentrations found in different rainfall events were highly variable, twenty of the values reported were in excess of the 0.350 μg/L LC50 values for *C. dubia*.

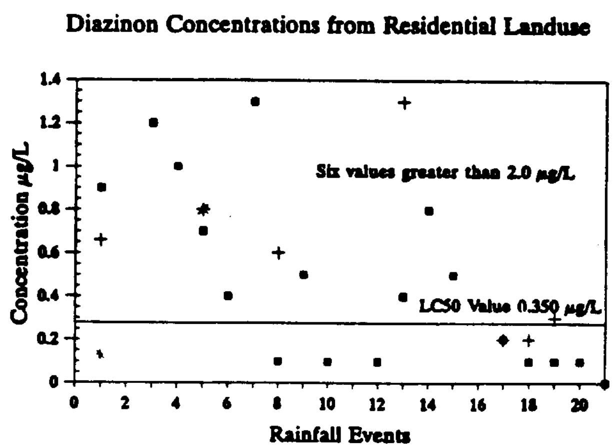

Figure 1. Diazinon concentrations from residential landuse and their relationship to the acute toxicity of diazinon to *Ceriodaphnia dubia*. Different symbols associated with the same rainfall event represent different sites.

The second most frequently measured pesticide was total chlordane which was found at seven sites, five residential and two commercial. A recent California Regional Water Quality Control Board memorandum (March 17, 1994) reported diazinon concentrations found in storm water samples collected in Stockton, California from residential and mixed landuse. Two rainfall events were monitored at thirteen sites.

The diazinon concentrations measured in these samples ranged from 0.160 to 1,050 µg/L. Eleven of the 13 sites had diazinon concentrations greater than the acute LC50 value for *C. dubia* (0.350 µg/L) and 100% *C. dubia* mortality was observed at most of the sites which were sampled.

Clearly, as far as pesticides are concerned, diazinon is a widespread toxicant in storm water runoff and is especially prevalent in samples from residential landuses. Two of the toxicity identification evaluations which were performed on acutely toxic samples from residential sites showed that non-polar organic chemicals were the likely causes of the toxicity and while it was not established without doubt that diazinon was the causative toxicant, all the available information points in that direction.

__Zinc__

Zinc is ubiquitous in its distribution, but was not included in this analysis for that reason. Rather, zinc was included because it helps define the role of toxicity testing in evaluating the impact of storm water events and because zinc is a significant toxicant in aquatic systems. One of the uses of the data collected in the Phase 2 study is to calculate EMC concentrations and to compare these with those observed in the NURP studies as well as other local studies. Therefore, it is important that all data which are collected and represent real values be included in the calculation of the EMC concentrations. The percentage of sites, events and the median concentration of zinc collected during the study showed, as one would expect, that zinc was found at all stations during every event (Table 2).

Landuse	Percentage of Sites with Zinc	Percentage of Events with Zinc	Median Concentration µg/L
Residential	100	100	65
Commercial	100	100	130
Industrial	100	100	110

Table 2. The distribution and median concentration of zinc amongst the landuses studied.

The landuse with the highest median zinc concentration was commercial (130 µg/L) followed by industrial (110 µg/L) and residential (65 µg/L). Thirty-six percent of the samples collected in the study contained zinc concentrations greater than the acute water quality criterion of 112 µg/L calculated based on an average water hardness of 28 mg/L as $CaCO_3$ (Figure 2). The concentrations reported for the same rainfall event were, as was true for diazinon values, highly variable.

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Zinc Concentrations in Storm Water

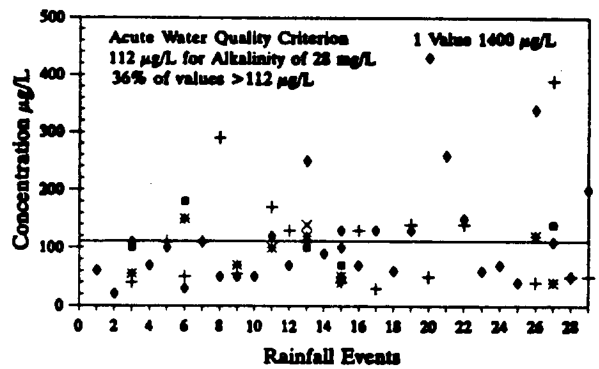

Figure 2. Zinc concentrations from storm water runoff and their relationship to the toxicity of zinc to *Ceriodaphnia dubia*. Symbols from the same rainfall event represent different sites.

In the Storm Water Discharge Characterization Final Summary Report--Task 2.0 (NCTCOG, 1993) from the Phase 2 study, the zinc concentration collected from one of the industrial sites was reported as 1,400 µg/L. In the report, this value was marked as an outlier which was defined as a data value which is obviously out of the expected range of the parameter being evaluated. In addition, in the initial analysis of the data collected in the study the following rule was applied to evaluate outliers. If the value of a parameter falls more than three standard deviations away from the average for that parameter, the value is scrutinized more closely and replaced with a blank if no other measured values are close. Subsequent to the sample for which the 1,400 µg/L zinc value was reported as an outlier another sample was collected from the same industrial site but in this case, acute toxicity tests were performed on the sample. The sample was determined to be acutely toxic to *C. dubia* with an NOEL of <50%. This was the single sample mentioned previously for which both a significant *C. dubia* response and a significant 15 minute EC50 for Microtox™ was calculated. A Phase 1, TIE was performed on the sample. The EDTA chelation

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fractionation step was the only fraction which removed toxicity. Further independent analysis of the sample showed that the concentration of both zinc and copper were present at acutely toxic levels and lead was present at chronically toxic levels. The zinc concentration was 1,720 μg/L while the copper concentration was 54 μg/L. An examination by City of Fort Worth personnel revealed the presence of a galvanizing company in the area drained by the outfall. Working with the galvanizer the City should be able to remove the toxicity associated with the facility. As mentioned earlier the analysis presented in this paper is based on data included in the Storm Water Discharge Characterization Final Summary Report--Task 2.0. As stated in the report these data are subject to revision. In the final analysis all data, including the outliers, collected during the Phase 2 study were used to calculate event mean concentrations (Young, 1994, personal communication).

These examples show the usefulness of the toxicity and TIE methods in sorting through toxicity. However, the toxicity methods which were employed in this study are not without weaknesses when applied to the analysis of episodic toxicity events. Foremost amongst these weaknesses are concerns about how well, if at all, these methods mimic exposure of aquatic organisms during episodic events. Collins, *et al.* (1992) state that exposure is a function of several factors including discharge volume, duration, frequency and mixing; receiving stream flow; and pollutant concentration. In 1982, EPA recognized that water quality criteria based on continuous exposure of organisms to constant concentrations of toxicants were probably overprotective when applied to episodic storm water samples. EPA (1982) published a procedure to adjust water quality criteria for exposures which were more in line with those observed in storm water runoff events. The Virginia Pollutant Discharge Elimination System permits for storm water discharges contains a toxic management program which integrates acute toxicity testing, chemical specific monitoring and a toxicity reduction evaluation component. Virginia's toxic management plan uses EPA recommended acute toxicity test methods for *C. dubia*, *Daphnia pulex*, and *P. promelas* but recognizes that exposure is a problem with this methodology (Collins, *et al.*, 1992). If traditional toxicity methods do not mimic episodic toxicity exposure, what methods might be used to evaluate episodic toxicity?

Monitoring Episodic Events

Aquatic animals have been shown to induce bioelectric signals into surrounding water which can be recorded as rhythmic analog signals representative of specific movement activities (e.g., gill beats, heart rates, etc.). In addition, gape measurements (the degree to which a bivalve is open or closed) have been successfully used with clams and mussels as a means to determine the status of this organism. Utilizing appropriate statistical techniques and accompanying electronics, changes in bioelectric action responses and gape can be detected, processed, and continuously recorded, and have been used in detecting water quality induced stress in aquatic organisms.

The concept of using bioelectric action potentials to monitor the well being of aquatic organisms is not new. In the early 1970's Cairns, *et al.* (1970, 1972, and 1975) proposed a biological monitoring system for watershed drainage that would provide an early warning of water pollution. In addition to stream surveys, Cairns and his co-workers described a unique system for automatically recording fish breathing and swimming activities in response to developing toxicity in effluents and ambient receiving waters. Since the early 1970's numerous attempts have been made to use remotely sensed bioelectric action potentials to detect adverse conditions (Morgan, *et al.*, 1981, 1986, 1987a, 1987b, 1988a, 1988b, 1989). Morgan, *et al.* (1986) have used signals generated by individually monitored trout to asses environmental conditions. The signals from the trout were accumulated for a 15-minute interval each half-hour. The data were held in memory of a data collection platform and transmitted to the National Oceanographic and Atmospheric Administration, Geostationary Operational Satellite System on six occasions each day. Broadcast data received by satellite were transmitted to a direct-readout ground station at the Tennessee Valley Authority. Ham and Peterson (1994) have evaluated the effect of low level chlorine concentrations on the valve movement of the Asiatic clam (*Corbicula fluminea).*

Europeans have also been involved in the use of remotely sensed bioelectric action potentials as a means of detecting adverse environmental conditions for aquatic organisms (Caspers, 1988; Matthias and Puzicha, 1990; Slooff, *et al.*, 1983). Specific biomonitors evaluated include the rheotaxis of fish (Juhnke and Besch, 1971) the respiration of rainbow trout (Slooff, 1979) and the electric field alteration of the tropical fish *Gnathonemus petersi* among others (Geller, 1984). A more recent European study used the mussel *Dreissena polymorpha* as a biological monitor (Borcherding, 1992).

Managing aquatic ecosystems at the watershed/drainage basin level has long been an objective of environmental managers. Watershed management by its very nature dictates that loadings to an aquatic ecosystem and their sources be understood. The storm water studies which have been and are being undertaken as part of the NPDES permitting process are making significant contributions to our understanding of loading. It is equally important that the impact of these loadings on the system be understood. The rapid evolution of computers, communications links, geographical information systems, remote sensing, and the information highway have, or will contribute toward advancing the tools necessary to achieve this objective.

The biomonitoring system we are developing and testing uses clam gape to continuously monitor, in near real time, the status of clams (*Corbicula fluminea*) at remote sites. Physically, the non-invasive system uses industrial proximity sensors aimed at foil targets located on the clams to record the gape of the animals (Figure 3). The prototype systems we have built, and are testing, monitor the gape of ten clams simultaneously.

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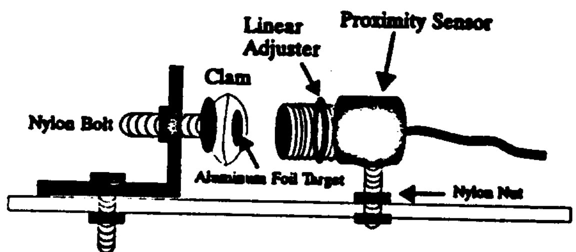


Figure 3. Clam biosensor schematic.

Conceptually (Figure 4) the biosensor system we are developing and testing includes the following components and is part of an overall strategy to manage watersheds:

1. The biomonitoring system consists of the continuous monitoring of clam gape at each site within the drainage basin being monitored.

2. A means to telemeter the data collected on the status of the clams back to a central receiving station.

3. An alarm system which is activated by the behavior of the clams. When the behavior of the clams is determined by a resident computer program to be out of range of normal a series of water samplers will be notified to begin taking samples and an event signal will be sent to the receiving station notifying the operator of an event.

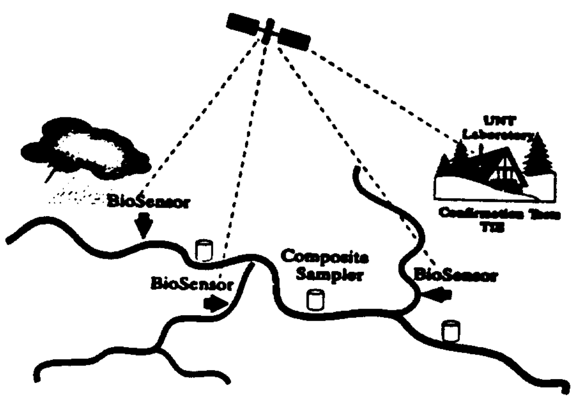


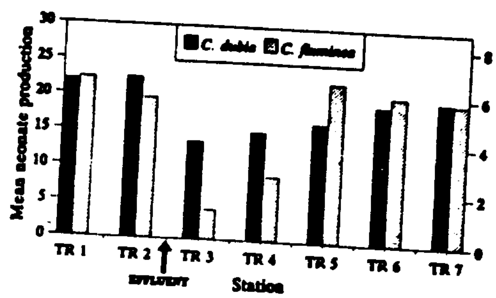
Figure 4. Diagram of the use of biosensors for watershed management.

4. The samples are retrieved from the samplers and toxicity is verified using *C. dubia* as the test organism. If the samples are verified as toxic a Phase I, TIE procedure is initiated using *C. dubia* as the test organism. The data from the complete TIE process should be sufficient to identify the causative toxicants. Based on information from the TIE the likely sources of toxicity can be identified and management actions can be undertaken.

Clearly for this monitoring system, or one with similar components, to be effective several important operational conditions must be established. The most important condition is the reliability of the monitor. One consistent problem we have encountered with the monitors we have used in the past is that the volume of information and the complexity of the bioelectric signals being monitored (fish EKG's, breathing, etc.) have been so great as to be nearly overwhelming. This does not mean they have not functioned well for the purposes they were intended, only that it would be advantageous to simplify the signals for this application.

The signals we are monitoring from the clams are greatly simplified. However, we must still establish the frequency of false positives and false negatives before the system can be considered useful. We are in the process of doing this now.

Comparison of *Ceriodaphnia dubia* & *Corbicula fluminea* Dechlorination



Sample period 11/90 to 9/92
C. dubia n=17 monthly grab samples; C. fluminea n=4, in situ 28 day exposure

Figure 5. Relationship between *C. dubia* productivity and *C. fluminea* growth.

The monitoring system must be sensitive to the presence of toxicants but not so sensitive as to falsely indicate damage to the system one is trying to protect. We have been using *C. fluminea* as an *in situ* biomonitor for some time (Figure 5). In this application caged young *C. fluminea* for which initial length and weight measurements had been taken were incubated *in situ* in the system to be monitored. After an incubation time of approximately a month the cages were retrieved and length and weight determinations were made. The relationship between the growth of *C. fluminea* and the productivity of *C. dubia* collected from the Trinity River in the DFW metroplex above and below a municipal WWTP. *C. dubia* productivity is based on grab samples collected from the Trinity River at the same sites the *C.*

fluminea were incubated. In this example the exposure of the organisms were different, but the responses were similar. The suspected toxicant causing depressed *C. dubia* productivity and the reduced *C. fluminea* growth was diazinon.

These data support the use of *C. fluminea* as a reasonably sensitive organism. Additional data collected during this and related studies suggest that the Trinity River was impacted beyond that observed for *C. dubia* and *C. fluminea*. The responses of *C. dubia* have been shown to be predictive of in-stream impact (Dickson, *et al.*, 1992).

The data on clam behavior can be telemetered back to a central receiving station from remote sites. We have done this in the past by collecting and transmitting fish breathing rates to an over-passing N.O.A.A. GOES satellite and then to ground stations. We envision coupling the biological monitors with a network of continuous monitoring gauging stations which record stage height, flow, and selected physical chemical factors which already exist (USGS, ORSANCO, TVA, etc.). While the system we are evaluating does not prevent toxicity from occurring it should distinguish between toxic events and non-toxic events thereby reducing the time and effort spent on non-toxic events (35% of the samples tested for toxicity by UNT for the City of Fort Worth in this study showed no toxicity to any of the test organisms used). Since the organisms are continuously exposed *in situ* the exposure regimes should be more realistic than those based on traditional toxicity methods. The exception to this will be the exposure for those organisms that might be entrained and move with the storm water as it travels down the receiving system. Coupling the biomonitors with TIE methodologies should permit the identification of causative toxics and provide the basis for reductions in those toxics. These methods plus the advances in remote sensing, GIS, computer technology, the information highway, file transfer protocol (FTP) sites and the internet should provide the technical basis for managing watersheds.

Acknowledgements

We wish to thank the City of Fort Worth, Mr. Gene Rattan and Mr. Brian Boerner; and the Texas Water Resources Institute, Dr. Wayne Jordan for their support with these projects.

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Methods and Procedures in Stormwater Data Collection

Thomas Brown, William Burd, James Lewis,
and George Chang, P. E.[1]

Abstract

This paper presents methods and procedures developed to ensure the quality of stormwater monitoring data produced by the City of Austin, Texas, Stormwater Monitoring Program. Since 1975, the City has monitored stormwater runoff to produce data used in many studies, to develop structural-control design criteria, and to develop watershed ordinances. These ordinances have minimized the impact of urban development on water quality and resulted in effluent limitations. Given this high visibility, the City has developed stormwater monitoring techniques and experimental designs to improve the processes of flow measurement, sample collection, data management, and data analysis.

Monitoring Program Goals and Objectives

The goal of the City of Austin's (COA's) Stormwater Monitoring Program (SWMP) is the collection and analysis of water quality data to guide the development of watershed ordinances, manage the City's waterways, and fulfill federal requirements. Stormwater monitoring has been used to comply with U.S. Environmental Protection Agency (EPA) National Pollutant Discharge Elimination System (NPDES) permit application requirements, review and improve the City's watershed ordinances, and evaluate the pollutant removal efficiencies of structural and non-structural Best Management Practices (BMPs). The SWMP has monitored runoff from a spectrum of land uses ranging from pristine, undeveloped watersheds in the Hill Country west of Austin, Texas, to highly-developed urban watersheds in the City's core.

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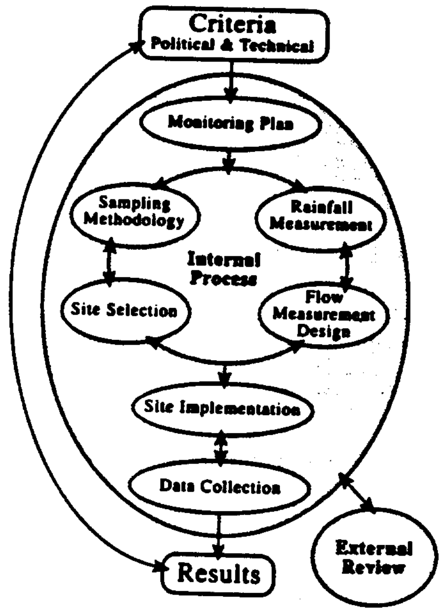

Figure 1. Stormwater Monitoring Process

Stormwater Monitoring as a Process

Stormwater monitoring can be considered as an expanded quality assurance and quality control (QA/QC) process (Figure 1). As in all integrated systems, errors occurring anywhere in the stormwater monitoring process tend to be translated into other components of the process--ultimately affecting the integrity of data. Therefore, careful planning at all stages of the stormwater monitoring process is the key element in the production of quality data (City of Austin, 1993a; City of Austin, 1993b).

a) Monitoring Plan

The monitoring plan defines the quantity and quality of data to be collected, the water quality parameters to be measured, the land use types and BMPs to be monitored, and the cost of data to be collected. The plan also specifies the type of monitoring equipment and software to be installed. The SWMP uses remote-controlled, automatic samplers that are operated from a central office (Figure 2).

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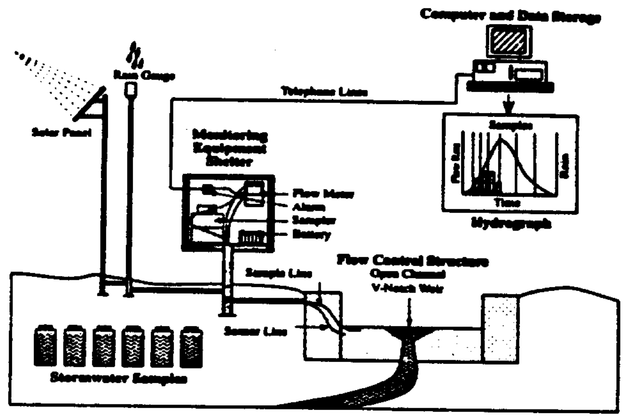

Figure 2. Remote-Controlled Stormwater Monitoring System

The number of storm events to be monitored at each site is determined mainly from the amount of rainfall and the number of dry days before storms. When the frequency distribution of storm sizes (Figure 3) is grouped according to storm-size class, the total average annual rainfall depths contributed by each storm-size class are roughly equal (Figure 4). According to previous data (City of Austin, 1990), the event mean concentrations (EMCs) for all types of watersheds vary by storm size and the number of dry days between storms. In Austin, a range of 18 to 24 storm events should be collected at each monitoring station (Soeur, et al., 1994). The range of storm events to be sampled has been determined by experimental design factoring three or four storm-size classes with two antecedent dry day classes (Figure 5). In order to conduct statistical comparisons, there must be at least three storm events collected for each combination in the experimental design matrix.

The SWMP analyzes 15 standard non-point source water quality parameters representing five categories of pollutants, including total suspended solids (TSS), oxygen-consuming constituents, nutrients, metals, and bacterial constituents. These parameters are commonly used in other studies to characterize point and non-point source pollutants (Environmental Protection Agency, 1983).

b) Rainfall Measurement

Rainfall data are used to relate rainfall amounts to the runoff volumes recorded at a monitoring site. All stormwater monitoring stations use tipping-

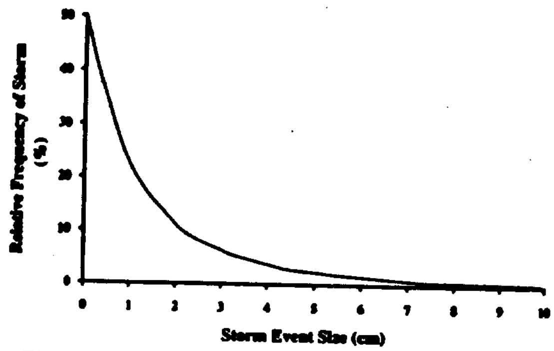

Figure 3. Relative Frequency of Strom Events Versus Storm Event Size Austin, Texas, 1950 to 1992

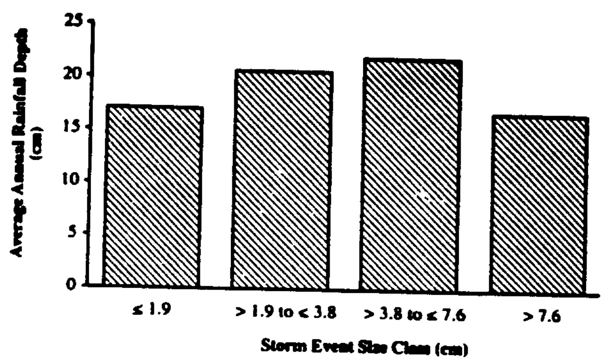

Figure 4. Average Annual Rainfall Depth per Storm Event Size Class Austin, Texas, 1950 to 1992

	Storm Event Size Class (cm)				
Dry Days before Storm Event	≤ 1.9	> 1.9 to ≤ 3.8	> 3.8 to ≤ 7.6	> 7.6	TOTAL
< 4	3 storms	3 storms	3 storms	3 storms	12 storms
≥ 4	3 storms	3 storms	3 storms	3 storms	12 storms
TOTAL	6 storms	6 storms	6 storms	6 storms	24 storms

Figure 5. Recommended Number of Storms to Monitor by Class

bucket rain gauges, which automatically record both rainfall amounts and rainfall intensities. The SWMP also uses rainfall data collected by the COA's Flood Early Warning System (FEWS) automatic rain gauges to supplement and verify the SWMP rainfall data. The high density of FEWS rain gauges (52 stations in Austin) is especially important during the summer months when highly-localized, tropical thunderstorms are common. Variation in rainfall within large watersheds is common during storm events.

c) Sampling Methodology

The SWMP uses the three standard sampling methods. Grab samples, when chemically analyzed, indicate water quality at a single moment in a hydrograph and are mandatory when manual or sterile sampling techniques are required. Flow-weighted composite samples are composed of a number of equal-volume aliquots collected at equal intervals of runoff volume throughout the hydrograph (Greenberg et al., 1992). When flow-weighted composite samples are chemically analyzed, the data directly yield an EMC for each water quality parameter. Discrete samples are sets of samples taken in some systematic manner throughout the hydrograph. Discrete samples show changes in pollutant concentrations throughout the hydrograph, but can be mathematically combined to yield an EMC for each water quality parameter (City of Austin, 1983).

During runoff events, different watershed types have varying pollutograph characteristics. For example, in small watersheds (< 162 hectares, 400 acres) with medium to high impervious cover, the concentrations of TSS, total phosphorus (TP), total Kjeldahl nitrogen (TKN), and total organic carbon (TOC) are greatest during the first flush of runoff, and then decrease over time (Figure 6)(Soeur, et al., 1994).

In contrast, in large watersheds (> 162 hectares, 400 acres) with a high degree of channel erosion, the concentrations of TSS, TP, TKN, and TOC correlate with flow rate and are greatest at the peak of the hydrograph (Figure 7)(Soeur, et al., 1994). In Austin, this example corresponds to larger urban creeks draining mixed land uses.

A refined method for discrete sampling collects samples more frequently when pollutant concentrations are changing most rapidly. In a small watershed, sampling events should occur during the rising stage of the hydrograph while retaining sample coverage of the tail on the falling stage of the hydrograph. In a large watershed, sampling coverage should be concentrated around the peak of the hydrograph while retaining coverage on the tails of the hydrograph. During flow-weighted composite sampling, EMC's in a small watershed are best represented if many aliquots of small volume are collected during smaller intervals of runoff volume.

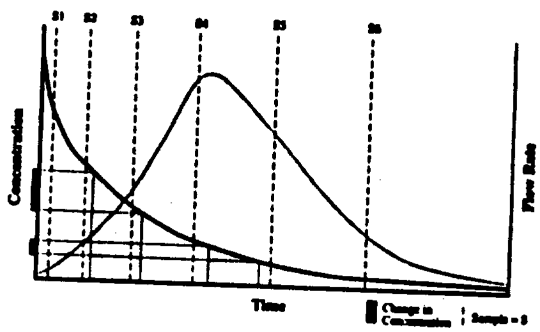

Figure 6. Small Watershed Pollutograph with Hydrograph

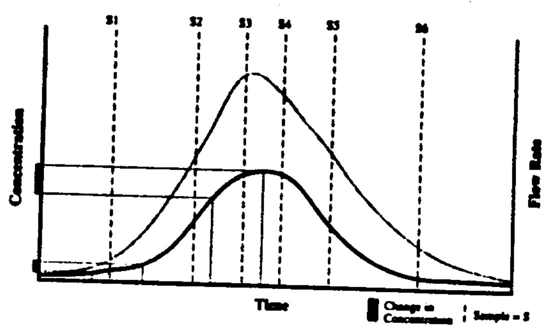

Figure 7. Large Watershed Pollutograph with Hydrograph

Each water quality parameter requires a certain sample volume for analysis (Environmental Protection Agency, 1992). Automatic samplers provide a limited number of sample bottles. The number of water quality samples collected for any monitorable storm event range between three and sixteen samples, depending upon the complexity and size of the hydrograph. To accommodate the need for more sample coverage of both the hydrograph and sample volume for the analysis of 15 water quality parameters, two automatic samplers can be used at each site.

Automatic sampling has certain inherent advantages and drawbacks. An automatic sampling system can be remotely controlled and programmed, reduce human sampling error, and reduce the danger to field personnel during storm conditions. Automatically-taken samples, however, may not be representative because of holding-time limitations of some parameters and sample contamination by the equipment. True duplicate samples cannot be taken with standard automatic sampling equipment. If the sample water is being transported over a relatively long distance (> 15 m. or 50 ft.) or up a steep gradient (approximately > 4.5 m. or 15 ft.), TSS may settle in the line during transit. Automatic sampling may be inappropriate for the collection of volatile organic compounds (VOCs), which require zero head-space sampling, and fecal coliform and fecal streptococci which, have a short holding time and could be cross-contaminated by the Teflon sample line (Environmental Protection Agency, 1992).

In contrast, manual sampling performed by trained staff does not require expensive equipment, always results in representative samples, allows duplicate QA/QC sampling, adjusts sampling for changing conditions, and provides information on flow conditions from field observations. Manual sampling is limited by safety concerns, the ability of personnel to respond in a timely manner, and the number of sites that can be handled in a given storm event (Environmental Protection Agency, 1992).

d) Site Selection and Watershed Documentation

Monitoring site selection requires much planning to achieve characteristic water quality data for a given land use. Ideally, a watershed should be selected that does not have significant point-source discharge (e.g., toxic waste dump, land fill, problematic industrial source, etc.) and is largely covered by the targeted land use or research objective. The selection of a monitoring site is also influenced by the nature of the channel at the proposed monitoring location. To most accurately characterize flow rate and calibrate the rating curve without a flow control structure, a channel should be straight, have uniform cross-sectional shape, and have a milder slope (e.g., slope < 0.02) over a relatively long stretch. The site must be safe for field personnel and secure for monitoring equipment. Ideally, the monitoring station should be accessible for maintenance and sample collection during storms and high water.

Once a prospective monitoring site has been identified, a watershed analysis and documentation process defines hydrographs (or peak flow versus time) for various types of storm events. This watershed information details drainage areas, impervious cover percentages, land-use types, soil characteristics, slope characteristics, flow patterns, detention features, and a computed runoff coefficient. In general, the channel should have enough capacity so that a two-year storm event can be monitored. The peak and average flow conditions help determine which flow control structure and flow monitoring procedure to use. Watershed documentation provides the quantitative information necessary to run computer simulations, such as Stormwater Management Model (SWMM) (University of Florida, 1988) that create synthetic hydrographs and calculate flow rates.

e) Flow Measurement

Determining flow rate through an open channel is the most difficult aspect of stormwater monitoring. The accurate measurement of stormwater discharges at a monitoring station is vital in calculating the EMC's for various water quality parameters. The SWMP uses four basic methods for determining flow: (1) appropriate flow control structures, such as weirs and flumes; (2) cross section area-velocity measurements to generate a flow-rating curve; (3) application of Manning's equation; or (4) using runoff coefficients to estimate runoff (Environmental Protection Agency, 1992). During storm events, field observations and video supply additional information on flow that might not be predicted by preliminary studies.

The SWMP uses flow control structures, such as weirs and flumes to give accurate flow measurement. Flow rating curves are well-established for both weirs and flumes (Bos, 1978; Grant, 1972), and the appropriate flow control structure can be selected according to its sensitivity to a certain range of flow. Flumes allow water to pass freely, limiting sediment and trash (that can accumulate behind weirs), but flumes also tend to be more expensive and difficult to construct than weirs.

The SWMP uses the area-velocity measurement method in larger channels and creeks where no flow-control structures exist. The COA contracts with the United States Geological Survey to generate flow rating curves in these cases (International Organization of Standards, 1983). The average velocity of flow is measured by a hand-held velocity meter.

The Manning's equation can be applied to pipe and channel flow, but accuracy depends on steady flow, straight channels, even and gentle slope, uniform roughness, and uniform channel shape over a long length of channel (Grant, 1992). Satisfaction of these conditions is rare in storm sewers. In a few cases when other methods are not appropriate, the SWMP calculates flow rates using a two-point measurement system based on the theory of gradually-varied flow (Figure 8)(Dalrymple, 1984; Chow, 1959). When using the two-point method to measure discharge in relatively long, straight channels, discharge can be accurately measured by the elevation change in the water's surface profile over distances greater than 20 m. (66.6 ft.). In shorter, straight channels, flow can be approximately measured using the average depth at two points and using that value in the Manning's Equation to calculate a discharge. This method is subject to errors up to +15% due to both the nature of the approximation used and the unsteady flow conditions of stormwater runoff.

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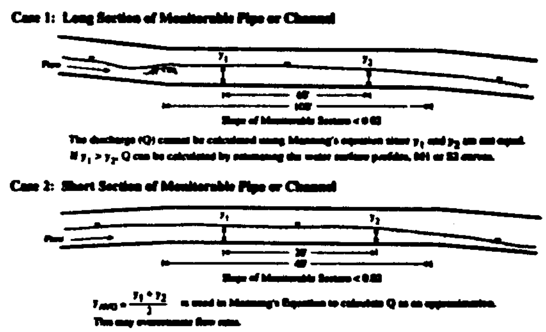

Figure 8. Flow Measurement with Two Points

Runoff coefficients, derived from synthetic hydrographs and the corresponding rainfall data, can be used to estimate flow. This method, used when no other option is available, can also be used as a check against other flow volume calculations.

f) Equipment Testing

The SWMP's flow meters were tested in a hydraulics laboratory flume to investigate equipment performance under a variety of controlled flow conditions. Bubbler, submerged probe, and ultrasonic probe flow meters were tested. Preliminary test results revealed that all flow meters accurately recorded depth at velocities lower than 1.5 m/sec (5 ft/sec). In the 1.5 to 2.1 m/sec (5 to 7 ft/sec) velocity range, 5% errors in depth readings were seen, and in the 2.4 to 3.0 m/sec (8 to 10 ft/sec) range, errors in depth of up to 20% were seen. These systematic errors are most likely produced by flow-induced pressure differentials around the exterior of the submerged sensors. The submerged pressure probes and bubbler lines must be oriented parallel to flow to minimize errors in depth readings at higher velocities. The bubbler sensor orifice must be pointed downstream for best accuracy.

g) Site Implementation

Monitoring site implementation is the culmination of an extensive planning process, which includes a sampling methodology, rainfall and flow measurement techniques, site selection, and watershed documentation. The typical monitoring installation consists of a modular equipment shelter, solar panel, rain gauge, buried conduits for various support systems, flow control structures, a system alarm, batteries, and phone lines or a cellular phone link (for isolated sites). All above-ground structures are modular in design for easy installation and removal, since most monitoring stations have an operational life span of three to five years.

Over the past two years, the SWMP's modular equipment shelters have been redesigned to improve ergonomics and security. The shelters have large interiors so that monitoring equipment is accessible for field operations and site maintenance. A rain guard can be deployed to keep personnel, water quality samples, and monitoring equipment dry when access is necessary during storms.

Modular weir plates have been installed at several monitoring stations and can be inexpensively modified if the actual runoff is found to be different from the calculated runoff values used to size the original weir. Deviations in actual runoff versus calculated runoff may result from watershed mapping errors or from other complex phenomenon in the watershed. For example, a calculated runoff coefficient may not reflect local hydrologic variations caused by a karst terrain. This condition affects all monitoring sites located in the recharge zone of the Edwards Aquifer, which underlies western Austin.

At one location, accurate flow measurement was not possible without channel realignment because the storm sewer channel had a steep slope (slope > 0.043), and was curved. A SWMP field team straightened the pipe's existing alignment, reduced a section of the pipe's slope (reduced slope = 0.004), and installed a rectangular weir near the location of the original outfall (Figure 9).

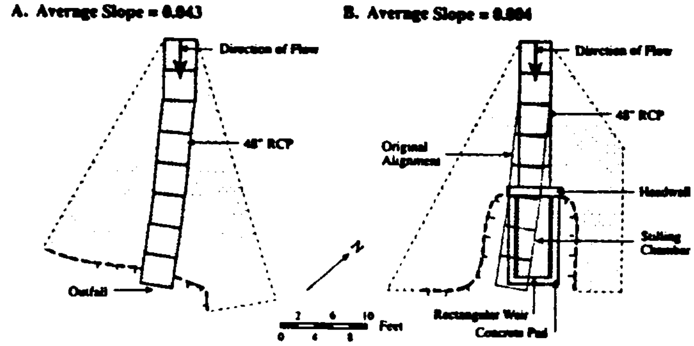

Figure 9. Realignment Plan for a Monitoring Site

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h) Data Collection

Weather conditions are closely watched by SWMP personnel when rain threatens. The local National Oceanic and Atmospheric Administration (NOAA) weather radar (shown continuously on local cable TV) is used to track storm development and movement. With advanced warning the SWMP field personnel cycle the equipment at the monitoring stations through a set of pre-storm preparations. Typical site maintenance includes checking bottle labels, icing sample bottles, checking system voltages, checking communication lines, cleaning rain gauges, and down-loading data stored in flow meters. Monitoring stations are also maintained on a weekly basis to accommodate surprise storms.

Rain and flow data are recorded at one minute intervals by a data logger inside the flow meter. During a remotely controlled operation, the data are transmitted from the flow meters to the office via telephone. The monitoring equipment can collect data independently. The down-loaded data are checked for errors by a computerized scanning program that detects outliers in rainfall data, and manual scanning of graphical flow and sample event data to verify data integrity. This verification process also identifies maintenance problems and double-checks sample-event data before sample bottles are sent to the laboratory.

When rain threatens, the automatic samplers at each monitoring station are programmed. This feature is useful should a storm hit without warning (e.g. in the hours before dawn). Even then, the monitoring staff can still be mobilized after a storm has begun to collect a balanced sample distribution across the hydrograph. A well-balanced sample distribution throughout any hydrograph is as much art as science, since there is no way to accurately anticipate runoff volume once a storm begins. The best way to achieve good sampling distribution at all monitoring stations is to watch the changing flow and rainfall conditions during a storm event and adjust the sample pacing accordingly.

The SWMP Chain of Custody documentation process has been extensively modified to facilitate sample documentation and communication between the field and laboratory. SWMP staff meet regularly with laboratory staff to coordinate sample collection and analytical QA/QC procedures.

The City's SWMP accumulates large amounts of flow, rainfall, and water quality chemistry data from each monitoring station for each storm event monitored. As additional monitoring stations become operational, the amount of data compiled will grow proportionally. Consequently, the data administration system must not only deal with the current information flow but also be capable of accommodating twice as much information by 1996.

Automated data management and storage save time in processing and reduce human error. Water quality and flow data are stored on disk in an hierarchical file structure such that analogous data classes are stored at the same levels. Data identity labels, such as monitoring site ID codes, facilitate automated data processing. The goal of data management is to file data in a system that is appropriate for the way the data is used during analyses. Qualitative and hard copy data are filed in a restricted central location. Copies for general use are kept in an accessible location, so that if a copy is lost or misplaced the archives are not affected.

i) External Resources

The SWMP utilizes an external, independent group of engineers, that serve as a professional review board to cover all aspects of the SWMP. The COA is also a member of a group of regional water quality agencies called the Joint Water Quality Monitoring Program which is establishing a regional water quality data base.

Conclusions

During the COA's long term Stormwater Monitoring Program (SWMP), the City has refined and standardized stormwater quality monitoring methods and techniques. These practices have improved the accuracy of flow measurements and led to the collection of representative stormwater quality samples. The complexity of natural phenomena remains a large focus with the SWMP despite the fact that emerging monitoring technology and less expensive information systems have improved the ease of the stormwater monitoring process. The collection of comprehensive hydrologic data ensures a more appropriate sample distribution. Design utilizing principles of hydraulics is critical, especially to benefit from the use of automated flow measurement equipment and flow control structures. From careful planning and implementation of a monitoring project to the field calibration of each site, the SWMP endeavors to develop and utilize methods and techniques to achieve data with consistent accuracy and significant statistical validity.

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Blackstone River Wet Weather Initiative

Wright, R. M.[1], M. ASCE; Roy Chaudhury, R.[2], A.M., ASCE and Makam, S.[3]

Abstract

A program, initiated by the U.S. EPA, to study the Blackstone River under dry and wet weather conditions was conducted to pinpoint and rank major sources degrading water quality. The river was monitored at 13 locations along 48 miles, in addition to, six tributaries and five point sources. Three storms were monitored for 23 constituents with at least ten samples at each of the stations. Methods of interpreting the water quality data and isolating the sources into dry and wet weather sources are presented. The wet weather component is studied to establish loadings from point sources, new materials (runoff related) and old materials (bottom sediment resuspension). A procedure to estimate annual loading rates is presented.

Introduction

Pollutants enter coastal waters either through direct discharge or via a tributary as an integrated watershed load. Water quality studies are typically done under dry weather, steady state conditions. In general, those types of studies are successful and pollution is readily measured and modeled. On the other hand, wet weather sources are more difficult to characterize and predict. Wet weather sources include storm water runoff, bottom sediment entrainment and combined sewage overflows.

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The Narragansett Bay (Bay) is one of the most important natural resources in Rhode Island (Figure 1). As an estuary, the Bay is the spawning grounds for many aquatic species and a major fisheries and recreational water course, and yet, it is continually under pressure to assimilate significant additions of pollutants. In 1989-90, a study was completed which identified and ranked the sources to the Bay (Wright 1991). The study concluded that the Blackstone River watershed was the major source of both nutrients and trace metals.

In 1991, the U.S. Environmental Protection Agency (EPA) reviewed and summarized all water quality data pertaining to the Blackstone River. As a recommendation of this report, a program was proposed to conduct interstate steady state and wet weather water quality monitoring surveys, to identify and characterize the major water quality problems in the watershed and to calibrate and validate steady state water quality models for application in developing waste load allocations.

Following this recommendation EPA, along with the Massachusetts Department of Environmental Protection (MADEP) and the Rhode Island Department of Environmental Management (RIDEM), developed the Blackstone River Initiative (BRI).

<u>Blackstone River Initiative (BRI)</u>

Phase 1 of the BRI was conducted jointly by the EPA, MADEP and RIDEM and included a comprehensive dry weather water quality sampling program on the river, tributaries and discharges. The results of the three surveys are summarized in Hartman (1992).

The water quality data were used by the Civil and Environmental Engineering Department at the University of Rhode Island (URI) (Wright et al. 1993; 1994) to calibrate and validate both QUAL2E (Brown and Barnwell 1985), a dissolved oxygen model, and Pawtoxic (Wright and McCarthy 1985), a trace metals model. These models are being used by both MADEP and RIDEM in their waste load allocations.

Phase 2 was a joint program by the EPA, MADEP, RIDEM, URI and the U.S. Geological Survey (USGS). The summary of the field program is reported in this paper. The program included the monitoring of the river under wet weather conditions for selected parameters including nutrients, trace metals, microbiological indicators and toxicity. The specific objectives of this study include the following:

1. To determine the spatial and temporal changes to water quality due to wet weather

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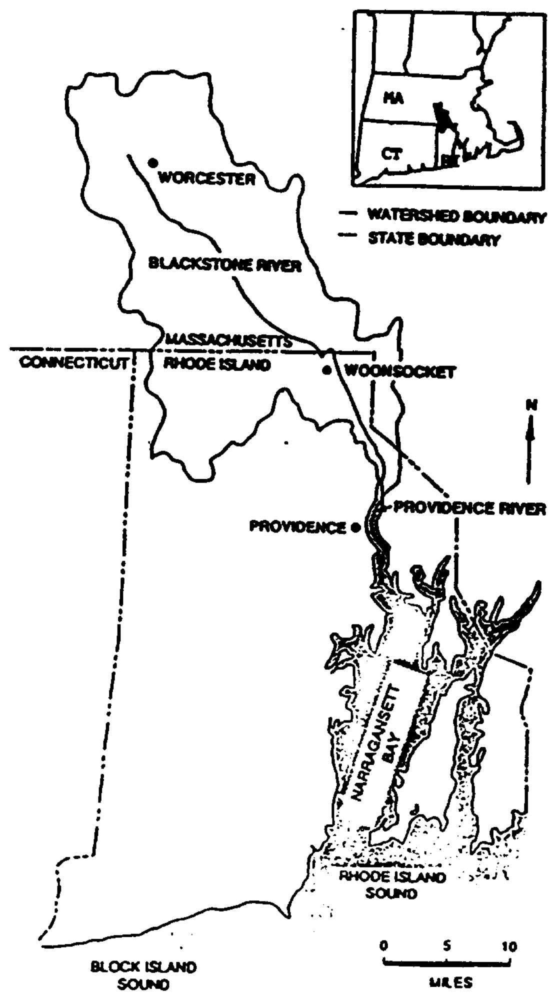

Figure 1: Blackstone River Watershed

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2. To identify and rank river reaches relative to wet weather loads and identify major wet weather pollutant sources
3. To determine the relative importance between wet weather and dry weather loadings
4. To forecast annual wet weather loading rates

System Description

The Blackstone River is an interstate waterway with its headwaters in Worcester, MA. It flows south through Pawtucket, RI into the Providence River and finally, Upper Narragansett Bay. The watershed area covers 1230 km^2 (480 mi^2) and its length is approximately 76.8 km (48 mi). The major tributaries to the river are the Quinsigamond, Mumford, West, Branch, Mill and Peter's Rivers.

The sampling stations are indicated on Figure 2 and listed in Table 1 for both Phase 1 and Phase 2 of the BRI. River mile points are listed from the mouth of the river starting with mile point 0. Only minor station modifications occurred between the dry and wet surveys.

Worcester is the second largest city in Massachusetts and historically has been identified as a major pollutant source to the river (Tennant 1973). The city's wastewater is treated at the Upper Blackstone Water Pollution Abatement District's (UBWPAD) wastewater treatment plant which is a secondary facility with average flows of 1.6 m^3/s (36.6 MGD) providing seasonal advanced waste treatment in the form of nitrification. Worcester also has a combined sewage overflow (CSO) facility which provides settling and disinfection. The CSO facility discharges between BWW00 and BWW01 while the UBWPAD discharges between BWW01 and BWW02.

The other significant urban areas along the river are the cities of Woonsocket, Pawtucket and Central Falls in RI. Woonsocket is serviced by a secondary wastewater plant, with a design flow of 0.70 m^3/s (16 MGD), that discharges directly to the Blackstone River between BWW17 and BWW18. Wastewater from the Pawtucket and Central Falls area is transported below BWW21 for treatment and discharge at mile pt. -2. Both Pawtucket and Central Falls have CSO's which discharge into the Blackstone River between BWW18 and BWW20.

The Blackstone River watershed has a significant industrial and manufacturing history. As a result, there are 20 river impoundments initially built for industrial water supply or hydropower. These impoundments are typically 40 - 60 years old, run-of-the-river, and no longer in use. Three of the largest impoundments are at Fisherville Pond above BWW06, Riverdale Dam at BWW07 and the Rice City Pond above BWW08.

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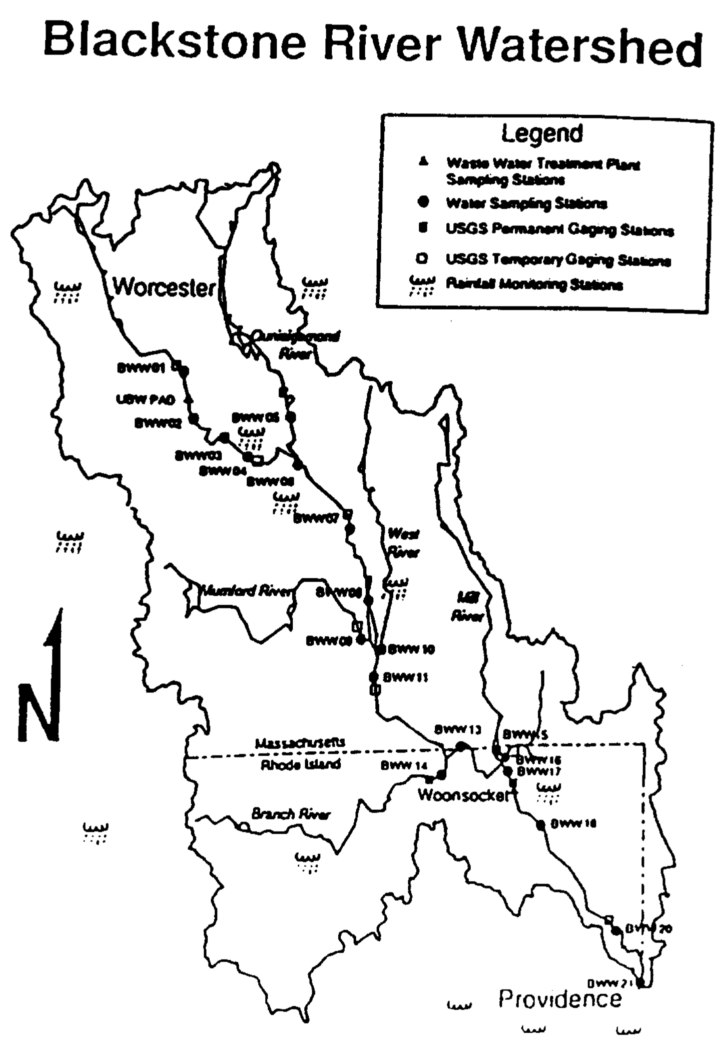

Figure 2: Water Quality Stations - Blackstone River Initiative

Table 1: Blackstone River Initiative Sampling Locations

Station ID		Location	Drainage Area		River Mile	
Dry Weather	Wet Weather		sq. km.	sq. miles	km	miles
Blackstone River						
	BWW00	Worcester, MA				
BLK01	BWW01	Worcester, MA	194.3	75.9	73.1	45.7
BLK02	BWW02	Millbury, MA	210.3	82.1	70.2	43.9
BLK03		Millbury, MA	233.0	91	66.1	41.3
BLK04	BWW04	Sutton, MA	252.9	98.8	63.7	39.8
BLK06	BWW06	Grafton, MA	382.7	149.5	58.1	36.3
BLK07	BWW07	Northbridge, MA	398.1	155.5	51.0	31.9
BLK08	BWW08	Uxbridge, MA	413.7	161.6	44.5	27.9
BLK11	BWW11	Uxbridge, MA	690.7	269.8	37.1	23.2
BLK12		Millville, MA	709.1	277.0	30.8	19.1
BLK13	BWW13	Blackstone, MA	963.3	376.3	26.6	16.6
BLK17	BWW17	Woonsocket, RI	1103.1	430.9	20.5	12.8
BLK18	BWW18	Cumberland, RI	1134.3	443.1	15.6	9.8
BLK19		Cumberland, RI	1143.6	446.7	13.0	8.1
BLK20	BWW20	Lonsdale, RI	1169.2	456.7	5.9	3.7
BLK21	BWW21	Pawtucket, RI	1228.8	480	0.0	0
Tributaries						
BLK05	BWW05	Quinsigamond River, Grafton, MA	87.8	34.2	58.7	36.7
BLK09	BWW05	Mumford River, Uxbridge, MA	175.4	68.5	40.8	25.5
BLK10	BWW10	West River, Uxbridge, MA	95.7	37.4	38.7	24.2
BLK14	BWW14	Branch River, Slatersville, RI	238.3	93.1	27.8	17.4
BLK15	BWW15	Mills River, Woonsocket, RI	58.9	23.0	21.3	13.3
BLK16	BWW16	Peter's River, Woonsocket, RI	29.7	11.6	21.0	13.1
Point Sources						
UBWPAD Woonsocket	WORCSO	CSO Facility, Worcester, MA			75.5	47.2
	UBWWTF	UBWPAD Facility, Worcester, MA			74.6	46.6
	WNWWTF	Woonsocket WWTF, Woonsocket RI			19.8	12.4
	BUCWTF	NBCBP, East Providence, RI			-3.2	-2
	BUCBYP	NBCBP Byp East Providence, RI			-3.2	-2

CSO = Combined Sewer Overflow; UBWPAD = Upper Blackstone Water Pollution Abatement District; WWTF = Wastewater Treatment Facility; NBC BP = Narragansett Bay Commission's Bucklin Point Facility; NBC BP Byp = Narragansett Bay Bucklin Point Bypass

Rainfall Criteria

Establishing rainfall criteria was critical to the success of the monitoring program and the interpretation of the data. The goal was to isolate the effect of a discrete event to permit the characterization of runoff and the determination of the impact on receiving water quality. Rainfall criteria were set in advance of the field program, consisting of a minimum duration of six hours, a minimum of 0.5 inches of total rainfall, an antecedent dry period (ADP) of 3 days and a post storm period of three days. The criteria is designed to sample storms associated with frontal systems that provide uniform rainfall over the watershed. Storm development and movement were tracked by meteorologist with the final decision for the call of the storm provided by URI.

A rainfall monitoring network was established to cover the study area, consisting of six gages maintained by the National Weather Service, 4 URI gages and 2 gages maintained by municipal wastewater treatment facilities (Figure 2). Three storms were successfully monitored on 9/22/92, 11/2/92 and 10/14/93, meeting all rainfall criteria with total rainfalls of 14 mm (0.55 inches), 23 mm (0.92 inches) and 20.3 mm (0.8 inches), respectively. The rainfall coverage for storms I and II were relatively uniform. Storm III ranged from 33 mm (1.3 inches) in the north at Worcester, MA to 14 mm (0.55 inches) in the south.

Sampling Protocol and Frequency

A total of thirteen water quality stations were sampled along the Blackstone River, as well as six tributaries and five point sources discharges. Stations were selected to isolate wet weather problem areas such as point sources, impoundments, combined sewer overflows and junk yards and to provide sufficient spatial detail in the system. The stations were compatible with previous water quality studies along the river.

A prestorm sample was collected 3-4 hours in advance of the storm to define the baseline dry weather loads. Initially, sampling was set at a higher frequency to identify the local stormwater and first flush contribution to the receiving water. A total of 15 samples were taken for each location starting at 3 hour intervals from time 0 (observed runoff) and continuing through 12 hours (5 samples), followed every 4 hours for the next 36 hours (9 samples) with one sample on the third day to define the end of storm. Samples were transported to a field lab centrally located in the watershed for processing and distribution. The list of constituents analyzed is given in Table 2.

Flow Measurements

Three permanent USGS gaging stations located at BWW05, BWW14 and BWW17 provided continuous flow information in the watershed (Figure 2). Additional information was derived from two stations maintained by the Army

Table 2: List of Constituents for the Wet Weather Program

Parameter	Units	Detection Limit	Methodology	Reference
Dissolved Oxygen	mg/l	0.1	DO Probe	1
Temperature	deg C	1	DO Probe	1
Conductivity	μmhos/cm	10	Conductivity Meter	1
pH		o.1	pH meter	1
Total Suspended Solids	mg/l	0.5	Gravimetric	1
Volatile Suspended Solids	mg/l	0.5	Gravimetric	1
Biochemical Oxygen Demand	mg/l	1	DO Probe	1
Chloride	mg/l	5	Orion Probe	1
Dissolved Ammonia	μg/l	5	Spectro-photometer	1
Dissolved Nitrate	μg/l	20	Auto Analyzer	2
Dissolved Phosphate	μg/l	20	Auto Analyzer	2
Sodium	mg/l	5	Flame AA	3
Calcium	mg/l	0.05	Flame AA	3
Magnesium	mg/l	0.05	Flame AA	3
Zinc	μg/l	10	Flame AA	3
Cadmium	μg/l	0.05	Graphite AA	3
Chromium	μg/l	0.2	Graphite AA	3
Copper	μg/l	0.5	Graphite AA	3
Lead	μg/l	0.5	Graphite AA	3
Nickel	μg/l	0.5	Graphite AA	3
Fecal Coliforms	md/100ml	1	mTEC	4
Enterococci	md/100ml	1	mE	4

AA = Atomic Absorption Spectrophotometer; 1 = APHA,APWA and WPCF (1989); 2 = MERL (1985); 3 = USEPA (1979); 4 = APWA,APHA and WPCF (1992)

Corps of Engineers and stage measurements taken at each station during each sampling interval. These stage measurements were converted to flows from rating curves developed by USGS and URI.

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Figure 3 illustrates the track of the storm for Storm II starting in Worcester at point A and increasing in magnitude as it progresses south to point D. Major increases in flow associated with tributaries are seen at points B and C.

Spatial and Temporal Changes

The concentration profiles for each event are evaluated by station. Some pollutant concentrations increased indicating significant sources of wet weather loads (ie. TSS, copper and lead) while other pollutants concentrations decreased, a result of dilution (ie. Ca and Mg).

An example case where the combination of the increase and decrease of individual constituents causes a greater environmental impact is seen with respect to the potential toxicity caused by trace metals. The EPA has established acute and chronic concentrations for trace metals using relationships based on hardness. When hardness decreases, the potential toxicity increases. Thus, in the Blackstone River, under wet weather conditions, the decrease of calcium and magnesium, and thus hardness and the increase of trace metal concentrations, results in violations of a greater magnitude (Figure 4).

The evaluation of wet weather concentrations for each event for the entire watershed also enables the identification of the major wet weather sources. For example, copper concentrations in Figure 5 indicate that the major sources occur at the headwaters between BWW00 and BWW04 (Point A). The CSO discharge between BWW00 and BWW01 and the UBWPAD discharge between BWW01 and BWW02 are contributors and were monitored. However, no major source was identified between BWW02 and BWW04, yet sharp increases of trace metals were observed. The land use in to this reach ranges from suburban to rural, without significant sources of runoff related trace metal inputs.

It appears that the wet weather observations are supported by the results of the dry weather surveys. Earlier observations related to the dry weather data (Phase I), indicated significant increases in metal concentrations due to UBWPAD inputs at BWW02. This was followed by a rapid loss of metals between BWW02 and BWW04. The mechanism of removal is not clear but appears to be either a result of settling or biological uptake. The reappearance of metals in this reach under wet weather is most likely a result of either resuspension or sloughing of biological material. The importance of evaluating the system under both dry and wet weather conditions is evident. Clearly, the results of the dry weather survey suggests UBWPAD is the original source.

Additionally, the concentrations decrease at BWW06 and BWW07 (Point B). This is due to the removal of pollutants in the impoundments above these stations. Below BWW07, the river enters Rice City Pond. Sharp increases in copper can be seen at BWW08 (Point C) at the Pond's outlet with concentrations translating further downstream. This source is a result of sediment resuspension. Unlike the

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BLACKSTONE RIVER INITIATIVE
STORM II - Flow (cfs)

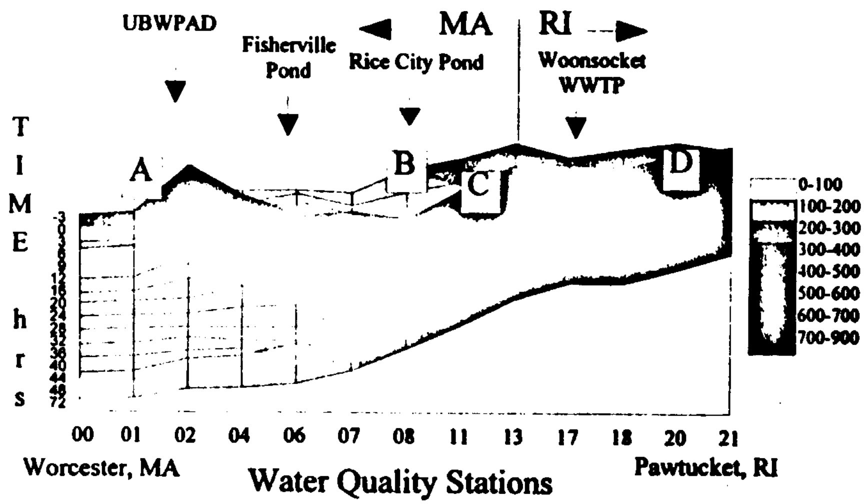

Figure 3:

impoundments upstream, Rice City Pond has seen a lowering of the dam height in recent years exposing historic sediments. As the river carves channels through the soft sediments of the impoundment, even moderate flows cause resuspension.

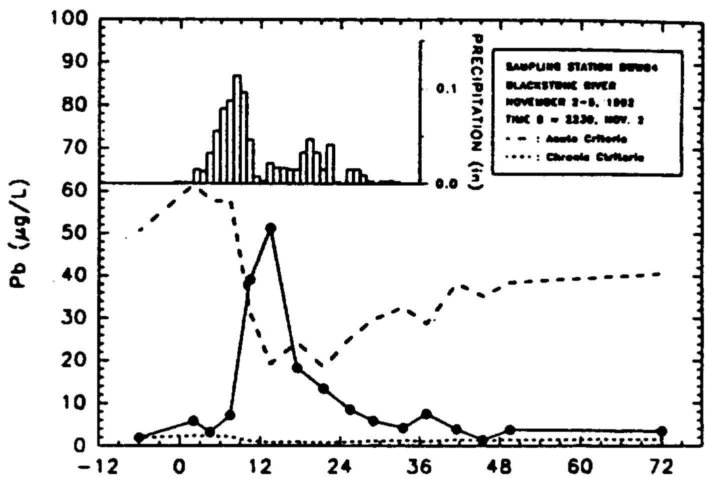

Figure 4: Concentration Profile at BWW04 - Lead

Wet Weather Loadings

The water quality data coupled with stream flows allow for the calculation of mass loading curves. These have been interpreted to define dry weather baseline loads as prestorm conditions and, for comparison, wet weather loads from the integration of the mass curves (Figure 6).

The wet weather mass loads for TSS, lead and copper are presented in Figure 7. The net gain or loss of mass by reach can be observed in Figure 8. These figures provide a spatial view of the river under wet weather conditions. Increases like that occurring between BWW01 and BWW04 are obvious while reductions in wet weather mass loadings are noticed between BWW04 and BWW07.

Pollutants associated with wet weather may come from either new sources (runoff induced) or old sources (river sediments). It is important to note that the former may be easier to control and regulate than the latter. The wet weather

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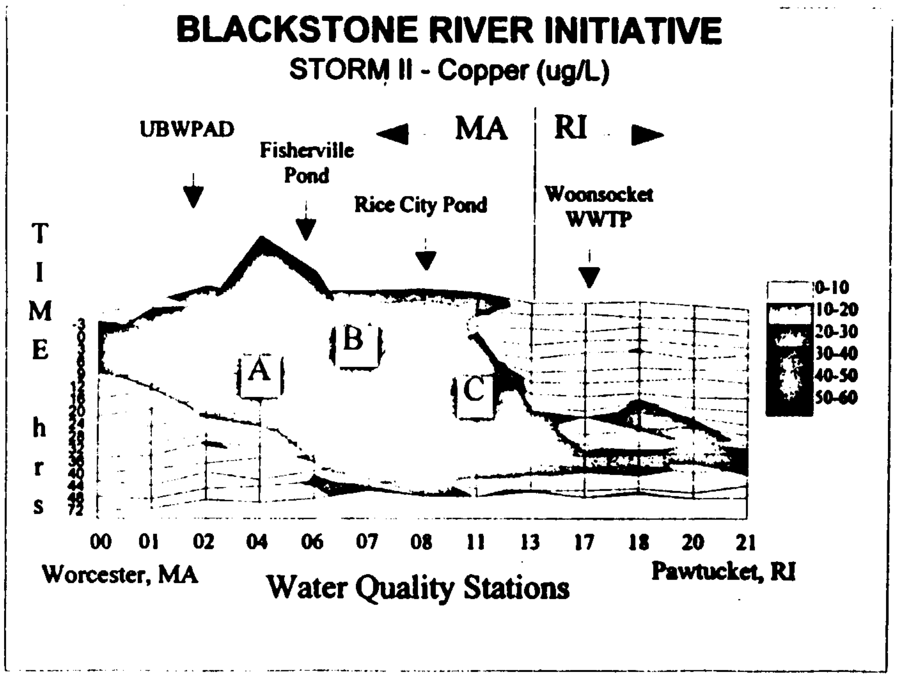
Figure 5:


BLACKSTONE RIVER INITIATIVE
STORM II - Copper (ug/L)
UBWPAD
Fisherville Pond
MA
RI
Rice City Pond
Woonsocket WWTP
TIME hrs
A
B
C
0-10
10-20
20-30
30-40
40-50
50-60
00 01 02 04 06 07 08 11 13 17 18 20 21
Worcester, MA
Water Quality Stations
Pawtucket, RI

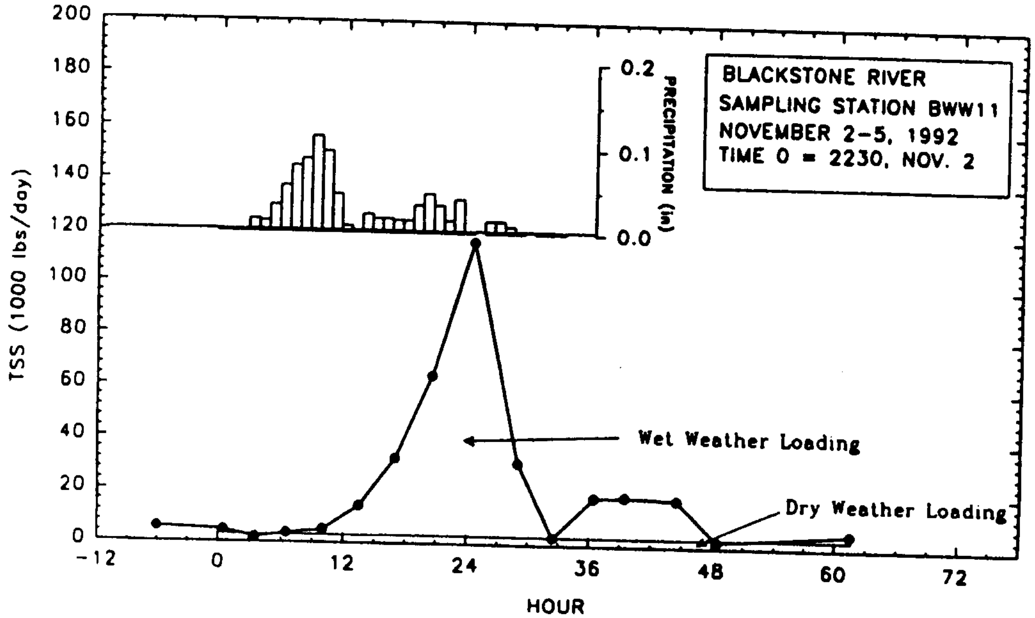


Figure 6. Separation of Dry and Wet Weather Loadings

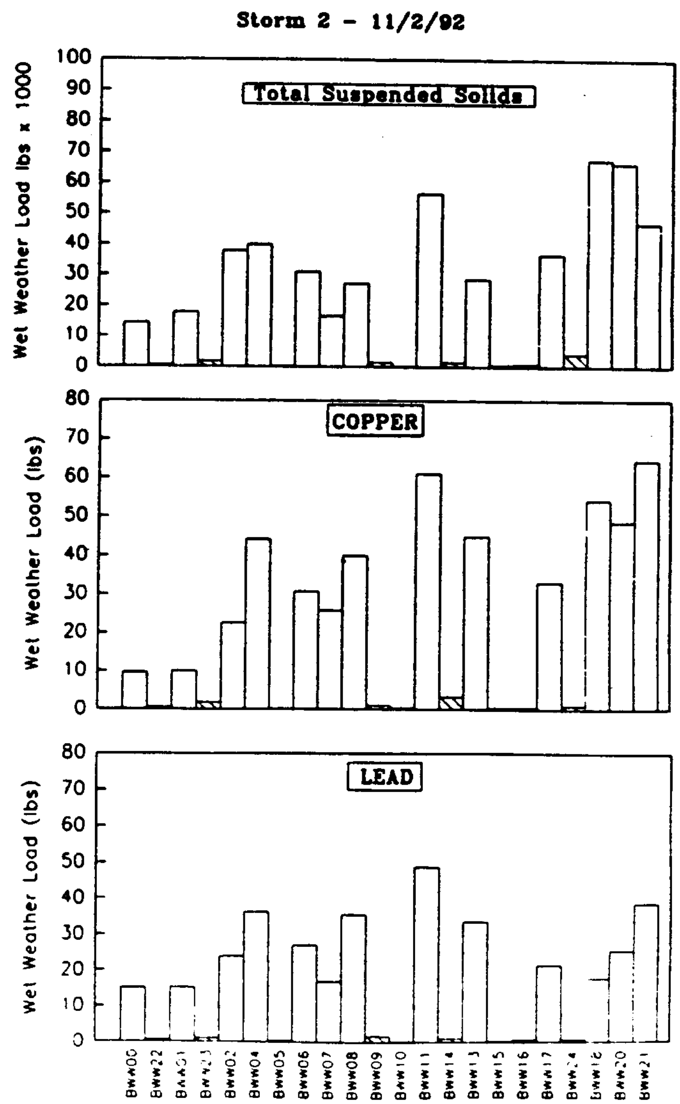


Figure 7: Wet Weather Loading by Station

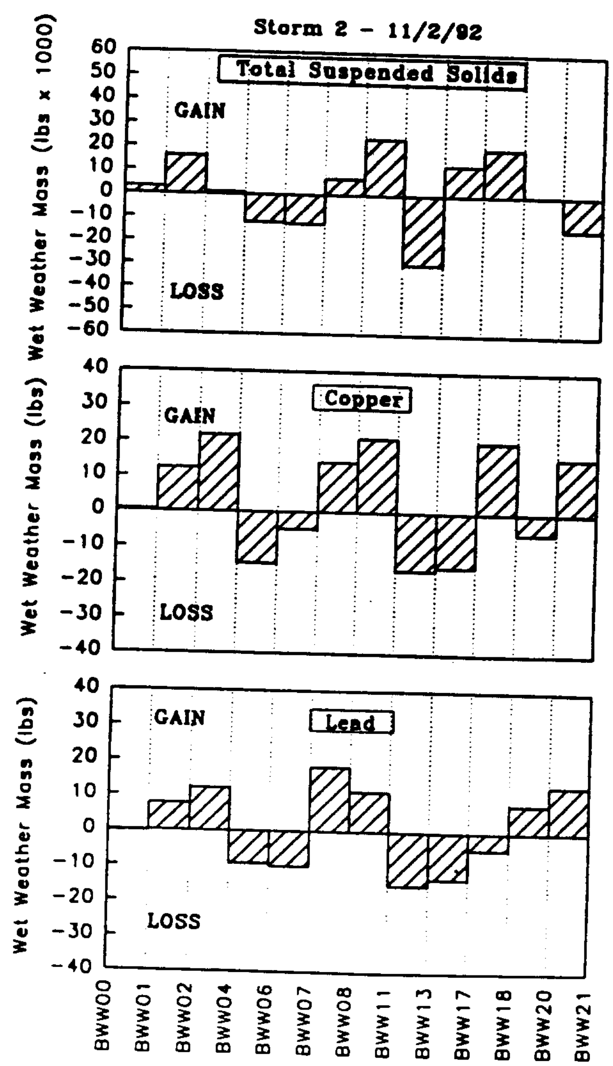


Figure 8: Net Gain or Loss by Reach

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component was separated into its new and old sources by estimating the resuspension component with the trace metal model, Pawtoxic (Roy Chaudhury 1991; Roy Chaudhury et al. 1993). Through application of the model for a range of flows, relationships were developed for each reach between net mass transported and flows. Resuspension is then estimated from these relationships for the observed flows during each of the wet weather sampling runs. The gain in the resuspension load between stations can be deducted from the wet weather load for an estimation of the new source. Figure 9 illustrates this application for the reach between BWW07 and BWW08. The results of this analysis for TSS, copper and lead is summarized in Table 3. With this method, the wet weather loads of Figure 7 may be refined further to provide an estimate of the resuspended and runoff loads as shown in Figure 10. Since the relationships are based on net mass transported, if net settling occurs within a given reach, a similar procedure can be followed to estimate the runoff component.

Figure 11 illustrates the movement of the mass loading of copper as a result of the wet weather event. The sharp increases in the Upper Blackstone at BWW02 and BWW04 (Point A) occur for samples taken between 6 and 36 hours with the peak at hour 6, while at BWW21, the increases are noted between hours 20 and 72, with a peak at hour 32. The progression of the storms impact downstream can be clearly tracked through the hydrograph (Figure 3) and pollutant (Figure 5) and the mass loading (Figure 11) curves.

Figure 11 also supports the partial removal of materials by BWW07 (See also Figure 8) with increases at BWW08 and BWW11. Further downstream it is evident that partial settling occurs by BWW13 and BWW17. The 3-dimensional plots also provided the opportunity to view smaller impacts like localized impacts of the CSOs in Pawtucket (BWW20 and BWW21) seen at hours 3, 6 and 9. Unlike the impacts on system flows, the tributary contribution to the mass loading appears minimum (Figure 7).

<u>Annual Loading Rates</u>

Empirical relationships between the wet weather pollutant mass and rainfall characteristics were evaluated initially by Wright et al. (1991) at BWW21, the mouth of the Blackstone River. These relationships when coupled with the historic rainfall records provided an estimate to annual loading rates. Projections of annual wet weather pollutant loadings at the mouth of the Blackstone River will be important to the restoration of the Blackstone River and to the ongoing Narragansett Bay study. A preliminary assessment of this relationship is presented for BWW21 (Figure 12) that includes the loadings calculated from the BRI.

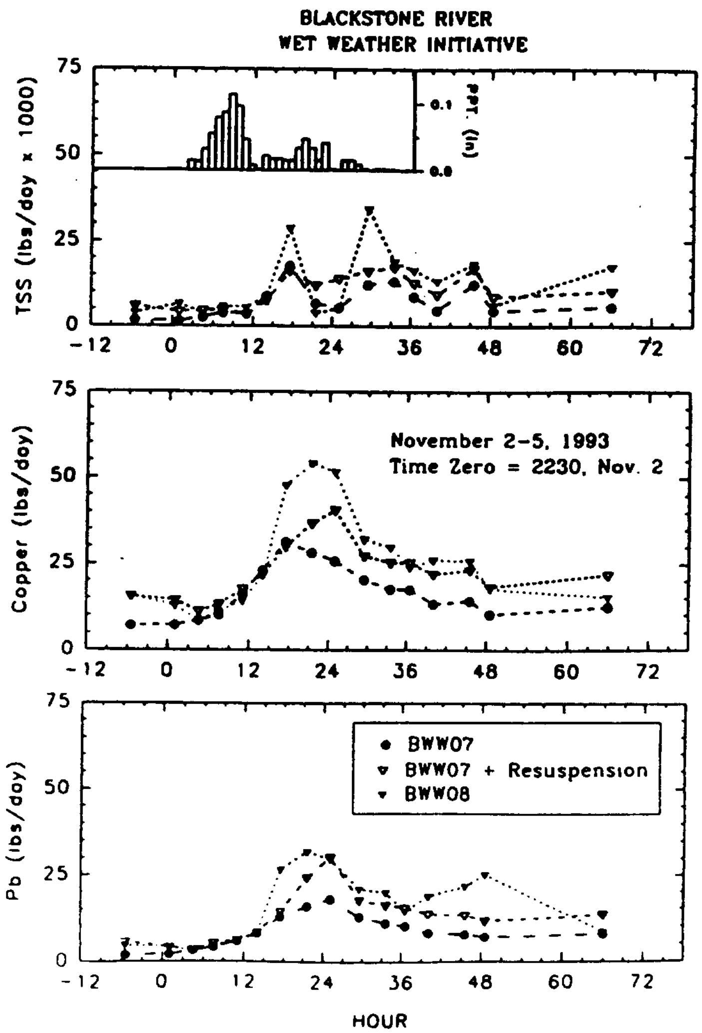

Figure 9: Estimation of Runoff and Resuspension

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Table 3. Runoff and Resuspension Loads Between BWW07 and BWW08.

Constituent	BWW07 lbs	BWW08 lbs	Loading Between BWW07 and BWW08	Resuspension lbs	Resuspension %	Runoff lbs	Runoff %
TSS	21600	38300	16700	6400	38.3	10300	61.7
Cu	47.2	72.2	25	15	60	10	40
Pb	26.7	49	22.3	12.6	55	9.7	45

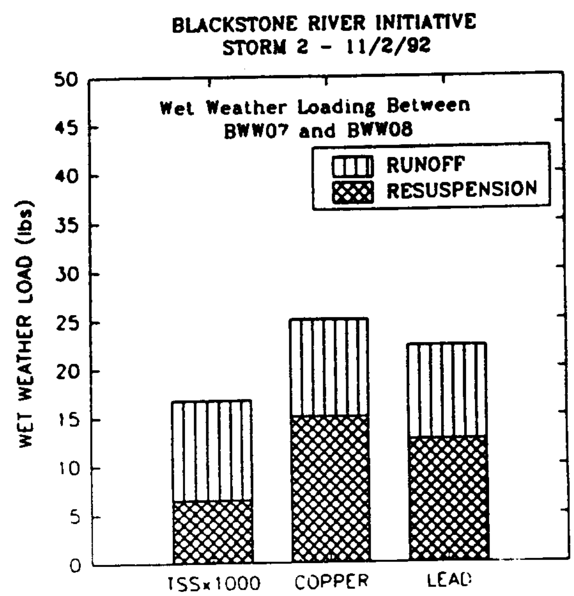
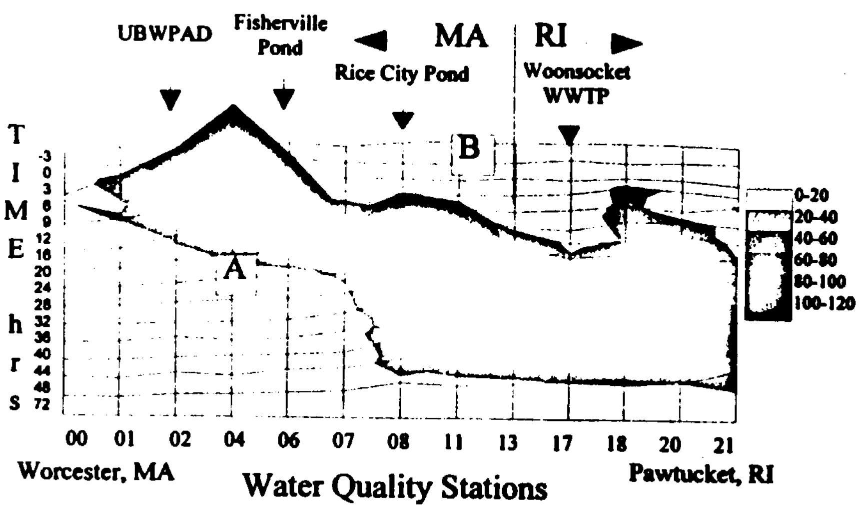


Figure 10:

Figure 11:

BLACKSTONE RIVER INITIATIVE

STORM II - Copper (lbs/day)



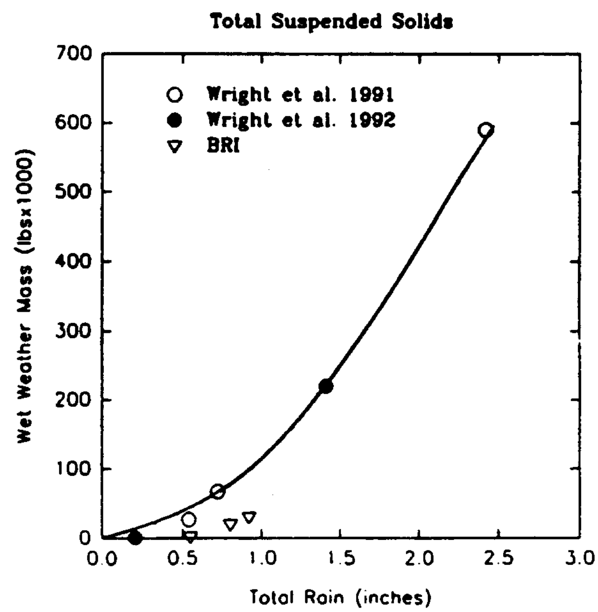


Figure 12: Wet Weather Mass and Total Rainfall Relationship

The dry weather models are utilized to predict annual dry weather loadings which are combined with the annual wet weather loadings to provide the total load by station as well as to the Bay. This enables the permitting process to encompass the impacts of runoff in the river as well as to the Bay.

Conclusion

A comprehensive wet weather monitoring program of an interstate river has been successfully completed. The program consisted of sampling at locations along the river, point sources and tributaries for three storm events to identify and rank sources.

Changes in the river were assessed for impacts from point sources, runoff and resupension of bottom sediments to water quality and water quality based toxic criteria. For initiating and focussing management alternatives, wet weather loadings are determined to identify and rank the various sources. River reaches may also be ranked to isolate locations for optimizing the institution of best management practices for nonpoint sources. Methods of determining annual wet weather loadings using rainfall characteristics are also discussed.

In systems such as the Blackstone River, gains and losses of wet weather materials due to resuspension and settling are a function of the existing physical attributes of the channel, baseflow and rainfall characteristics. Design solutions to remedy adverse wet weather impacts need to account for the conditions that would result in no losses (worst case), also including natural and man-made changes to the channel. Improvements instituted by waste load allocations for dry weather conditions should also be accounted for during the wet weather permitting process.

Acknowledgements

This project is sponsored by the U.S. Environmental Protection Agency (Region I) and Rhode Island's Department of Environmental Management.

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SESSION IV: NPDES Compliance Monitoring

DISCUSSION

Methods and Procedures in Stormwater Data Collection
Thomas Brown, William Burd, James Lewis and George Chang

The Austin sampling program is not an NPDES required program. All samplers have a telemetry connection so that they can be interrogated before the storm to insure that they are working, to turn them on if necessary, and to change the frequency of sampling during the storm if the hydrograph indicates this is desirable.

Separated storms for sampling into 4 classes, based on total rainfall per storm, so that each class produces approximately the same amount of volume on an annual basis.

The NPDES program should be based on a regionally coordinated program, rather than on individual programs from a number of cities in the region. This will provide better QA/QC and a comparable data base for individual areas (jurisdictions) in the regional area.

Questions/Comments

Question: How do you calibrate pressure flow monitors?
Answer: Hard to calibrate at higher flows, due to unsteady flow, hysteresis loops, etc. A 20% difference was found at high flows (between measured and actual).

Question: What are costs of your monitoring program?
Answer: About $1 million /year (plus a USGS contract for $300,000 with $100,000 matching funds).

Biological and Chemical Testing in Stormwater
William T. Waller, Migulel Acevedo, Eric Morgan, Kenneth Dickson, James Kennedy, Larry Ammann, H. Joel Allen and Paul Keating

Looked at time to death in addition to classic 48- and 96-hour tests. Remember that in toxicological studies organisms respond to extreme events, and not to the means.

In the Fort Worth study we performed a toxicity identification evaluation (TIE).

The TIE found no toxicity for fathead minnows; for ceriodaphnia, there was < 100% survival for 12 out of 24 events. Thus 50% showed a toxic response. Only one event had both ceriodaphnia and Microtox toxicity responses.

Diazinon appears to be a problem in the South across the country (available over the counter), but does not seem to be a problem in the North. There was no analysis for other consumer-applied pesticides, including chlordane, endosulfan, and eldrin, in stormwater samples.

Another way to measure toxicity in-situ - a proposal:

- A biosensor approach using a proximity sensor that tells how far open an Asiatic clam is (the clam is the living material that is open when it is happy and closes during times of toxicity)

This biosensor approach does not deal with bioaccumulation or biomagnification.

Believes that sediment toxicity will be a major problem in the future.

Questions/Comments

Question: Shouldn't the indicator species chosen be specific to the ecosystem being evaluated?

Answer: No. An inference can be made with confidence that the test organism, or biosensor, is responding to stream conditions present, similar to previous studies performed in the laboratory and in the field.

Comment: The clam idea, if it works, could be an excellent way to reduce sampling costs. If the clam or indicator organism is in stress, then start the hunt for the chemical(s) that is(are) causing the stress. Need to develop a protocol that links toxicity testing to the chemical testing that must follow to identify the cause.

Question: Clams also close when the water is clean - how do you sort that out?

Answer: (Herricks) It's related to how often they close and how long they close. Still have a number of things to work out for this test.

Question: How does toxicity testing in samples taken from stormwater and then used to do 48- and 96-hour toxicity tests relate to stormwater toxicity that lasts for much shorter periods of time.

Answer: Need to be reasonable here. Probably should be looking at "time to die" over periods of about 2 hours.

Blackstone River Wet Weather Initiative
R. M. Wright, Roy Chaudhury, S. Makam

The Blackstone River is unique in the Northeast because the city of Worcester is in the headwaters, whereas in most rivers in the NE, the city is at the mouth of the river.

CSO basins in Worcester; 19 small impoundments w/ low head dams; Woonsocket is about 2/3 of the way down the basin; there is a tidal barrier at the bottom.

Minimum rainfall criteria: 0.5 inches, 6-hr duration, 5-day dry period, 3-day post storm dry period (Editor's note: Here, again, is an instance where EPA-specified criteria cannot be used).

Sampling frequency:

- Pre-storm - 3-4 hrs before rainfall
- During Storm - 3-hr increments for the first 12 hrs, 4-hr increments for the next 36 hrs.

This is different from the protocol used for end of pipe monitoring because of the size of the watershed (Base flow is 260 cfs).

Be certain to look at dry and wet weather loads and identify and differentiate water quality problems that are due to dry weather flows from those that are due to storm flows.

Questions/Comments

Comment: You do not have total and dissolved fractions during wet weather because of cost to do this. (Editor's note: This would seem to make it difficult to determine whether toxic concentration exceeds acute level, since dissolved fraction is not known).

Comment: Their problem (in the Northeast) with numerous abandoned small impoundments (at abandoned mills, etc.) is one which will require a much broader (regional) approach.

General Questions

Question: (Austin) Why do you modify sample intervals based on pre-storm radar returns?

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Answer: Radar helps the sampling team get ready for the storm by telling them how much time they have to respond, and letting them know when a storm peters out and the sampling event should be aborted.

Comment: (Austin) They have some problems with EMCs, and therefore try to get flow volume-weighted means.

Question: (for Waller-Fort Worth)The toxicity tests use bottled water that has been spiked with a known concentration of pollutant, and an introduced or artificial organism. How can these tests be used to assess the toxicity of a particular stream with its own population of aquatic organisms?

Answer: It is possible to make an inference from the laboratory data previously collected on an organism's response to a pollutant to those conditions found in the field at a particular site. If a toxic response has been observed for a test organism in the laboratory, chances are good that there is some source of toxicity in the water body being tested.

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STORMWATER PERMITTING
AN INDUSTRIAL EXPERIENCE

P. Charles Beck[1]

ABSTRACT

The impact of the NPDES stormwater permit program on a water reliant Fortune 500 company located in the semi-arid west is discussed. The results of a stormwater outfall sampling program are presented. Modifications to the facility were made as a result of the sampling and site inspection program. The problems and successes of the stormwater permit program from an industrial environmental manager's perspective are presented. Concerns about the future direction of the program and economic impact on industry are raised. A balanced cost-versus-benefit analysis of the program before the enactment of additional regulatory requirements within the stormwater program is needed. Industry must be an active participant in the development of future regulations.

INTRODUCTION

This paper offers the perspective of a Fortune 500 company located in the semi-arid west. It will address a company's experiences with the stormwater permit program and briefly discuss some positive and negative aspects of the current stormwater program. It will also offer thoughts about the future of the program. The views are those of the author and do not necessarily represent those of Coors Brewing Company.

First some background information for those not familiar with Coors Brewing Company. Coors Brewing Company, America's third largest brewery, is headquartered in Golden, Colorado. Golden is located in the foothills of the Rocky Mountains twelve miles west of Denver, Colorado. The company also has operations in Memphis, Tennessee and Shenandoah Valley, Virginia.

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[1]Manager, Environmental Engineering, Coors Brewing Company, CE 200, Golden, Colorado 80401

The Golden plant is the largest single-site brewery in the world with a brewing capacity of over 20 million barrels of beer per year. This is the equivalent flow of 2.63 cfs or 1,180 gallons per minute...24 hours per day, 365 days per year.

The physical plant straddles a river known as Clear Creek, a major tributary of the South Platte River. Clear Creek is a heavily allocated river supplying seven major water supply and irrigation conveyances. The Clear Creek headwaters are located within the historic mining districts of Central City and Blackhawk and the Eisenhower Tunnel-Loveland Pass region near I-70. The old mining districts have been identified as CERCLA Superfund sites due to the extensive mineral production and processing activities. The area is dotted with old tailings piles, mine shafts and abandoned processing mills. As a result, water quality in Clear Creek suffers from acid mine drainage and heavy metals pollution from numerous sources plus the effects of rapid urbanization associated with the revitalization of gambling in the Central City and Black Hawk area.

Water flow in the river is highly seasonal and dependent upon winter snowpack and rainfall. During a normal year, flow can range from 22.7 cms to 28.3 cms (800 to 1,000 cfs) to less than 1.42 (50 cfs) in parts of the river. This year the peak flow at the USGS gauging station at the mouth of Clear Creek Canyon was 23.2 cms (820 cfs). The average annual rainfall in the Golden area is approximately 330 to 356 mm (13 to 14 inches).

The brewery has been located in the same area for its entire 120-year existence. Besides the brewing and packaging facilities, Coors operations in the area include three coal-fired power boilers, two waste water treatment plants, a can manufacturing facility (4 billion cans per year), a can lid or end manufacturing facility and a glass bottle plant.

Coors has additional property holdings that include an abandoned landfill and an operating gravel mine and asphalt batch plant. The gravel mine and asphalt plant are operated by others.

CURRENT PERMIT STATUS

The NPDES stormwater permit program is a delegated program administered by the Colorado Department of Health (CDH), Water Quality Control Division. Coors has been issued six general stormwater permits for both Light and Heavy Industry General Stormwater Discharge activities. The permits cover approximately 180 outfalls to either Clear Creek or tributary creeks and irrigation canals. The NPDES discharge permit for the waste water treatment plants is in a renewal process with a final draft expected by mid-September 1994. The new NPDES permit incorporates a complete section on stormwater for the brewing and can manufacturing plant operations. Coors will then operate under four general stormwater permits and the NPDES discharge permit.

SAMPLING PROGRAM

1991 Program

Along with other major industrial concerns Coors was caught up in the initial permitting frenzy in 1991. Coors, by virtue of having one of the largest ammonia based refrigeration systems in the world, was and still is a "313" industry or heavy industry. The decision initially was made to pursue an individual industrial permit using the "Form F" application; however, Coors never submitted the "Form F" because the decision to issue general permits was made just weeks before the individual application due date.

Maps and Surface Areas

Some twenty-five maps have been assembled on CAD using field data that required some 16 person-weeks to gather. The total area surveyed included approximately 300 hectares (742 acres). Two-hundred-and-three (203) hectares (501 acres) are pervious land which includes railroad staging yards and equipment staging areas and undeveloped land. There are 72 impervious hectares (178 acres) that include parking lots, truck aprons and roads. Twenty-five hectares (63 acres) are under roof. At the time of mapping in 1991 the total number of outfalls was 182.

Sampling Data

Form F required sampling all outfalls unless a case could be made to group essentially identical outfalls together under the provision of similar activities and physical characteristics. To reduce the number of samples and control the analytical costs, the 182 outfalls were grouped into five major categories and the number of samples was reduced to twenty-two. The twenty-two outfalls were selected based on access safety and on their being representative of the industrial activity in the area. Both manual sampling and automatic sampling techniques were tried. Manual sampling was the most effective. The automatic samplers did not work satisfactorily particularly in collecting composite samples during storms of short duration.

A team of six people was formed to manually sample assigned outfalls. Sampling protocols were established internally since there were no published sampling requirements available.

Sixteen of the twenty-two outfalls were successfully sampled during the summer and fall of 1991. Both grab and composite samples were obtained and analyzed for up to twenty-seven different parameters.

Rainfall was, and still is, measured using a standard tipping bucket rain gauge connected to a Campbell Scientific datalogger. During the sampling period of June to October the Golden site received 198 mm (7.8 inches) of rain in 50 storms. Of the 50 storms 28 were greater than the 2.54 mm (0.1 inches) required for sampling. The maximum storm occurred in August and produced 41.7 mm (1.64 inches) of rain. The maximum rain rate was in June and was 69.3 mm/hr (2.73 inches/hour).

The parameters measured included nutrients (pH, TSS, Oil & Grease, BOD5, COD, TKN, Total P, etc), metals (Cu, Cd, Pb, Ag, Cr, Zn, Fe) and organics (624, 625 series). Tables 1 and 2 summarize the results for the grab samples for selected nutrients and metals during the 1991 sampling. The results for the composite samples were similar but the values were slightly lower. No significant volatile or semi-volatile compounds were found.

	pH	TSS	BOD_5	COD	O&G	TKN	NH_3	NITRATE
MAXIMUM	8.80	1060	3190	2510	10.8	137.0	36.9	78.1
MINIMUM	3.03	5	10	5	1.0	.5	0.8	1.7
AVERAGE	6.68	113	336	351	3.0	23.5	4.3	13.6
MEDIAN	6.67	31	26	75	1.7	6.6	1.2	6.0
STD. DEV.	1.3	249	828	669	2.7	36.6	8.6	21.5

Table 1. 1991 Stormwater Sampling Results for Nutrients (Values in mg/l)

	Fe	Cd	Cu	Cr	Pb	Zn
MAXIMUM	13000	10.8	220	110	40	6900
MINIMUM	0	0	6	0	0	30
AVERAGE	2279	1.8	45	13	18	921
MEDIAN	1400	0.6	14	7	17	220
STD. DEV.	3079	2.7	60	26	11	1667

Table 2. 1991 Stormwater Sampling Results for Metals (Values in ug/l)

Both the nutrients and the metals data show a wide range in variation. The data are skewed by one or two outfalls with very high values. This is noted by the difference between the average and median values. Table 3 compares the metals numbers with some existing water standards to offer some perspective about the significance of the values. The average stormwater values fall within the requirements for both bottled and/or drinking water and RCRA Health Based Standards. The metals values are in some cases above the Warm Class II aquatic life stream standards as established by CDH. Given that the data are for single point samples from different outfalls under different storm conditions it would not be good practice to draw too many conclusions from this data comparison. The data do suggest that additional work would be needed to fully assess the distribution of the data for any given outfall for any given parameter.

METAL	Health Based Std RCRA 40CFR260.2 ug/l	Bottled Water 21CFR103.35 ug/l	STORMWATER MAX ug/l	GRAB SAMPLE AVERAGE ug/l	CDH STREAM STANDARD (Warm II @ 116 ppm Hardness)
Fe	NA	NA (300*)	13,000	2,300	NA
Cd	5	10 *	11	2	1.3
Cu	NA	100	220	45	13.5
Cr	100	50 *	110	13	234
Pb	15	50 *	40	19	4.8
Zn	7000	5000	6900	920	120
Ag	50	50 *	4.9	.33	.4

* — ALSO A DRINKING WATER STANDARD PER CDH SCCR1002-1.

TABLE 3 -- Stormwater Metals Comparison

Follow-up Actions

The outfalls which had unusually high parameter values were examined and modified to reduce the source or sources of the problem. For example, the outfall with the 3190 mg/l BOD5 was near a spent yeast drying facility and spilled yeast was responsible for the high value. This prompted a review of the storm drains around the yeast drying facility. Modifications were made to reroute the storm drains to a process waste water drain in the high risk areas around the yeast plant.

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The review of the sampling data resulted in modifications of several other potential problem areas within the plant. Roof drains on fermenting buildings were rerouted from a Clear Creek discharge to the process waste water collection system. Storm drains in high traffic garage areas were modified to collect up to a five year storm event into the sanitary sewer system. Lean-to roof structures have been installed over waste material collection bins and over above ground fuel storage facilities. Manual valves have been installed on outfalls with a high potential for substance spills.

Coors has been under no direct order from a regulatory agency to correct any of the problem outfalls other than the guidance in the general permit. The installation of corrections and modification have been voluntary and done willingly in the spirit of good corporate citizenship. Coors will continue to make minor improvements in the physical plant which will directionally improve the quality of stormwater.

The current sampling program for Coors calls for sampling of ten outfalls a single time for four parameters (pH, Oil and Grease, TOC and BOD5) and for sampling three additional outfalls twice for the four parameters plus selected metals. An estimate of the discharge volume is also requested. The requirements are for 1994 and 1995 only.

The sampling data is to be included in an annual report to the regulatory agency. It has not yet been stated by the regulatory agency how these data will used in the future. It is not clear how this stormwater sampling program will address measurable changes in stream quality. Will the data form a basis for numeric limits or mandatory BMP installation and performance standards? Based on previous experience, industry becomes concerned when reporting numbers to a regulatory agency about how the data will be used and what future requirements may result from the data.

ADDITIONAL COMMENTS

The current stormwater general permit program is, overall, a reasonable program for industry. However, other topics within the stormwater permitting program are of interest to industry.

Regulation Burden

American industry, particularly manufacturers, is surrounded by environmental regulations. The flow of all significant materials into and out of any manufacturing/industrial complex is now controlled in one fashion or another. The stormwater program and its permit requirements are considered to be either redundant or of a relatively minor consequence within the industrial environmental regulation arena. From the regulatory manager's perspective it overlaps the RCRA and Community Right to Know programs and the Spill Prevention and Emergency Response Planning programs. This overlap creates some unnecessary costs for industry. These costs are carried by industry and ultimately by the public through higher product prices.

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<u>Program Cost</u>

The cost to prepare either the individual permit application or the Stormwater Management Plans was much higher than originally estimated by the EPA. This was aggravated by the switch from the EPA Individual Permit program to the State General Permit Program in 1991. Coors has spent over $250,000 in the mapping, sampling and administration effort over the last three years. The EPA estimated cost of $15,000 to $20,000 to complete the individual industrial permit application was off by a factor of ten. It is not known if the EPA has developed any figures relating to the on-going costs of the program in terms of annual report preparation, sampling and BMP installation. The Coors experience is not unique. In comparing notes with other major industries in the Denver front range area, Coors cost was not unusual or out-of-line. Cities may have experienced similar discrepancies between the EPA cost estimates and the actual cost of the application and plan preparation.

<u>Poorly Defined Program Goals</u>

The understanding of the Stormwater problem and the long-term goals of the program are limited. The specific lasting effects on the river system from non-point source runoff have not been widely discussed in the trade literature. The benefits of the stormwater program have not been effectively communicated to industry and the true costs appear to be much higher than original estimates.

The NURP study demonstrated that levels of contaminants in the stormwater exceeded stream standards. The study did not address, in depth, the acute or chronic effects on the receiving waters from the contaminants originating from the urban and industrial environment versus background levels from non-agricultural land sources.

Because of the lack of a clearly defined problem, the industrial environmental manager tends to be less than enthusiastic about committing resources toward an equally poorly-defined solution. Resources are better utilized addressing the NPDES point source, RCRA waste handling and CAA air emissions programs, which are better defined, more visible and supported with very active regulatory staffs.

<u>Minor Inconsistencies</u>

Lastly the general permits contain inconsistencies in the application of industrial activity restrictions. For example, in the Colorado General Permits irrigation return flows are allowed but air conditioning condensate flows are not. Irrigation flows are often cited as being major sources of suspended solids, pesticides and phosphates. Fire fighting activity water is allowed, but water from the code required hydrant testing is not allowed due to chlorine levels in the testing water. Building foundation dewatering water can be discharged if it is not contaminated, but no standard is cited for defining contamination.

Successes

The NPDES Stormwater Program for industry is successful on several counts. The improvements to water quality resulting from the program will not often be as dramatic as the point source program, they should be positive for receiving water quality. The permit program is raising the awareness of the effects of outdoor industrial activities on water quality within the industrial community.

System Understanding

The preparation of the Stormwater pollution prevention plans required by both the light and heavy industrial permits have caused Coors to closely examine its external work activities and the relationship of those activities with the physical layout of the facility.

The initial mapping and site inspection activities revealed areas where simple, inexpensive changes could be made right away. These areas were prioritized and included in the Pollution Prevention Plan and in the budget planning process for the company. If more complex and costly changes are required in the future then the planning and design process will be facilitated by the mapping program.

Illicit Discharge Elimination

Both the initial and on-going inspection and mapping programs have identified illicit connections and discharges that were previously either undiscovered or forgotten. For the Coors facility, the most common illicit connections were groundwater dewatering collection systems under and around production buildings and HVAC condensate drains. The ground water drains were repiped to the wastewater system. As HVAC condensate drains are identified they are rerouted to the waste water collection system.

Spill Reduction

The three-year spill history review called for in the Pollution Prevention Plan placed emphasis on the correction and modification of areas that had a history of repeated spill events. Coors had experienced repeated discharges from process roof vents in the beer fermenting area and periodic spills from the loadout system for waste beer and related byproducts. In each case the system was modified to reroute the discharges to the waste water collection system.

In other cases, where the spills are more random and much less frequent but the activity concentration was high, the drains were equipped with valving to control the discharges to the local waters.

<u>Improved Storage Practices</u>

Material handling and storage practices have been inexpensively modified to reduce exposure to stormwater. Simple roof structures over material storage areas and material handling areas have reduced stormwater contact with these operations.

Scrap material hoppers used to collect segregated construction debris, such as wood, mild steel, etc., have been either relocated under roof or have had simple covers installed. Outdoor housekeeping practices have received renewed interest from the Environmental Specialists in each operating area in response to the semi-annual inspection program. Housekeeping activities as simple as street sweeping and trash barrel pickup are monitored more closely. The annual inspection program focuses attention on the activities and site conditions which would affect the quality of stormwater leaving the property.

<u>Employee Awareness</u>

The Stormwater program requires employee training. At Coors the stormwater training program has been incorporated into an existing mandatory OSHA program. This is given once a year to all Coors Brewing Company employees and contract employees working on site. The impact for the stormwater program from training program is an increased awareness that spills and careless material handling can affect more than just the immediate area. An unrealized side benefit might be the employee thinking twice before dumping pesticide wastes or radiator fluid on the street at home and finding an alternate means of disposal. This is an area where the local municipalities and industry could work together.

<u>Regulatory Approach</u>

A final success is the approach taken by the regulators within our state. They have recognized the inherent limitations and pitfalls that exist within the regulation. But, more importantly, they have recognized that the intent of the current regulation is pollution prevention. As a result, they have provided a constructive and positive framework for most industry to work in. The enforcement focus has been on the recalcitrant industries which make no positive effort to correct overt problems or industries that could pose a significant risk to the public.

FUTURE DIRECTIONS

What is the future for the Industrial Stormwater Program? The Clean Water Act Reauthorization, which will dictate the future, is stalled for 1994 but the status of the stormwater portion of the Act will likely be addressed in the next congressional session.

Historically, new regulations demand an improvement in the ambient quality of the regulated media, be it air, water or solid waste controls. It is reasonable to expect that the new CWA will require some form of improvements in stormwater quality from both the municipal and industrial sectors of our economy. The timing, nature and level of improvement is still an open question. Will the new stormwater regulations mandate numeric standards or major structural changes to control the quality of stormwater discharges and move away from the current emphasis on pollution prevention?

Congress might be encouraged to adopt numeric standards for stormwater discharges as an expedient measure, particularly if the current round of monitoring data is taken out of context and used without a sound scientific base. Numeric standards and mandated structural controls could prove to be very costly for both industry and municipalities to implement and for the regulatory community to administer. The benefits of numeric standards and structural controls have yet to be adequately identified, much less quantified in receiving waters. It is important to understand at the outset of the program how the dollars spent on stormwater quality improvements will benefit the receiving waters. A recent editorial entitled "Costs of Cleanliness" (6/13/94)in the Washington Post called for "..a careful balancing of costs and benefits.." for environmental programs. The editorial noted that the current cost of environmental programs are "sufficiently large to effect the way the whole economy works".

As pollution prevention practices such as spill control, material handling and housekeeping improvements (non-structural Best Management Practices(BMP's)) are implemented within a facility under the current program, the major pollutant components should, directionally, be reduced and controlled for a relatively small cost. However, there are no provisions to quantify the change in stormwater quality as a result of the same improvements through the current sampling program.

The next increment of control, which include structural BMP's and involve major modifications to the infrastructure of a facility, could be very costly. Yet neither the short term nor the long-term effectiveness of the structural BMP's in controlling specific pollutants has been adequately defined to the point where the BMP's can be implemented with confidence. Therefore the ultimate cost per kilogram of pollutant controlled cannot be well defined and could be quite high.

<u>Basin Paradigm</u>

The air pollution arena provides some insight to a possible future program. The attainment or non-attainment status of a regional air basin is a determining factor in the level of control required for a discharging industry. The RACT (Reasonably Available Control Technology) and LAER (Lowest Achievable Emission Rate) criteria are used for determining a "reasonable" cost per ton of pollutant controlled against the local pollutant reduction requirements for the air basin. Both the RACT and LAER criteria are associated with a set of known control technologies and a related cost-per-ton of emissions controlled.

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A similar program could be used for stormwater discharges. The RACT/LAER approach would be used if a receiving water was not achieving a given stream quality criteria within a drainage basin. Based on the quantity and quality on the discharge water certain BMP's could be required if an existing facility is modified or a new facility is built within a given attainment or non-attainment drainage basin.

If a form of the air permit paradigm is used then a valid and enforceable algorithm which balances area of the country, individual stream flow and recovery factors, rain event factors, structural and non-structural control effectiveness factors, discharge flow and pollutant concentrations against a new stormwater stream standard (both chemical and biological standards) would be required. All sources, municipal, industrial and agricultural, contributing to the basin must be included and the control burden could be prorated on a mass/volume basis. This is recognized as being an extremely complex problem with no easy or inexpensive solutions. Creative and innovative solutions will be required. For example, a water pollutant trading program could be established for a basin where the most cost effective means of reducing contaminants is used to improve basin quality. The costs and credit for the reduction would be shared between industry point and non-point dischargers, sanitation district point dischargers and other non-point dischargers.

The cost and time to establish and implement an equitable and enforceable program nationwide will be tremendous. The subsequent monitoring and enforcement costs to both the regulated community and the regulators will also be very high. These costs must be balanced against the economic and quality of life benefits of the program.

Industry, through trade organizations and professional societies, must be an active participant in the development of any future stormwater discharge standards. For industry the costs associated with government regulations and mandated programs are increasing daily.

The current stormwater program, an integral part of a general pollution prevention program, is, in all likelihood, reducing the pollutant loading to the nations rivers and streams. If the United States is to maintain its competitive position in the world market then a very hard look must be given to the cost versus the true economic benefit for all new and reauthorized environmental programs. Industry must work diligently within our political framework toward the establishment of a rational and economically feasible stormwater program for the country in the future.

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STRATEGIES FOR USING NPDES STORM WATER DATA

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ABSTRACT:

This paper discusses monitoring requirements in the National Pollutant Discharge Elimination System (NPDES) storm water permitting program and reflects upon what has been learned since November 16, 1990, when the NPDES storm water program regulations were promulgated.

The monitoring required of regulated municipal separate storm sewer systems (MS4) and of storm water discharges associated with industrial activity are summarized. Examples of municipal separate storm sewer system monitoring are highlighted along with EPA's experience with the storm water monitoring data reported by industries for the group application process. Possible future directions for storm water monitoring for municipal and industrial NPDES storm water discharges are discussed.

INTRODUCTION:

The 1987 amendments to the Clean Water Act added Section 402(p) to the Act which directed EPA to establish and carry out a two-phase National Pollutant Discharge Elimination System (NPDES) storm water point source permitting program. To initiate this permitting effort, EPA published regulations on November 16, 1990 which defined the types of municipal and industrial storm water discharges that would be regulated under the first phase of the program,

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and which laid out specific permit application requirements. Storm water discharge monitoring requirements were an important part of the permit application process and will be an important component of NPDES storm water permits.

During the permit application process, storm water monitoring was required for regulated municipal separate storm sewer systems (MS4s) and storm water discharges associated with industrial activity. In general, the monitoring efforts yielded important information for NPDES storm water permit writers as well as for the permittees. However, a number of important lessons have been learned that should allow permitting authorities and the regulated community to simplify and strengthen storm water monitoring efforts in the future.

BACKGROUND:

The NPDES program provides three major tools for requiring and collecting monitoring data: permit applications; permit requirements; and information requests made pursuant to Section 308 of the Clean Water Act. Permit applications are generally national requirements which can provide a snapshot of the discharger once every five years (NPDES storm water permits are usually issued with a five year term). Monitoring data in permit applications is generally used for the purpose of supporting the issuance of the permit.

Although some monitoring requirements for NPDES permits are established in national regulations, such as the effluent guidelines, most permit monitoring requirements are established by permit writers on a permit-by-permit basis. This provides a great deal of flexibility to tailor monitoring requirements to each individual discharger. In addition, since permits are written for a five-year term, they can be used to require comprehensive monitoring programs that have the potential to evaluate discharge trends.

Requests for information under Section 308 of the CWA are usually done more on an as necessary basis, and can provide a mechanism to fill some of the gaps associated with applications and monitoring requirements in permits or to answer other necessary permitting questions.

The NPDES program takes two very different approaches to controlling pollutants in storm water discharges. Storm water requirements for industrial facilities are established in permits issued by EPA or by an authorized NPDES State. The second approach to storm water controls is through the involvement of municipal governments. Under this second approach, EPA or authorized NPDES States issue permits for discharges from municipal separate storm sewer systems which require the municipal permittee to develop and implement municipal storm water management programs.

One of the major differences between the industrial and municipal approaches is the programmatic flexibility available to develop monitoring programs. As discussed below, the NPDES program relies heavily on the use of general permits to authorize storm water discharges associated with industrial activity. In addition, industrial sites may be one of many sites in a watershed, or within a State, that discharges storm water. These factors tend to limit monitoring efforts to evaluating the nature of storm water discharged from a site and evaluating the effectiveness of the pollution prevention measures implemented at the site.

On the other hand, permits for municipal separate storm sewer systems have a much broader scope which allows consideration of more comprehensive monitoring approaches. As originally intended, storm water monitoring during the term of the NPDES permit for regulated municipal separate storm sewer systems was to be a flexible plan developed by the municipality, and approved by the permitting authority, to meet and support the purposes for the monitoring that the municipality itself identifies as important.

Monitoring for Municipal Separate Storm Sewer Systems (MS4s):

For municipal separate storm sewer systems (MS4) serving a population greater than 100,000, monitoring requirements were established as part of a two-part permit application. For the part 1 permit application, MS4s were required to report the results of field screening efforts to detect the presence of dry-weather discharges, e.g., illicit connections or illegal dumping. Visual observations, including simple colormetric tests, of dry weather flows were used to assist in identifying illicit connections. These were conducted at up to 500 major storm sewer system outfalls, depending on the size of the municipality. The part 2 permit application focused on reporting the results of wet-weather monitoring from representative municipal storm sewer outfalls in a plan approved by the appropriate permitting authority.

Wet-weather monitoring requirements for the part 2 permit application included submittal of quantitative data on physical and chemical characteristics of the discharge taken from at least 5 to 10 representative outfalls during 3 storm events; estimates of the annual pollutant load and event mean concentration of the cumulative discharges from all known municipal outfalls, and proposal of a schedule to provide seasonal loading and event mean concentration estimates for constituents detected during sampling for each major outfall.

Permits for discharges from municipal separate storm sewer systems will require the municipal permittee to develop and implement municipal storm water management programs which focus on implementing non-traditional control measures for priority sites and areas. The nature of these programs presents a number of opportunities that well-designed monitoring programs can support.

Monitoring for Storm Water Discharges Associated with Industrial Activity:

The NPDES regulations provided three different options for industrial facilities with storm water discharges to apply for permit coverage: individual applications; group applications; and submittal of a notice of intent (NOI) to be covered by a storm water general permit. Each option represents a distinct approach to collecting monitoring data.

Individual applications for most types of storm water discharges associated with industrial activity require site-specific narrative information, as well as monitoring data from a representative storm event. Individual industrial permit applications required monitoring for;

- Any pollutant limited in an effluent guideline to which the facility is subject
- Any pollutant listed in the facility's NPDES permit for its process wastewater (if the facility has an existing NPDES permit)
- O&G, pH, BOD_5, COD, TSS, total phosphorus, TKN, and nitrate plus nitrite nitrogen
- Any pollutant known or believed to be present [as required in 40 CFR 122.21(g)(7)]
- Flow measurements or estimates of the flow rate, the total amount of discharge for the storm events sampled, and the method of flow measurement or estimation
- The date and duration (in hours) of the storm events sampled, rainfall measurements or estimates of the storm event (in inches) which generated the sampled runoff, and the time between the storm event sampled and the end of the previous measurable (greater than 0.1 inch rainfall) storm event (in hours). In addition, individual applications must contain a certification that all storm water outfalls have been tested or evaluated for the presence of non-storm water discharges.
- Separate analyses were required for both a grab sample and a flow-weighted composite sample. Grab samples, only, were required for oil and grease and pH.

The Agency developed the group application process to lessen the monitoring burden on industrial facilities and to provide a large, nationally consolidated database of monitoring data from classes of industrial facilities. The

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group application process was intended to encourage similar types of industrial facilities to participate in one data collection effort, thereby compiling information on the class of facilities. EPA provided an incentive for industrial facilities to participate in a group application by only requiring a small percentage of the facilities in the group to monitor, provided the facilities were representative of the members in the group. Designated samplers in group applications monitored for the same requirements described for individual applications.

Over 65,000 industrial facilities representing 1250 groups initially participated in the group application process. Approximately 3,500 of these industrial facilities provided storm water monitoring data. This database represents the most comprehensive collection of storm water data from industrial facilities assembled to date.

The Agency is in the process of finalizing an innovative monitoring approach proposed in the multi-sector industrial storm water general permit based on the data received during the group application process. EPA used the data to identify pollutants of concern for each industrial sector, to help identify high priority industries for future monitoring under the permit, and for selecting the most appropriate pollution prevention measures and BMPs. Under the proposed multi-sector industrial permit, monitoring for the high priority sectors is designed as an incentive for industry to implement more effective storm water pollution prevention plans. Under this incentive, if storm water monitoring shows that pollutant concentrations are below specified levels, the industrial facility no longer is required to monitor under the permit.

Most storm water general permits for industry do not require monitoring data to be submitted during application for coverage. General permits for storm water may identify targeted classes of facilities to conduct monitoring as a condition of the permit. Several factors have helped shape the approaches to developing monitoring requirements in permits for storm water discharges associated with industrial activity, including the large number of facilities that need to be covered by permits, difficulties in sample collection, and variability of data.

The NPDES regulations provide that permits for most types of storm water discharges associated with industrial activity must, at a minimum, require dischargers to conduct annual site inspections to identify sources of pollutants to storm water and evaluate pollution prevention measures. This requirement does not preclude the establishment of additional monitoring requirements on a case-by-case basis by the permit writer.

The baseline storm water general permit issued by EPA for industrial activities provides that most types of facilities do not have to conduct monitoring, but must conduct the annual compliance site evaluation. Under this permit, priority facilities that are thought to present higher risks have been required to conduct chemical monitoring of their storm water discharges in addition to conducting the annual inspections.

EPA has initially targeted classes of industrial facilities that need to conduct storm water monitoring on the basis of available information and best professional judgement. Monitoring requirements are intended to help regulators and permittees identify sources of pollution at facilities, evaluate the risk posed by the storm water discharges, evaluate the effectiveness of control measures and establish a database to support more applicable and effective permit requirements in the future.

For any NPDES permittee monitoring their storm water discharge, data collection procedures described in 40 CFR §122.21(g)(7) are required to be followed. Analytical methods are required to be conducted in accordance with 40 CFR Part 136.

Under 40 CFR §122.21(g)(7), specific storm event criteria were defined within which storm water sampling was required to be conducted:

- Rainfall depth must be greater than 0.1 inch.
- The storm must be preceded by at least 72 hours of dry weather
- Where feasible, the depth of rain and duration of the event should not vary by more than 50 percent from the average depth and duration.

These additional technical criteria were established to: (1) ensure that adequate flow would be discharged; (2) allow some build-up of pollutants during the dry weather intervals; and (3) ensure that the storm would be "representative," (i.e., typical for the area in terms of intensity, depth, and duration). Collection of samples during a storm event meeting these criteria also ensures that the resulting data will portray more consistent conditions at each site. However, the permitting authority was authorized to approve modifications of these criteria, especially for applicants in arid areas where there are few representative events.

EPA published a storm water monitoring guidance document that describes in detail the methods used for storm water discharge monitoring (5).

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MUNICIPAL STORM WATER MONITORING RESULTS:

To illustrate potential uses of wet-weather monitoring data in support of municipal storm water management programs, highlights from the cities of Austin, TX, and Charlotte, NC and the counties of Santa Clara Valley, CA and Montgomery County, MD are discussed below. In addition, a brief discussion is provided on the use of monitoring data to support watershed planning activities in the State of Wisconsin. These examples illustrate how storm water monitoring has been put into practice at various levels. It should be emphasized that these are not the only approaches that may be adopted. Recent studies using biological and habitat assessments suggest that there are a number of cost-effective techniques to accurately assess the extent of impacts associated with storm water discharges (19, 20, 23, 25, 27, 28).

Storm Water Monitoring in Austin, TX:

Austin, TX has maintained a storm water monitoring program for over 10 years. The purpose of the program is to collect information on the quality of urban runoff, evaluate the performance of structural controls, and to support the development of design guidelines for storm water quality controls (16). The impetus for this program was to support efforts at protecting several environmentally sensitive watersheds. These watersheds serve as a source of groundwater recharge to the Edwards Aquifer which discharges to Barton Springs (an important recreation resource) or to two lakes that serve as the primary drinking water supply for the city. The storm water monitoring program in these watersheds is used to support the implementation of the city's watershed protection ordinances.[5]

In a five year summary of results (1984 to 1988), the city monitored at seven sites corresponding to watersheds or catchments ranging from 3 to 371 acres in size (16)[6]. The percentage of impervious cover at these sites ranged from 3% to 95%. With the exception of the control watershed and a low-density residentially developed site, all other watersheds or catchments had structural controls that provided detention and/or filtration.

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[5]Austin's storm water monitoring program is also augmented by a cooperative monito..ng program with USGS.

[6]The sites monitored included one undeveloped watershed serving as a control, four catchments coinciding with either low or medium density residential development, one high-developed mix between residential and commercial and one highly developed commercial. Five of the seven sites were substantially below 100 acres in size.

A separate study of sampling data (17) found that:

- First flush concentrations were notably higher compared to average concentrations from a subsequent sampled runoff intervals;

- A majority of pollutants are not washed away from impervious surfaces during the first 1/2 inch of runoff. As the amount of impervious surface increases, there is a generally negative trend in the percent removed in the first 1/2 inch of runoff as the volume of runoff increases. A significant pollutant loading will continue to exist if storm water controls are designed to only treat the first 1/2" of runoff.

In addition, analysis of rainfall and sampling data resulted in the development of percent annual pollutant loading curves expressed on the basis of runoff amount and degree of impervious cover. An additional study of monitoring data (1984 to 1989) yielded estimates of removal efficiencies for various structural controls (18). The study also examined the effects of design and maintenance on removal efficiency. The results are used as a basis of maintaining design guidelines for storm water quality control structures (15).

Charlotte, NC In-Stream Water Quality Problem Rating Scheme:

The City of Charlotte, NC has developed a stream problem rating system which is designed to characterize and prioritize stream segments based on a series of pollutant parameters believed to reflect water quality conditions in the stream segment (14). More specifically, the City has developed limiting concentration ranges for a number of indicator pollutants which are segregated into three action rating levels; No Action, Watch, and Action. In order to develop a reliable rating system, the City consulted numerous information sources currently in existence, e.g., NC Sanitation Foundation Index, NC Water Quality Index, 305(b) reports, and water quality standards for the State of North Carolina. Specific range limits were established for dissolved oxygen, fecal coliform, PO_4-P, NO_3-N, BOD_5, total solids, pH, turbidity, lead, and zinc. An exceedance frequency was then developed for each pollutant which established the number of times a limiting concentration could be exceeded before a stream segment was classified as either in the Watch or Action levels. Using a Geographic Information System (GIS), monitoring data were then sorted in order to establish an action level for each stream segment. Charlotte's Part 2 Permit Application indicates that for 27 individual stream segments, the majority of the monitored stream segments were rated as either Action or Watch for all indicator pollutants except for total solids and pH.

The City also developed an action-level correlation matrix for each indicator pollutant based on typical pollutant sources or activities. These sources or activities include; construction runoff, sanitary sewers, fertilizer application, industrial facilities, transportation, illicit connections, agriculture runoff, wastewater treatment plant discharges, residential runoff, and animal waste. The matrix can be used to investigate the most likely source of a problem based on the action level produced for an individual stream segment.

Santa Clara Valley Non-point Source Pollution Control Program:

Santa Clara Valley Water District (SCVWD) is the lead or managing agency working in cooperation with 14 other California municipalities addressing issues related to non-point source pollution control. The purpose of monitoring to collect data necessary to assess compliance with a copper wasteload allocation established for the San Francisco Bay (a 304(l) listed waterbody), and to monitor for pollutants that have caused frequent exceedances of numeric water quality objectives (WQO) (24).

In their FY92-FY93 Annual Report, Santa Clara Valley reported that acute water quality objectives are frequently exceeded for total copper and total zinc, and sometimes for total lead. Chronic water quality objectives are frequently exceeded for total copper, total zinc, and total lead. The Report further notes that acute exceedances were not observed for the dissolved metal concentrations and infrequent chronic exceedances were observed for dissolved metals. Chemical analyses were performed on flow-weighted composite samples collected from several in-stream monitoring stations. The results of the toxicity testing revealed that collected samples were toxic to *Ceriodaphnia*, however, test results were variable based on the season that samples were collected.

Statistical analysis of the data revealed that long-term trend analysis could be performed for a number of pollutants at two stream stations (one in the Guadalupe River and one in Coyote Creek). Conversely, data variability was observed to be much greater at two other in-stream stations (Calabazas Creek and Sunnyvale East Channel). The Annual Report noted that statistical methods would allow for grouping of the data for long-term trend analysis from Calabazas station with that of Guadalupe River and Coyote Creek stations. Extensive channelization in the Sunnyvale East Channel is believed to be a reason that monitoring data cannot be used with other stations for long-term trend analysis (24).

Santa Clara Valley has also instituted a comprehensive source identification program to identify potential sources and land uses suspected of contributing significant amounts of toxic metals. For example, Santa Clara Valley recently completed a study of the contribution of heavy metals from automotive brake pads (Woodward-Clyde 1994). The results of this study suggest that brake pads

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could potentially contribute on average between 53%, 3%, and 6% of the total annual loads for copper, lead, and zinc, respectively[7]. Santa Clara Valley has also instituted a toxicity control program (TCP) in an effort to identify appropriate measures to reduce toxicity.

Montgomery County, MD's Alternative Monitoring Strategy:

Montgomery County, MD is a MS4 regulated under Phase I of the NPDES Storm Water Program. The County is proposing an alternative to the historical emphasis on accumulating chemical and physical water quality data (29). The County has noted that focusing exclusively on traditional monitoring approaches, i.e., chemical-specific monitoring, is not necessarily the most appropriate means for accurately assessing impacts associated with storm water. In particular, the County recognizes that the effects of storm water discharges are cumulative in nature (e.g., anthropogenic enrichment of streambed sediments, degradation of aquatic habitat, and loss of benthos and fish species diversity) and cannot be exclusively attributed to urban runoff quality alone. Consequently, the County is proposing to use bioassessment techniques, complemented with physical and stream habitat assessments.

The County's strategy includes the collection of baseline data necessary for the development of biological water quality criteria and envisions the eventual development of aquatic life use classes that contain biological, chemical, and physical attainment criteria. This approach is expected to provide the basis of conducting long term trend assessments of receiving water quality (29).

For example, the County suggests that the degree of impairment could be plotted along the entire reach of a stream segment, similar to an approach currently in practice by Ohio EPA. Those areas which indicate significant impairment would be specifically targeted for further investigation and would also serve as a basis of documenting management program effectiveness. The County's proposed monitoring program is intended to reflect the movement towards holistic approaches to ecosystem protection.

Wisconsin DNR Priority Watershed Planning:

In recent years, numerous States and municipalities have instituted comprehensive watershed planning processes for storm water management. Wisconsin DNR has established a watershed approach as part of its Priority Watershed Planning Program (21). The program consists of three major components; a priority watershed plan, an engineering feasibility study, and an

[7]Estimates for copper ranged from approximately 19% to 75% of the total annual load to South San Francisco Bay. Similarly, the range for lead and zinc were estimated to be approximately between 1% to 4% and 2% to 9%, respectively.

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implementation phase. There are a number of elements contained within the priority watershed plan, they include:

a. **Identification of Current and Desired Beneficial Uses:** This element includes results of fish and benthos surveys that quantify existing levels of use. Other habitat surveys may also be included.

b. **Problem Evaluation:** This element includes evaluation of problems that are contributing to impairment of the water resource and, therefore, preventing the attainment of designated uses. Evaluations have included habitat and streambank inventories to determine the suitability of resources to support different aquatic life beneficial uses. This information in conjunction with fish/benthos surveys can then be used to determine the extent of impairment and to identify possible sources contributing to the impairment[8].

c. **Sources of Problems:** This element addresses specific problem sources that are believed to be contributing to receiving water impairment. A distinct aspect of this element of the program is its extensive use of the Source Loading and Management Model (Pitt 1991). Unlike many other urban runoff models in practice, SLAMM was specifically designed as a planning tool for storm water quality management and did not originate as a flood control planning and design tool.

Since storm water impacts are principally cumulative in nature, SLAMM data inputs focus on watershed and land use development characteristics. Consequently, SLAMM is intended to provide information on the significance of different sources, control measures, and drainage characteristics on urban runoff quality[9].

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[8]For example, the inability of urban resources to meet their designated uses was frequently attributed to periodic flooding and poor water quality. The results of these evaluations could lead to the adoption of goals to reduce streambank erosion, including establishing flow reductions in order to prevent flushing of spawning areas and protection of fish refuge areas (22).

[9]SLAMM represents a tradeoff between the cost of extensive data collection and providing information to support planning level decision-making. It also provides an opportunity to quickly consider the costs and benefits of many different control strategies. The development of SLAMM's specifically focuses on the hydrological characteristics of frequent small storm events which are critical in storm water quality investigations (21, 22).

d. **Identification and Evaluation of Suitable Source Area, Drainage System, Outfall, and Receiving Water Controls:** Once problem sources (pollutants and flows) have been identified, this element focuses on the selection of different control strategies. In particular, selecting the individual or mix of controls effective in removing the types of pollutants found, e.g., particulate vs. dissolved metals. SLAMM model output includes pollutant concentrations (particulate & dissolved), flow, and estimate control costs on an areal basis.

e. **Selection of Urban Runoff Control and Habitat Improvement Program:** In this element, the most effective control strategy is selected after considering other programmatic factors including cost.

The second major component of the Wisconsin Priority Watershed Planning program is the engineering feasibility analysis which follows the completion of the watershed plan. Since, the watershed plan is structured around general land use categories, the engineering feasibility analysis allows for consideration of site specific conditions within a particular watershed or basin that may limit or prohibit the use of control strategies identified in the watershed plan.

a. **Site Specific Area Availability, and Groundwater and Infiltration Conditions:** This element considers potential options for the siting of controls, including retrofit opportunities. Other considerations include identification of sites to promote infiltration provided infiltration rates and groundwater conditions satisfy established standards.

b. **Flooding and Drainage Benefits of Water Quality Controls:** SLAMM cannot be used to perform hydraulic analyses, therefore drainage or local flooding conditions may be required to determine the potential benefits of siting storm water quality controls.

The final component of the planning process is the implementation phase which entails the development of a cost-sharing agreement. Using information from the previous planning steps, the agreement specifically identifies types of cost-sharable projects that may eligible for matching State funds.

EPA also reviewed available sampling data and information from 23 municipal part 2 permit applications located throughout the U.S. The purpose of this review was to obtain a greater appreciation of the efforts involved in collecting storm water sampling data and to gain some insights on the results. Of these 23 municipalities, at least 14 provided some sampling data which could be used for further analysis. Due to the substantial differences in the amount of sampling data between municipalities and gaps in data, this paper does not attempt to draw conclusions about national trends with respect to the pollutant concentration values. However, sufficient information was available from permit applications, to support some general observations:

- Residential and commercial areas represented an estimated 31% and 27% of sites sampled, respectively[10];
- Approximately 96% of the sampled sites corresponded to a single land use classification;
- The median size of the catchments or watersheds sampled was estimated at 47 acres and ranged in size from 8 to 2,252 acres[11].
- The median value for sampled watershed impervious area was estimated at 47%.
- The average number of sampled sites was estimated to be 6, and ranged from 3 to 10.
- The median and average number of sampled storm events was estimated to be 7 and 12, respectively. An estimated 80% of the municipalities sampled more than the minimum 3 representative events required. Approximately 47% sampled more than 10 storm events.
- Approximately 8 municipalities reported that storm event characteristics were consistent with EPA criteria or satisfied modifications in the criteria by State permitting authorities. Most municipalities reported difficulties with start-stop events, meeting the 72 hours of dry-weather, and/or achieving a total rainfall accumulation greater than 0.1 inch.

[10]Information on land use type was provided for 36 sampling sites.

[11]This does not include several watersheds monitored by USGS which ranged in size from 4,032 acres (6.3 sq. mi) to 74,240 (22.3 sq. mi.).

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RESULTS OF GROUP APPLICATION MONITORING:

The discharge data collected under the NPDES Storm Water Group Application process is perhaps the largest and most comprehensive industrial storm water discharge data set compiled to date. The data set includes the monitoring results from approximately 3,500 industrial facilities which were selected as representative of their larger industry groups. The data includes results collected from a wide variety of industrial activities. It includes data submitted by manufacturing facilities with little exposure of activities to storm water such as electronic manufacturing facilities to facilities with high degrees of exposure such as scrap recycling facilities. Table 1 lists the sectors of industrial activities for which data was received and analyzed.

There are, however, a number of limitations to the data set which should be considered when analyzing and reviewing the data. The following paragraphs describe some of these limitations.

Monitoring Facilities Were Not Selected Randomly:

The facilities which were designated as samplers in the group application process were not selected at random. The group application requirements established a number of criteria which the monitoring sub-group was required to satisfy. These criteria, which are described in the previous section, were designed to ensure geographic distribution, and representation of the various significant materials and material management practices. EPA required a group to satisfy these criteria prior to approving Part 1 of the application. EPA did not require the groups to randomly select their facilities, therefore once the application criteria were satisfied, a group organizer had discretion in the selection facilities to be monitored.

Monitoring and Analyses Were Typically Performed for Only One Storm Event:

The regulations require facilities to submit analytical results for samples collected from one representative storm event (see the previous section for a discussion of the representative storm event requirements). A significant majority of the facilities limited their monitoring to one storm event, therefore the data does not reflect any variation in concentration that may occur at a facility from storm event to storm event.

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TABLE 1

INDUSTRIAL SECTORS/GROUP APPLICATIONS	
SECTOR	**ACTIVITIES REPRESENTED**
1	Timber and Wood Products
2	Paper and Allied Products
3	Chemicals and Allied Products
4	Lubricants and Asphalt Products
5	Stone, Clay, Glass and Concrete Products
6	Primary Metal Industries
7	Ore Mining and Dressing
8	Coal Mining
9	Oil and Gas Extraction
10	Mineral Mining and Dressing
11	Hazardous Waste Treatment Storage or Disposal Facilities
12	Industrial Landfills, Land Application Sites and Open Dumps
13	Used Motor Vehicle Parts
14	Scrap and Waste Materials
15	Steam Electric Power Generating Facilities
16	Railroad Transportation Vehicle Maintenance Areas
17	Vehicle Maintenance Areas at Truck Terminals, Bus Terminals, Bulk Petroleum Stations, and Postal Service Facilities
18	Water Transportation Vehicle Maintenance Areas
19	Ship Building and Repairing, and Boat Building and Repairing
20	Air Transportation Vehicle Maintenance Areas
22	Domestic Wastewater Treatment Plants
23	Food and Kindred Products, and Tobacco Products
24	Textile Mill Products, and Apparel and Other Fabric Products
25	Furniture and Fixtures
26	Printing Publishing and Allied Industries
27	Rubber and Misc. Plastic Products
28	Leather and Leather Products
29	Fabricated Metal Products
30	Industrial and Commercial Machinery, and Transportation Equipment
31	Electronic and other Electrical Equipment and Components, Measuring, Analyzing, and Controlling Instruments; Photographic and Optical Goods; Watches and Clocks

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Only Half of the Designated Samplers Are Included in the Data:

There were over 6,800 designated samplers from the approved group applications, however, only about 3,500 of these facilities submitted data by the deadlines for EPA to incorporate their data into the analyses. The remaining facilities were not able to meet the application deadline primarily due to a lack of representative storm events during the time frame in which they intended to sample.

Monitoring and Analyses Were Performed by the Permit Applicants:

All data were submitted to EPA by the permit applicants. None of the monitoring or analyses were performed by the Agency. Applicants were required to collect samples in accordance with the regulations under 40 CFR Part 122.21 and analyses were required to be performed in accordance with approved methods under 40 CFR Part 136.

Permit Applicants Determined if They Were Required to Sample for a Portion of the Pollutants:

Within part VII.C of the Storm Water Permit Application form 2F there are a number of pollutants which an applicant is required to sample if he or she "'knows or has reason to believe'... are present in an effluent based on an evaluation of the expected use, production, or storage of the pollutant or on any previous analyses for the pollutant."

Analyses of the Group Application Monitoring Data:

Group application monitoring data were entered into a data base for analyses. Applicant's monitoring data were categorized into one of 31 industry sectors (See Table 1). Categorization was based upon the Standard Industrial Classification (SIC) code of the facility when provided, or upon the narrative description of the industrial activities at the facility when an SIC code was not included in the application. Data within each sector was analyzed separately.

Prior to analyses, units for each of the pollutant data values were standardized to mg/L (except pH, fecal coliform and several other pollutants not measured in mg/L). Pollutant values reported as below detection limit, or not detected were assigned a concentration of 0.0 mg/L for the statistical analyses.

Analyses of the data were performed using the UNIVARIATE procedure of SAS (SAS is a statistical analyses software package developed by the SAS Institute). For each pollutant sampled at least once within each sector, the following statistics were calculated:

Total Number of Observations,
Total Number of Non-Detects Reported,
Total Number of Detects Reported,
Mean Concentration,
Standard Deviation,
Minimum Concentration,
Maximum Concentration,
Median Concentration (the concentration which was greater than half of the

values reported),
95th Percentile Concentration (the concentration which was greater than 95 percent of the values reported), and
99th Percentile Concentration (the concentration which was greater than 99 percent of the values reported).

Statistics were calculated separately for the grab samples and for the flow proportional samples. Tables 2 and 3 present a portion of the results of the analyses. Table 2 lists median pollutant concentration of the grab samples for select pollutants. Table 3 lists median pollutant concentrations of flow proportional composite samples for select pollutants.

Use of the Group Application Data in Permit Development:

The results of the group application data analyses were utilized by the permit writers to develop targeted pollution prevention plan requirements and to select industries and pollutants for further monitoring.

Permit writers utilized the monitoring data to identify pollutants which are likely to be present in high concentrations for an industry sector. They then identified the potential sources of the pollutants and selected pollution prevention measures or structural controls which could be practicably implemented or installed at an industrial facility.

Development of Permit Monitoring Requirements:

The selection of industry sectors for monitoring under the terms of the permit was based in part upon the results of the group application monitoring data. Discharges from the following industries were identified as requiring analytical monitoring as a result of the prioritization analysis: facilities engaged in wood preserving or wood surface treatment, chemical and allied products manufacturing facilities, concrete and clay products manufacturing facilities, primary metals facilities, ore mining and dressing facilities, landfills and land application sites, scrap and waste material processing and recycling facilities, steam electric generating facilities, ship and boat building and repair yards, waste water treatment works, food and kindred products facilities, leather tanning and finishing facilities, and fabricated metal products facilities.

Table 2 - Median Pollutant Concentrations (mg/l) in Grab Samples of Industrial Storm Water Discharges

Sect.	BOD_5	COD	TSS	TKN	NO_2, NO_3	Total P	Total Cu	Total Pb	Total Zn
1	13	131	242	1.6	0.32	0.29	0.03		0.37
2	8	61	41	1.8	0.50	0.18			
3	7	58	40	1.9	0.80	0.24	0.01	0.01	0.24
4	7	48	93	1.1	0.30	0.14			
5	5	51	200	1.2	0.60	0.28	0.02	0.01	0.14
6	11	71	72	2.0	0.68	0.17	0.10	0.02	0.45
7	9	71	403	2.6	0.75	0.30	0.14	0.00	0.59
8	2	6	150	2.6	0.40	0.04			
9	10	82	75	0.8	0.15	0.18			
10	5	33	181	1.1	0.65	0.20			
11	12	41	128	1.3	0.50	0.10			
12	7	31	633	1.1	0.50	0.50		0.08	
13	6	61	183	1.9	0.83	0.05			
14	9	120	148	2.1	0.61	0.29	0.26	0.21	1.40
15	4	33	44	1.3	0.36	0.29	0.00	0.00	0.05
16	6	118	172	1.5	0.92	0.54			
17	8	64	104	1.4	0.60	0.33	0.01	0.01	0.13
18	7	93	135	1.6	0.60	0.10		0.05	0.22
19	3	53	17	1.0	0.72	0.00	0.15	0.04	
20	8	44	29	1.6	0.41	0.20	0.03	0.02	0.08
22	12	69	68	1.5	1.09	0.50	0.01	0.00	0.07
23	14	77	73	2.4	0.56	0.56	0.04	0.01	0.21
24	8	44	36	1.7	0.39	0.15	0.01	0.02	0.19
25	9	83	130	1.7	0.90	0.20	0.04		0.78
26	9	49	30	1.5	0.82	0.14	0.03	0.03	0.37
27	7	53	44	1.4	0.58	0.19	0.00		0.19
28	11	82	49	4.3	1.20	0.16			
29	8	56	76	1.4	0.74	0.22	0.03	0.00	0.36
30	6	36	30	1.3	0.58	0.14	0.01	0.00	0.20
31	6	46	29	1.0	0.51	0.13	0.00	0.00	0.09

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Table 3 - Median Pollutant Concentrations (mg/l) in Flow Proportional Composite Samples of Industrial Storm Water Discharges

Sect.	BOD_5	COD	TSS	TKN	NO_2 NO_3	Total P	Total Cu	Total Pb	Total Zn
1	17	122	230	1.5	0.33	0.30	0.03		0.30
2	8	51	13	1.8	0.47	0.16			
3	6	41	25	1.7	0.82	0.22	0.00	0.01	0.24
4	4	50	46	1.0	0.3	0.15			
5	4	44	149	1.0	0.60	0.25	0.04	0.01	0.18
6	8	60	69	1.6	0.77	0.14	0.07	0.02	0.43
7	6	160	330	3.2	0.86	0.38	0.09	0.05	0.66
8	4	14	251	1.5	0.61	0.00			
9	7	92	48	0.9	0.12	0.07			
10	5	37	296	0.8	0.76	0.24			
11	7	34	32	0.9	0.34	0.09			
12	4	28	370	1.0	0.50	0.38		0.18	
13	6	60	226	1.8	1.32	0.11			
14	9	110	85	2.2	0.80	0.29	0.22	0.22	1.70
15	4	39	40	1.0	0.45	0.27	0.02	0.07	0.06
16	6	89	90	1.4	0.78	0.45			
17	6	48	67	1.1	0.52	0.30	0.01	0.00	0.11
18	6	51	68	0.8	0.65	0.17		0.00	0.21
19	1	28	8	1.0	0.72	0.06	0.09	0.01	
20	5	36	22	1.4	0.43	0.20			0.04
22	8	61	56	1.3	0.87	0.44	0.02	0.00	0.06
23	11	63	54	2.0	0.55	0.48	0.03	0.01	0.24
24	7	37	22	1.5	0.40	0.11	0.01	0.03	0.21
25	6	73	91	1.3	0.68	0.19	0.00		0.40
26	6	39	28	0.8	1.05	0.13	0.03		0.52
27	7	43	30	1.2	0.67	0.16	0.05		0.24
28	10	50	86	3.5	0.9	0.18			
29	7	48	32	1.2	0.76	0.21	0.02	0.00	0.21
30	5	29	17	1.1	0.45	0.13	0.01	0.00	0.14
31	5	24	14	1.01	0.51	0.16	0.00	0.00	0.09

Observations Derived from the Group Application Data:

Despite the limitations discussed, the data collected through the NPDES storm water group application process contains a great deal of information regarding the quality of storm water discharges associated with industrial activity.

The concentration of pollutants in storm water discharges varies widely among facilities within an industry sector and between the different industry sectors. A number of factors influence the concentration of pollutants in storm water discharges associated with industrial activities, including: the amount and types of materials exposed to storm water; the amount and intensity of rainfall; and the types of best management practices employed at a facility. Given the number of factors influencing pollutant concentrations, and the wide variation in conditions at the facilities conducting sampling, it is not a surprise that discharge concentrations of pollutants vary a great deal. Figures 1 and 2 illustrate this variation for total suspended solids (TSS) concentrations in storm water discharges. Figure 1 is a plot of the cumulative distribution of TSS concentrations in discharges from all industry sectors. Figure 2 is a plot of the cumulative TSS concentration distribution for discharges only from scrap recycling facilities.

The highest pollutant concentrations were generally found at industries with the most industrial activity exposed to storm water. While industrial activity is not the only factor that influences the presence of pollutants in storm water, the data do show that there are generally higher concentrations of pollutants found in storm water discharges from facilities where the majority of activities are performed outdoors as opposed to facilities where activity generally takes place indoors. Figures 3, 4 and 5 compare the levels of pollutants from three high exposure industries (ore mining and dressing, industrial landfills and scrap recycling facilities) to three low exposure industries (furniture and fixture manufacturing, printing and publishing, and electronic equipment and instrument manufacturing). Figure 3 compares median concentrations for three conventional pollutants. Figure 4 compares median concentrations for nutrients and Figure 5 compares median concentrations of metals.

MONITORING NEEDS IN THE FUTURE:

Municipal Storm Water Monitoring:

Revision of Municipal Application Requirements:

The existing NPDES permit application requirements for discharges from municipal separate storm sewer systems serving a population of 100,000 or more were designed to provide information for first round permits. A major goal of these applications was to provide an initial description of the system and its discharges. The application used a number of sources of information to address this goal, including narrative descriptions of land use, rainfall data, site inspections of selected outfalls to screen for problems associated with non-storm water discharges and limited discharge monitoring data. As municipal storm water programs evolve, issues such as program effectiveness and identification of specific water quality problems become more important so that limited resources can be more effectively targeted to address these problems.

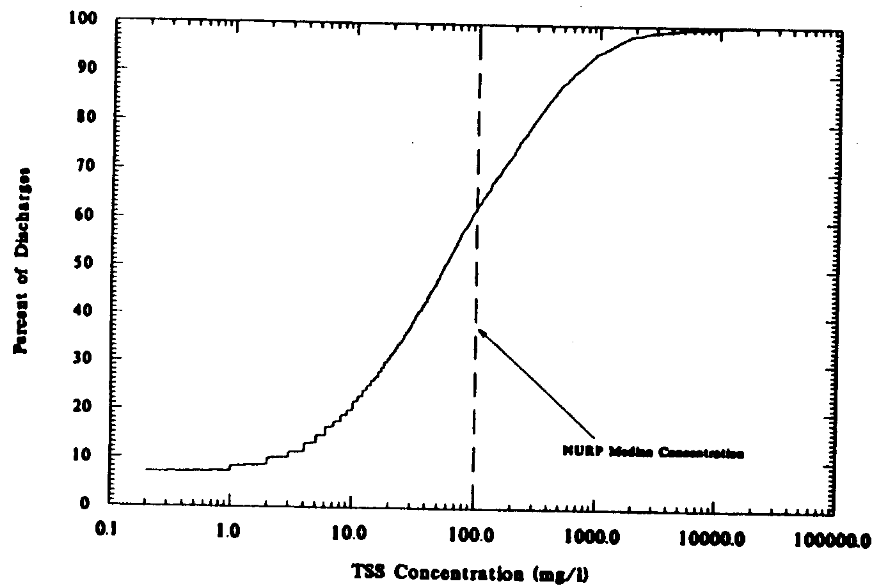

Figure 1. Cumulative Frequency Distribution of TSS Concentrations In Storm Water Discharges From ALL Industry Sectors

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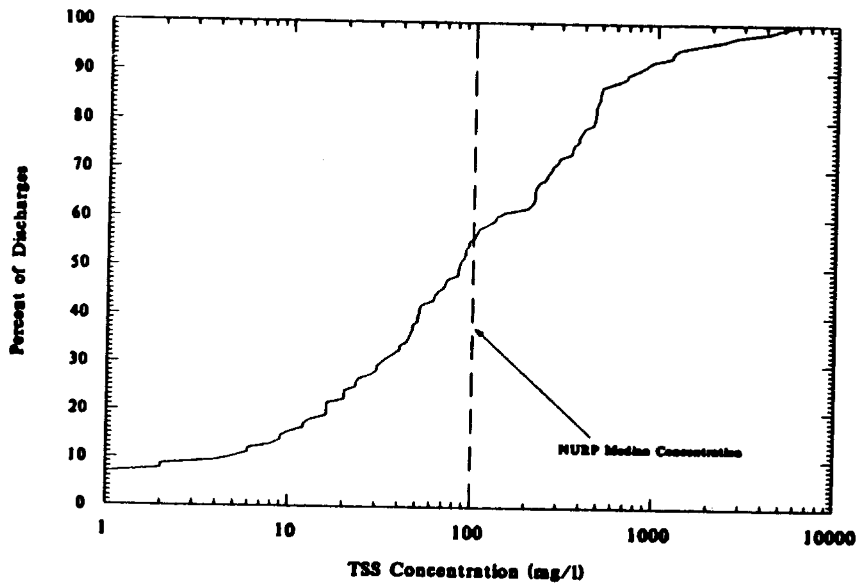

Figure 2. Cumulative Frequency Distribution of TSS Concentrations In Storm Water Discharges From Scrap Recycling Facilities

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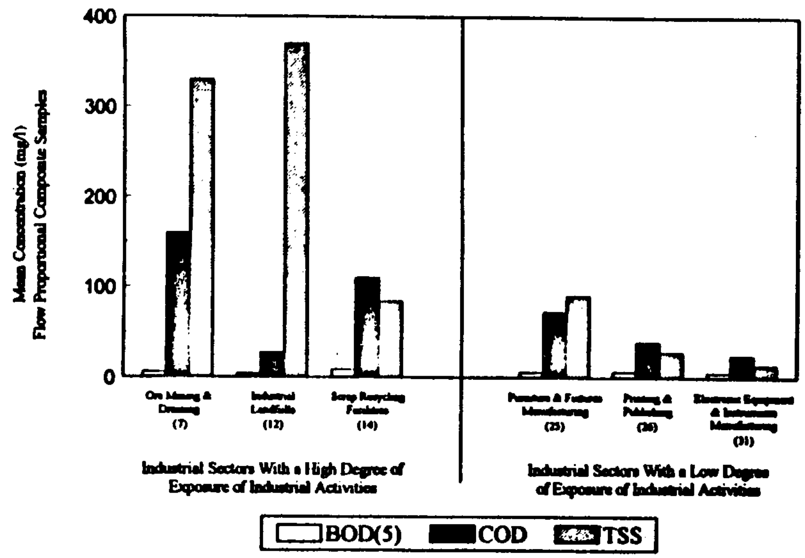

Figure 3. Comparison of Conventional Pollutant Concentration In Storm Water Discharges from Industry Sectors With High vs. Low Levels of Exposure

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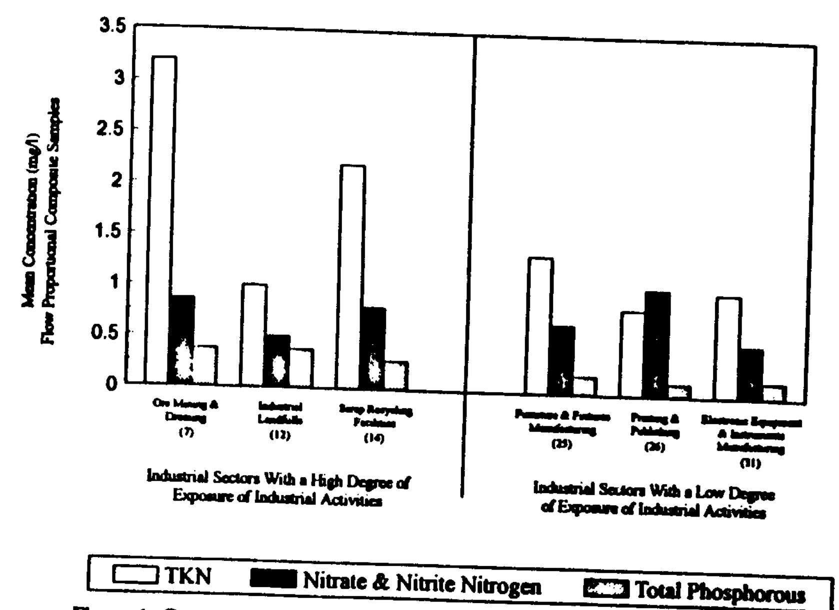

Figure 4. Comparison of Nutrients Concentration In Storm Water Discharges from Industry Sectors With High vs. Low Levels of Exposure

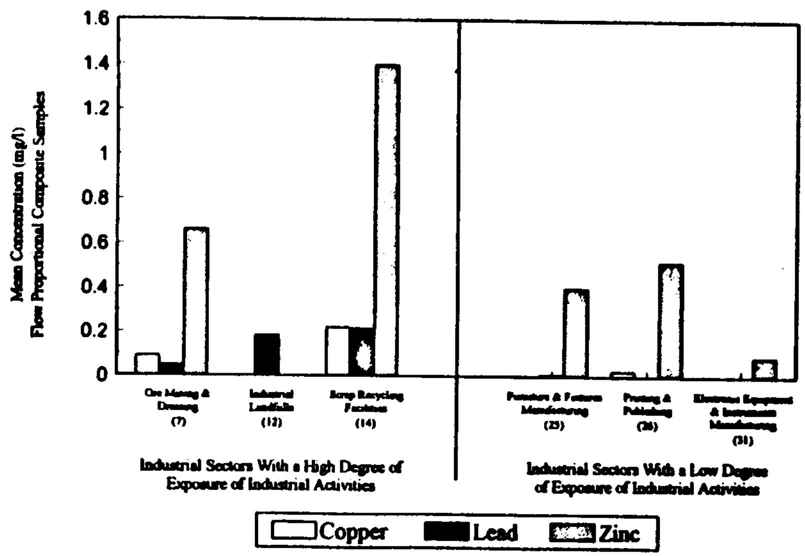

Figure 5. Comparison of Metals Concentration In Storm Water Discharges from Industry Sectors With High vs. Low Levels of Exposure

In addition, site-specific requirements for monitoring programs will give individual municipalities direction to their monitoring efforts. These factors will change the monitoring requirements in future municipal storm water permit applications. This change in emphasis may result in a shift from discharge monitoring to the use of alternative monitoring tools such as environmental indicators.

For many types of municipal storm water controls, municipalities will be required to identify priorities for implementation. Priorities for implementing controls will be based on a number of factors, including the potential for discharges to cause or contribute to water quality impacts, the nature of the discharge, and the effectiveness of potential management measures, the geographic location of the municipality, the size and type of receiving water body and the resources available to the municipality. Providing useful information to evaluate these factors should be a major consideration in the development of monitoring requirements in permits for municipal separate storm sewer systems (MS4s).

In addition, application requirements must be developed for any additional "Phase II" municipal separate storm sewer systems that are brought under the NPDES program in the future. One goal of the NPDES program for municipal separate storm sewer systems will be to strongly encourage municipalities to take regional and watershed approaches that involve interaction and coordination amongst municipalities. One critical programmatic step that can be taken to encourage regional/watershed approaches is to synchronize the resubmittal of applications for municipal separate storm sewer systems currently subject to the program with the first time submittal of applications for surrounding "suburban" Phase II municipalities. Failure to synchronize these submittals will greatly decrease opportunities for municipalities to coordinate storm water monitoring efforts, and may result in independent, uncoordinated efforts by individual municipalities.

Use of Biological Assessment Methods:

Given the complex nature of storm water impacts and attempts to put issues associated with urban runoff quality in the proper context with other runoff related problems (e.g., flooding, aquatic habitat degradation, and sediment enrichment), one prevailing misconception is the need to focus exclusively on urban runoff quality.

Despite the emphasis in the permit application on pollution prevention and identifying potential pollutant sources, it is important to be aware of the significance of other contributing sources. More specifically, practices which produce excessive amounts of runoff, frequently result in substantial alterations to aquatic habitat, e.g., streambank erosion, streambed instability, loss of refuge areas, anthropogenic-enrichment of bed sediments, flushing of juvenile aquatic life forms, and siltation of spawning areas. An example from the State of Ohio illustrates this point.

Lessons from Ohio's Ecological Assessment Program:

Ohio recently adopted numeric biological criteria for its State Water Quality Standards (WQS). A comparison between measured biological impairment and

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chemical water quality criteria exceedance frequency revealed that biological impairment was evident in nearly 50% of assessed segments where no ambient chemical water quality criteria exceedances occurred (27). This result could suggest that chemical water quality criteria are not stringent enough, however, Ohio observed that in cases where only biological impairment was observed, the causes of impairment, principally low dissolved oxygen/organic enrichment, habitat alteration, and siltation, are not directly measured by chemical specific monitoring, with the exception of low dissolved oxygen.

Chemical causes of impairment were observed in 30.7% of assessed segments. However, the ability to detect chemical exceedances is heavily dependent on other factors such as adequate sampling frequency and the selection of monitoring parameters. More importantly, however, Ohio's experience underscores that both chemical and non-chemical causes can simultaneously contribute to biological impairment which is only evident using bioassessment techniques (27, 28).

Limitations of Chemical-Specific Monitoring:

As noted above, a prevailing misconception is that monitoring requirements during the permit term must focus exclusively on chemical-specific monitoring. Chemical-specific monitoring does not necessarily result in a good representation of receiving water impacts due to storm water discharges. Furthermore, relying extensively on chemical-specific monitoring data as a basis of prioritizing the investment of resources could lead to inadequate coverage of other areas that are greater sources of receiving water impairments. Numerous papers on this subject have noted the growing trend to use other techniques (e.g., bioassessments, habitat evaluations, and sediment analysis) for assessing receiving water impacts (19, 20, 23, 25, 27, 28).

Monitoring During the Permit Term:

The regulations, as they apply monitoring during the permit term, do not specifically require MS4s to perform chemical-specific monitoring only. The regulations provide flexibility to a MS4 to design a monitoring program to support the objectives of their storm water management program. However, MS4s should take into consideration three significant factors when designing a monitoring program:

1. Complying with the statutory provision that effectively prohibits non-storm water discharges into storm sewers;

2. Information to support a determination that pollutants are being reduced to the maximum extent practicable; and

3. Information to support a determination as to whether discharges from MS4s are or are not attaining applicable State water quality standards.

The implications of each of these points are discussed below.

Non-storm Water Discharges:

The statutory provision regarding the effective prohibition on non-storm water discharges to storm sewers is fairly specific. EPA expects that field screening for illicit connections and illegal dumping will continue during the permit term as a monitoring condition. However, it is also expected that MS4s will use the results of previous screening efforts to establish long term priorities based on some appropriate ranking criteria, e.g., proximity to sensitive receiving waters, extent of directly connected impervious cover, use of raw materials in industrial manufacturing, age of system, potential for inflow from sanitary sewers, and evidence of past problems.

Achieving the Maximum Extent Practicable Standard:

Monitoring programs can provide information to support a determination that the storm water management program is reducing the amount of pollutants to the maximum extent practicable. MS4s may elect to conduct long-term trend analysis as a basis of supporting estimates that pollutant are in fact being reduced. However, methods other than chemical-specific monitoring may be used as a basis of meeting the MEP standard.

MS4s may propose to use other alternative monitoring assessment techniques, e.g., bioassessments, habitat evaluations, sediment quality analysis, etc, to demonstrate long term trends. EPA recognizes that in many instances, MS4s do not possess the in-house expertise to perform such assessments. However, a number of States are already performing such assessments and may be ready source of information.

Some factors that should be considered in advance before adopting an alternative monitoring approach include:

- The type of assessment technique to employ, e.g., narrative bioassessment vs. multi-metric indices such as the Index of Biotic Integrity (IBI) or Invertebrate Community Index (ICI);
- Current State regulations and practices;
- The extent to which basins or watersheds are impacted by other stressors;
- Availability of applicable technical and scientific expertise;
- Limitations of assessment techniques;
- Experience of in-house personnel; and,
- Cost.

From the perspective of a MS4, cost of monitoring will be an important concern. However, experiences from Ohio's ecological assessment program reveal that the cost of using bioassessment techniques is very competitive with chemical-specific monitoring.

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Attainment of Water Quality Standards:

The ability of storm water discharges from MS4s to meet applicable State water quality standards remains an important issue but is required under the current statutory framework. Numerous organizations and municipalities have asserted that such a goal is neither realistic or achievable because of the unique aspects of storm water discharges, while others maintain current water quality standards are not applicable to wet weather discharges. This is a complex issue and more complete answers will require further investigation. Given the cumulative effects of storm water discharges on receiving water quality and the significance of other factors such as runoff quantity, habitat alterations, geology, and hydromodifications, future storm water monitoring programs will likely evolve from an emphasis on chemical-specific monitoring alone, to one that more fully integrates other methods such as the use of environmental indicators.

Industrial Storm Water Monitoring:

Evaluating Effectiveness of General Permits for Industrial Facilities:

NPDES permits for storm water discharges associated with industrial activity are unlike NPDES permits for traditional sources such as sewage treatment plants and industrial process wastewaters in that they generally do not rely on the use of numeric effluent limitations. Rather, most NPDES permits for storm water discharges associated with industrial activity have required the implementation of pollution prevention measures and best management practices (BMPs). While the pollution prevention/BMP approach has a number of programmatic advantages, a major disadvantage of this approach is that it becomes more difficult to evaluate the effectiveness of the permit requirements. Ensuring that pollution prevention plans are effective should be a key objective of industrial storm water monitoring.

EPA is currently reviewing a number of methods to evaluate the effectiveness of permit requirements for storm water discharges associated with industrial activity and storm water monitoring results may play an important part in this effort. These include identifying measures, such as the number of industrial facilities that have obtained permit coverage and that have prepared pollution prevention plans to control their storm water, reviewing select pollution prevention plans to extract unique, innovative and creative techniques for storm water control, conducting pollution prevention plan audits of certain high priority facilities, working with industry trade associations and other groups to initiative cooperative efforts to assess the effectiveness of permits for industrial storm water, implementing environmental indicators, and possibly collecting and analyzing trends in storm water monitoring results for industrial dischargers across the country.

As more NPDES permitting is conducted on a watershed basis, monitoring of industrial storm water discharges will be necessary for developing State watershed strategies, identifying high priority sources within watersheds and for calculating wasteload allocations for permitting purposes.

SUMMARY:

Due to the nature of storm water impacts, it is expected that municipal storm water monitoring programs will evolve over time as MS4s gain greater familiarity with site-specific storm water problems. Given that many MS4s are dealing with issues of storm water quality for the first time, monitoring programs can be expected to vary in their complexity and NPDES storm water permitting can allow for this flexibility. EPA also recognizes that cost of monitoring will also be a significant factor, however, EPA encourages MS4s to design monitoring programs that yield useful information to support their storm water management program. Monitoring programs need to be carefully designed to accomplish useful purposes both in the short-term and in the long-term for the regulated municipality, its citizenry, as well as for NPDES the permitting authority.

To accomplish this, municipal storm water monitoring efforts must be carefully designed with a specific programmatic purpose in mind, and then the most appropriate monitoring tools should be selected to meet this purpose. Municipal storm water monitoring programs can be designed to support specific goals, including:

- Identifying/evaluating pollutant levels of discharges from areas and sites;
- Evaluating hydraulic conditions;
- Characterizing the performance of specific controls and providing information to support site-specific BMP designs;
- Evaluating the overall effectiveness of a storm water management program;
- Identifying water quality impacts and/or trends in water quality;
- Estimating/refining estimates of pollutant loadings;
- Supporting watershed protection/planning efforts; and,
- Supporting physical, chemical and biological assessments of receiving waters;
- Supporting national trends monitoring.

With the initial implementation of NPDES requirements for storm water, a number of key questions and issues have arisen in relationship to the purpose and methods for monitoring. Underlying these questions and issues is the central goal of trying to find the appropriate mix of monitoring tools to get information in a cost-effective manner to successfully implement NPDES storm water programs. Monitoring approaches developed under the NPDES storm water program should consider a broad set of monitoring tools, including environmental indicators. This is particularly true due to the intermittent nature of storm water discharges; the significant variability of pollutants in storm water; and the difficulties in correlating end-of-pipe storm water discharge data directly to water quality impacts and benefits.

EPA anticipates that a number of monitoring approaches will play a part in municipal storm water monitoring strategies in the future, including: discharge monitoring for chemical-specific parameters or toxicity, biosurveys, bioassessments, habitat assessments, instream monitoring, and sediment monitoring. Different goals for a municipal storm water management program can be best supported by different monitoring approaches.

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In some cases, municipal monitoring efforts conducted during the permit application process did not fully provide the kind of feedback that is necessary to develop the most effective storm water management strategies. EPA is looking at ways to improve municipal storm water monitoring during the permit application process to be more efficient and to derive the greatest benefits from the data collected. Such improvements can be incorporated into the NPDES regulations when the second phase of the NPDES storm water program is implemented and be made applicable to the monitoring that will be necessary when permits are re-issued to phase I municipalities.

For storm water discharges associated with industrial activity, storm water monitoring also plays an important role. As a result of the monitoring efforts during the permit application process, EPA and the NPDES authorized States will be able to write more applicable storm water discharge permits. Such information will also enhance dischargers' ability to identify pollutants of concern at the facility and to target pollutant sources when designing storm water management programs and pollution prevention plans.

Under the terms of an NPDES permit, storm water monitoring should be emphasized as a valuable tool for assessing the effectiveness of an industry's storm water pollution prevention plan and for examining possible receiving water impacts. With reliable storm water data, an industrial operator should be able to determine if current pollution prevention measures are adequate, or if additional measures, and possibly treatment controls, will be necessary. In addition, the ongoing effectiveness of the storm water pollution prevention plan can be assessed by tracking pollutant discharges over time. Finally, and most importantly, where necessary, monitoring of high-risk facilities can be required to ensure compliance with applicable State water quality standards.

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STORMWATER MONITORING: LOCAL MUNICIPAL PERSPECTIVES

Doug Harrison[1]

Abstract

This presentation reviews the stormwater program mandate imposed on local agencies, the role of monitoring in the mandate, deficiencies which can be expected in the monitoring results and the impact of these deficiencies on the administration of local stormwater NPDES permit programs.

Introduction

There was a time in the recent past when, as a stormwater agency administrator I was looking forward to the monitoring programs required by the stormwater NPDES permit regulations. Frustrated by the obligation to implement a water quality control program and to comply with pre-existing unrelated standards without benefit of supporting data, the pendency of a structured program of scientific measurement was encouraging.

Implementation of the mandated stormwater monitoring programs through the NPDES permits promised help in defining the physical and chemical character of urban stormwater. In addition, these monitoring efforts promised the ability to identify the long-term changes produced by the stormwater permit programs. Unfortunately, the optimism generated by anticipation of solid stormwater quality data is rapidly deteriorating.

On the basis of an increasing body of work, it seems clear stormwater cannot, within the limits of existing resources, be characterized sufficiently accurately to determine the appropriateness or effectiveness of the stormwater quality controls local agencies are required to implement. Paradoxically, it is likely monitoring activities will divert critical funding away from activities which could actually improve stormwater quality.

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<u>The Stormwater Quality Mandate</u>

The Congress, in enacting the Water Quality Act of 1987 attempted to clarify the stormwater obligations created by the Clean Water Act. In short, Congress imposed two basic mandates on municipalities that owned and operated stormwater systems.

1. ". . . effectively <u>prohibit</u> non-stormwater discharges into the storm sewers"; and

2. ". . . <u>reduce</u> the discharge of pollutants to the maximum extent practicable . . ." (emphasis added) (WQA, 1987)

To demonstrate "reduction", which is the obvious test of compliance with the Congressional mandate, a local municipality must first establish the current volume of pollutants being discharged. Secondly, the municipality must then determine, with accuracy at least equal to that in the initial determination, how much of the pollutants previously discharged are no longer being discharged. To arrive at this determination, the community must, of course, be able to distinguish between the changes in pollutant discharges caused by factors unrelated to the controls and those produced wholly by the controls.

To insure that these measurements are produced, the stormwater NPDES program regulation promulgated by EPA (November 16, 1990) added certain monitoring requirements to the congressional mandate. The regulation established a two-part application process which leads to an NPDES permit for the stormwater system. Monitoring requirements are contained in each of these three elements.

<u>Part I Application Requires:</u>

". . . quantitative data describing the volume and quality of discharges from the municipal storm sewer . . ."

". . . description of known water quality impacts."

". . . a field screening analysis for illicit connectings and illegal dumping.

<u>Part II Application Requires:</u>

". . . provide information characterizing the quality and quantity of discharges . . . from representative outfalls . . .;"

". . . estimates of the annual pollutant load of cumulative discharges . . . and the event mean concentration of the cumulative discharges . . . from all identified municipal outfalls for [specified constituents]."

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Permit Program Requires:

". . . monitoring program for representative data collection for the term of the permit . . ."

". . . monitor and control pollutants in stormwater discharges to municipal systems from . . . industrial facilities . . ."

"Assessment of Controls; estimated reductions in loadings of pollutants from discharges of municipal storm sewer systems . . ."

". . . identification of water quality improvements or degradations . . ." (USEPA, 1990)

In short, the regulation prescribing the elements of the permit program and related application process, outlined five questions local agencies are required to answer:

1. How much pollutant is being discharged?
2. Where is it coming from?
3. What harm has it caused?
4. How do you propose to reduce it?
5. How much did you reduce it?

Given the assumption that it was possible to generate data which would provide answers to these questions, the requirement for local municipalities to produce answers was logical. What is now in doubt however, is the validity of the underlying assumption.

If, in fact, it is not possible to accurately answer these questions the municipality is left in pursuit of a mandate which devours resources without any means of determining results or benefits. Of even more concern, municipalities are left without a defense for allegations of violation of the CWA.

The Critical Role of Monitoring in the Stormwater NPDES Program

Because of the previous conclusion, the justification and the potential for success or failure of the stormwater NPDES permit program is anchored to the monitoring element of the mandate. Only with accurate quantification of the stormwater problem, its sources and the achievable results can the stormwater program maintain its political priority, justify the allocation of resources, and provide the necessary means of enforcement. Clearly, the Congressional mandate for business and local government to spend hundreds of millions of dollars annually on stormwater quality was sold on the basis that preliminary conclusions generated by NURP could be specifically confirmed and quantified by a nation-wide permit driven monitoring program.

The Multiple Objectives of Stormwater Monitoring

Because of the inherent dependency of the stormwater regulatory effort on the program's monitoring component, that component has been assigned a variety of diverse objectives by the many key parties of interest.

- Activists, regulators and legislators must use the monitoring process to demonstrate that stormwater pollution is, in fact, a major controllable source of adverse environmental impacts, warranting the massive expenditures required to achieve "clean-up".
- Enforcement interests must demonstrate that site and use specific sources can be accurately measured to support the civil and criminal actions brought against CWA violators.
- Municipalities and business require data which will support the diversion of financial resources to stormwater quality, and to differentiate between inefficient controls and those which are cost effective.

Many other interests also color the structure of the monitoring program. Some are involved for the pure delight of research; others have an interest shaped by a profit and loss statement.

The impact of such a diversity of interests is compounded by two additional factors which are most significant. The first is the absence of a national strategy for stormwater monitoring and data development. The second is the ad hoc nature of the stormwater permit, with the structure of each of the permit monitoring programs being determined at the discretion of a relatively independent permit writer.

Unlike NURP, which established clear objectives and guidelines toward the goal of a nationally significant data base, the stormwater NPDES permit program has as many different monitoring strategies as it has permits.

The result of this diversified interest in stormwater monitoring has been a predictable disjointedness among the various monitoring programs. Some are conducting research on beneficial use impacts; others are examining sources. Some are examining land use differences while others try to explain hydrologic impacts. Some are still trying to determine how stormwater discharges differ from traditional

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point source discharges, and others are evaluating available forms of pollutants in the stormwater. Some may even be trying to do it all. Certainly, because of its complexities, every municipality could conduct focused stormwater quality research unique to their locale, and many permit writers are appearing to require it.

Recognizing that much monitoring and research is now underway, the question that must be asked is whether the results will be sufficiently accurate to justify either the cost of the stormwater quality program — or the cost of the monitoring itself.

Relationship Between Monitoring Costs and Stormwater Program Costs

The matter of stormwater program costs has been hotly debated. Estimates to fully implement the congressional mandate have ranged from the absurdly low levels presented by EPA in its November 1990 regulation ($14.5 million annually) (USEPA, 1990) to the fearfully high levels estimated by the APWA, Southern California Chapter in May 1992 ($542.0 billion annually) (James Montgomery, 1992).

Cost estimates defining stormwater program needs have been as detailed as the use attainability analysis performed by the City and County of Sacramento ($2.0 billion, local need) (Walker, 1993). Others, like EPA's 1992 Needs Survey Report to Congress ($116.5 million, national need) (USEPA, September, 1993) have excluded virtually all implementation costs associated with the stormwater NPDES permit program requirements.

The real issue buried in all of the rhetoric is "what do you get for what you spend?" It is in the satisfaction of this issue that monitoring again assumes the central focus of the entire stormwater quality program. Stormwater managers are being repeatedly asked by policy makers and administrators to demonstrate that the dollars invested will produce a verifiable result.

Unfortunately, a growing body of evidence is suggesting that, as currently structured, our stormwater monitoring program can do neither. More discouraging is that substantial increases in data usefulness cannot be achieved without massive increases in the resources allocated to the monitoring effort.

It has long been recognized that the variables associated with urban runoff, which include the limitless multiplicity of sources, the episodic nature of runoff events, the massive magnitude of source areas and flow volumes, and the unknown assimilative capability of receiving waters, prevented any hope of discreet cause and effect findings from stormwater monitoring. Expectations were high, however, that changes in the long-term stormwater quality trend lines produced by broadly based consistently applied control practices could be observed and measured, providing a form of program assessment and a measure of cost effectiveness.

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However, recent work by Woodward-Clyde (reviewed at this conference) has produced conclusions which create reservations about the validity of even this more conservative expectation. Specifically, Woodward-Clyde's work has produced the conclusion that significant increases will be required in monitoring program expenditures if changes in long-term stormwater quality trend lines are to be measured with any significant confidence.

The Woodward-Clyde analysis has determined that, for the Fresno California metropolitan area, 64 composite samples per year will be required over a ten year test period to detect with 80% confidence a 20% change in copper concentrations. This contrasts with the monitoring plan which was to be made a condition of the Fresno NPDES permit, that plan proposing 15 samples per year. However, we now know that at 15 samples, the Fresno program has only a 15% chance of detecting a 20% change over the 10 year test period.

Correspondingly, Woodward-Clyde's work indicates it will be much easier to detect large changes in the long-term stormwater quality trend lines. For example, again in the Fresno California case, the planned 15 sample per year program has a 48% chance of detecting a 30% reduction, and a 79% chance of detecting a 40% reduction.

The obvious caveat for program managers is the imperative of insuring that the control program creates a big change in stormwater quality. If not, your monitoring program is not likely to detect the impact at any significant confidence level.

The significance of this information to stormwater program managers can be seen in Table No. 1. The table contrasts the monitoring program costs required under the pending Fresno area NPDES permit with the costs required to increase the confidence level of confirming a 20% change in stormwater quality from 20% to 80%.

As currently structured, the Fresno area NPDES stormwater permit program will expend $1.55 million dollars over the next ten years on monitoring (assumes annual expenditures of 1994 levels), but will achieve only a 20% probability of detecting a 20% change in stormwater quality. Based on the Woodward-Clyde work, to increase the confidence level to 50% the program must increase monitoring expenditures to $5.33 million; and to reach the 80% confidence level it must expend $5.84 million.

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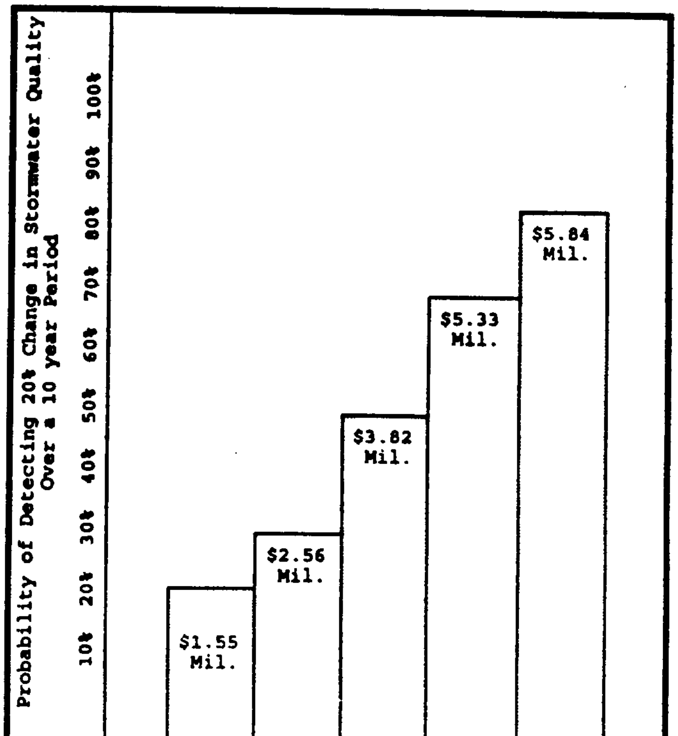
TABLE NO. 1

Monitoring Costs To Detect a 20% Change in Stormwater Quality (10 Year Test Period; Fresno CA)



Ten Year Monitoring Program Costs

(Annual costs in 1994 dollars; sampling, laboratory, and analytical costs only, excludes equipment and installation.)

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Stated another way, the permit program now allocates 21% of the program budget to monitoring. To increase the confidence level of the monitoring results to 50%, the percentage of the permit program resources allocated to monitoring must increase to 27%. To achieve the 80% confidence level, 41% of the program's resources must be directed to monitoring.

Correspondingly of course, increases in the monitoring budget decrease other elements of the stormwater program such as public education, legal enforcement, or — heaven forbid — annual reporting. This places before the local program manager the unique dilemma of maximizing expenditures that are likely to produce a change in stormwater quality, while pursuing a "low confidence" monitoring program; or, increasing the confidence level of the monitoring by reducing the things which are likely to improve stormwater quality. The other option, of course, is simply to divert more money from other municipal needs to invest more in stormwater monitoring.

Arguing strongly for restraint in inflating monitoring budgets, in addition to the resultant reduction in stormwater control practices, is the related difficulty in identifying the cause of an observed change in stormwater quality. Even at the 80% confidence level of detecting a change, it remains doubtful the monitoring program can identify with any confidence, the cause of the change detected. Whether it was the program itself, some specific element of the program, or some other series of events, that produced the observed change is likely to remain an important unknown.

The scope of this issue becomes more visible when statewide and nationwide impacts of raising the monitoring confidence level are considered. While an admittedly primitive approach, the Fresno program can be used to create such an estimate. If it can be assumed Fresno is relatively representative of the stormwater monitoring programs in California, it can be estimated that annual stormwater monitoring activity would have to increase from the $3.7 million actually expended statewide in 1993-94 to $9.1 million in order to achieve the 50% confidence level, and to $13.9 million to reach the 80% confidence level.

Relatedly, if California bears the same permit program monitoring cost relationship to the rest of the nation as it does with respect to the total of all permitted municipalities (35.4% of all permitted communities are in California) (USEPA, October, 1993), it is possible to estimate the confidence level cost impact on a national basis. On this basis, the nationwide cost to achieve the 20% confidence level will total $10.45 million per year. (This represents an estimate of the basic permit monitoring requirement cost which will be incurred by the total of all permitted municipalities assuming no substantive variances from the obligations imposed on California communities). To achieve the 50% confidence level, annual nationwide monitoring costs must increase to an estimated $25.75 million; and to achieve the 80% confidence level, the annual nationwide costs must increase to $39.4 million. (It is noted that monitoring costs, expressed in annual terms, must continue at the same level for ten years to produce the desired confidence level data base.)

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Conclusion

The stormwater quality program is the object of intense scrutiny by political, environmental, municipal, and business interests. However, because the program's accountability to all of these interests is so completely dependent on reliable data, the program cannot achieve the objectives ascribed to it without an effective monitoring program producing dependable information.

It is this manager's opinion that the requisite information cannot be developed, and the ascribed objectives cannot be achieved without fundamental changes in the structure of the stormwater quality program.

First, we must change the presumption that stormwater quality problems and solutions can be as easily identified and quantified as other point source problems; and the presumption that given a little time, we can drive stormwater quality into compliance with traditional standards.

It seems a reasonable conclusion that, if we can't clearly measure how much stormwater quality has been changed, it is not likely we can measure how much pollution stormwater carried to begin with. Relatedly, if it is so difficult determining if all of the things we did caused a change, it is even more unlikely we can measure the change caused by any one thing we've done. The same conclusion also applies to accurately identifying the stormwater pollution sources.

Secondly, we must change our approach to defining the problem and testing for solutions. The weak repetitious characterization studies, haphazard source investigations and miscellaneous "nice to know" projects occurring through the permit process must be replaced with a national stormwater quality monitoring and research strategy. Specific goals and objectives must be developed and then implemented through the permit programs by means of specifically focused target/pilot studies. Only that duplication necessary for statistical confidence should be permitted and all efforts should be held accountable to rigid procedural guidelines and QA/QC standards.

The sampling, analysis and development of conclusions should be routinely supervised by a national data coordinating unit, and the data aggregated into a functional data base for use by the political, environmental and municipal interests. From such a data base, appropriate discharge standards for both end-of-pipe and receiving water conditions can then be extracted and useful measurements for assessing effective control practices can be developed.

Unless there is such a change in the structure of the stormwater monitoring program, we are destined to invest a major portion of the stormwater program finances in activity which produces dubious information and no stormwater quality improvement.

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Given the magnitude of costs associated with the stormwater quality program, our nation's municipalities simply can not afford to have such a large percentage of its expenditures so unproductively used. Neither can we afford to impose such a devastatingly expensive standards compliance mandate on the basis of irrelevant or inaccurate data. Only with the proper structuring and conduct of a nationwide monitoring strategy can we produce the data necessary to insure successful attainment of the rightful objectives assigned to the stormwater program.

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HOW CONGRESS SHOULD ACT ON STORMWATER

Howard Holme[1]

August 10, 1994

ABSTRACT

Cities, industry, and the EPA have resisted, not implemented, stormwater regulation aimed at the near perfection of Water Quality Standards, for over 20 years. The past statutory approach should be repealed and replaced. Congress should rewrite the statute to initiate a flexible, voluntary, cooperative program using a reasonable amount of federal and state or local funding to fix real water quality problems cost-effectively by letting potential and actual polluters bid to reduce pollution.

INTRODUCTION

The author of this paper describes what he thinks should be done with the stormwater subsection of the Clean Water Act (CWA), subsection 402(p). His vision is very different from the way the subsection has been in various forms over the past 22 years, and very different from the proposals Congress is currently contemplating in competing drafts.

The past program is a failure. Can this stormwater program be changed into what the population, the cities, the U.S. Environmental Protection Agency (EPA), and the Congress want? They want a better, more flexible CWA, using partnerships between the federal, state, and local governments, and business, based on good science and realistic risk assessment, designed to reduce damage

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to human health, the economy and the environment from harmful sources of pollution, and to prevent or reduce the worst pollution for the least necessary cost.

The format of the paper is first to state a proposed amendment to Section 402(p), and then to defend it in the form of a proposed Conference Committee report, which repeats and explains the amendment.

PROPOSED AMENDMENT TO SECTION 402(p) CONCERNING STORMWATER.

Section 402(p) of the Federal Water Pollution Control Act (33 U.S.C. 1342(p)) is repealed (along with its supporting regulations, guidelines, and opinions) and reenacted to read as follows:

"(p) MUNICIPAL, INDUSTRIAL, AND OTHER STORMWATER DISCHARGES.--

"(1) GENERAL RULE.--Permits for discharges composed of stormwater are not required under this Act, though they may be subject to Section 319, relating to nonpoint source management programs.

"(2) VOLUNTARY PROGRAM.--The Administrator may establish a voluntary program to reduce the discharge of pollutants from stormwater as follows:

"(A) The Administrator shall consult with persons with expertise in the management of stormwater (including officials of local and state governments, the Soil Conservation Service and scientists), to prepare a request to the National Academy of Sciences to use existing stormwater monitoring and other information and knowledge to report to the Congress by January 31, 1997

"i) compiling a database of stormwater data to be available to the public,

"ii) analyzing stormwater data,

"iii) estimating the present danger or lack of danger of stormwater discharges to human health and the environment, using realistic risk assessment assuming average populations and fully stating uncertainties, "iv) describing programs which the Academy would recommend for entities which want voluntarily to reduce pollution in the most cost-beneficial manner, estimating the economic costs and benefits to the human economy from such programs.

"(B) The Congress authorizes $ _ billion per year from Fiscal Year 1998 to 2002, to be spent for those projects which

"i) are authorized by the local and state governments in the areas directly affected by the projects as well as by the Administrator, and for which local and state governments authorize 50% of the necessary total governmental expenditure,

"ii) prevent or reduce the discharge of particular pollutants in ways that will have the greatest benefit to human health and the economy for the least cost,

"iii) rely on private parties and governments (neither of which shall be preferred over the other) to enter closed bids for the reduction of amounts of the pollutants. Closed bids shall be accepted on the lowest cost per gram of pollutant, either for prevention of otherwise expected discharge of pollutants or reduction of present discharge of pollutants."

PROPOSED CONFERENCE COMMITTEE REPORT ON PROPOSED AMENDMENT TO SECTION 402(p) CONCERNING STORMWATER.

The text of the proposed amendment is repeated in bold, with explanation following.

Section 402(p) of the Federal Water Pollution Control Act (33 U.S.C. 1342(p)) is repealed (along with its supporting regulations, guidelines and opinions)

History of the stormwater effort.

"Storm water means storm water runoff, snow melt runoff, and surface runoff and drainage," 40 CFR § 122.26(b)(13) (1992), but not infiltration. 55 FR at 47,996. Federal law has consistently required National Pollutant Discharge Elimination System (NPDES) compliance for point source discharges of stormwater since 1972. 33 U.S.C. §§ 1311, 1341, 1342 (sections 301, 401, and 402 of the CWA). Various regulatory attempts and lawsuits did not lead to

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cleanup of stormwater. 1973 EPA regulations and large exemptions; NRDC v. Train, 396 F. Supp. 1393 (D.D.C. 1975), aff'd. NRDC v. Costle, 568 F.2d 1369 (DC Cir. 1977); EPA regulations in March 1976, EPA regulations in 1979; NRDC v. EPA, 673 F.2d 392 (DC Cir. 1980); EPA regulations September 26, 1984, 49 FR 37,998; EPA proposals in March and April 1985, 55 FR 47,991. The Water Quality Act of 1987 attempted to cure the general lack of stormwater permits by suspending the permit requirement and allowing EPA to adopt stormwater permitting regulations in phases.

"Phase I" regulations were adopted by the EPA on November 16, 1990, primarily to regulate discharges from municipal separate storm sewer systems serving populations of at least 100,000. 55 FR 47,990.[1]

Regulations for "Phase II" (all other stormwater discharges) were originally required to be issued by October 1, 1992, and Phase II sources were not required to obtain a stormwater permit until October 1, 1992. EPA missed the original October 1, 1992 deadline, and Congress shortly thereafter extended the Phase II deadlines two years to October 1, 1994. 42 U.S.C. § 1342(p).

EPA solicited public comment on possible approaches for developing the Phase II program, and raised questions of amending the CWA to allow EPA to regulate problem stormwater discharges rather than requiring regulation of all Phase II facilities. 57 FR 41,344, 41,349, (Sept. 9, 1992).[2] Many commenters suggested suspending Phase II.

The program has failed. It costs too much and provides too little benefit.

Through 1994, the stormwater regulatory program has been a failure. Past programs were going to cost too much money for too little benefit.

The costs were too great. Full construction of advanced treatment plants for stormwater from municipalities serving populations of at least 100,000 were estimated (in the most comprehensive study yet done) to have a capital cost of $406 billion and annual costs of $542 billion--about one-tenth of the Gross National Product.[3] Yet even this impossible level of spending probably would not meet Water Quality Standards (WQSs).

Sacramento estimates it would cost $2 billion to try, (valiantly but unsuccessfully) to meet WQSs for 5 metals. Sacramento studied the cost of compliance with only 5 common metals, chromium, copper, lead, and zinc, ignoring organics because "few data exist on the concentrations of organic pollutants."[4]

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"Stormwater discharges to the Sacramento River will be unable to achieve the water quality-based effluent limitations for copper and zinc even with the use of a mechanical treatment facility (similar to a water treatment plant) employing lime precipitation, sedimentation and filtration, in combination with discharge through an outfall designed for rapid mixing."

"The estimated present worth cost of such a system, designed to handle flows associated with the *mean annual storm, is on the order of $2 billion.*"

Denver estimates it would cost more than *$1 billion* for structural Best Management Practices (BMPs), a far less expensive treatment alternative. Cities over 100,000 in population have already spent an estimated $130 million to prepare for NPDES permit applications.

No one has demonstrated a problem from stormwater runoff serious enough to justify huge unfunded mandates.[5]

The Nationwide Urban Runoff Program (NURP), designed to find water quality problems caused by urban runoff, found surprisingly few problems. We quote NURP's primary findings, which it underlined:

1. Frequent exceedances of heavy metals ambient water quality criteria for freshwater aquatic life are produced by urban runoff. . . .

2. Although a significant number of problem situations could result from heavy metals in urban runoff, levels of freshwater aquatic life use impairment suggested by the magnitude and frequency of ambient criteria exceedances were not observed. . . .

> However, those NURP project studies which examined this issue did not report significant use impairment problems associated with urban runoff.

3. Copper, lead and zinc appear to pose a significant threat to aquatic life uses in some areas of the country. Copper is suggested to be the most significant of the three. . . .

> [Except in the southeast and southern regions of the country] problems would be expected only in rather unfavorable conditions. . .

4. Organic priority pollutants in urban runoff do not appear to pose a general threat to freshwater aquatic life. . . .

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5. The physical aspects of urban runoff, e.g., erosion and scour, can be a significant cause of habitat disruption and can affect the type of fishery present. However, this area was studied only incidentally by several of the projects under the NURP program and more concentrated study is necessary. . . .

6. Several projects identified possible problems in the sediments because of the build-up of priority pollutants contributed wholly or in part by urban runoff. However, the NURP studies in this area were few in number and limited in scope, and the findings must be considered only indicative of the need for further study, particularly as to long-term impacts. . . .

7. Coliform bacteria are present at high levels in urban runoff and can be expected to exceed EPA water quality criteria during and immediately after storm events in most rivers and streams. . . .

8. Domestic water supply systems with intakes located on streams in close proximity to urban runoff discharges are encouraged to check for priority pollutants which have been detected in urban runoff, particularly those in the organic category. . . .[6]

Most of EPA's budget is devoted to avoiding human contact with toxic substances, and avoiding cancer. In 1987, EPA listed its priorities and estimated numbers of cancers in Unfinished Business.[7] *EPA failed to estimate or estimated less than one death per year from point source and nonpoint source discharges to surface water, groundwater contamination other than municipal or hazardous waste sites, and discharges to wetlands, estuaries, coastal waters and oceans.*[8]

The past approach is repealed, in recognition that the premise of compliance with WQSs is impossible and unnecessary to meet.

The core premise underlying stormwater regulation has been that stormwater would meet the near perfection of WQSs, sooner or later. EPA has, several times, interpreted WQSs to apply to stormwater permits for both industrial and municipal discharges. EPA Office of General Counsel opinion on "Compliance with water quality standards in NPDES permits issued to municipal separate storm sewer systems," (E.P.A.G.C., January 9, 1991 from E. Donald Elliott, Assistant Administrator and General Counsel (LE-130), which cites 1991 WL 326640. CWA Sections 402(p)(3)(B)(iii), 301(b)(1)(C), 53 FR 49,457 (Dec. 7, 1988), 40 CFR 122.44(d). These authorities are repealed.

Even the 1994 proposed reauthorizations in both Houses of Congress were based on that premise. S. 2093, Sec. 402 said "during the 10-year period" following enactment municipal storm sewer permits "shall not require compliance

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with numeric effluent limitations and water quality standards." (proposed amendment to Section 402(2)(D). Senate Report 103-257, "Water Pollution Prevention and Control Act of 1994, Report of the Committee on Environment and Public Works to accompany S. 2093, May 10, 1994. This report says "When this [10 year] period expires, NPDES permits for stormwater discharges *must include enforceable numeric effluent limitations in the same manner as any other NPDES permit*. The "Substitute House Legislation to Reauthorize the Clean Water Act Introduced April 21, 1994, BNA Daily Environment Report, No. 78, pp. E-1-E--53 (April 25, 1994), amendment to the same section prohibited, with exceptions, permit requirements to comply with numeric effluent limitations or applicable water quality standards before December 31, 2009.

The premise of the last 22 years is impossible and unnecessary to meet. For example, June 23, 1994, the Committee on Ground Water Cleanup Alternatives of the National Research Council said restoring contaminated groundwater to safe drinking standards, as called for in federal laws, is not technologically feasible. The 1972 Clean Water Act which set the idealistic goal "to restore and maintain the *chemical, physical, and biological integrity of the nation's waters*." Section 101(a). "Integrity" could have been interpreted under Webster's Third International Dictionary to mean "complete or undivided," but instead has been interpreted to mean "an uncompromising adherence to a code of moral, artistic, or other values"[9] of fractions of one part per billion, trillion, and even quadrillion. Chemical integrity of water, at least as many would interpret the term now, means H_2O, and nothing but H_2O. The Congress established "the national goal that the discharge of pollutants into the navigable waters be *eliminated*." Section 101(a)(1). Except with a permit, generally "the discharge of *any* pollutant by any person shall be *unlawful*." Section 301.[10] Yet many regulations and programs are justified by reference to, and blind attempts to, achieve this impossible dream.

Combined Sewer Overflows (CSOs), being addressed in new subsections 402(q), are now recognized as not being able to reach WQSs by 2009, but only "reasonable progress toward attainment of applicable water quality standards." The society cannot and should not make all water that clean. WQSs are often hundreds or thousands of times more stringent than drinking water standards, and unnecessarily stringent, especially during short storm events.

The past goals cannot be met even when the nation spends tens of billions of dollars per year for over 3 decades (1972 to 2009). WQSs will not be achievable in 2009, just as they are not achievable in 1994. Further, the problem of stormwater regulation does not justify the attempt.

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"(p) MUNICIPAL, INDUSTRIAL, AND OTHER STORMWATER DISCHARGES.–"

Past legislation to clean up stormwater has dealt exclusively with municipal and industrial stormwater from point sources. Stormwater, in the normal sense of water from storms, forms all the fresh water on the earth, both surface and ground water, from both point and nonpoint sources. The distinctions between surface versus ground water, piped versus street flow runoff, and urban versus exurban are increasingly artificial as people clean up even more sources of pollution. As this program moves from a command and control program to a voluntary program, it makes sense to allow pollution prevention and pollution sources such as agriculture to join in the pollution reduction. Thus, "other" stormwater discharges are now included.

"(1) GENERAL RULE.–Permits for discharges composed of stormwater are not required under this Act, though they may be subject to Section 319, relating to nonpoint source management programs."

Because the past program has failed and would not reasonably be expected to succeed in terms of reaching WQSs, this amendment changes the approach of the program and removes it from the water quality permitting program. It does not repeal other programs which also reduce stormwater pollution.

"(2) VOLUNTARY PROGRAM.–The Administrator may establish a voluntary program to reduce the discharge of pollutants from stormwater as follows:

"(A) The Administrator shall consult with persons with expertise in the management of stormwater (including officials of local and state governments, the Soil Conservation Service and scientists, to prepare a request to the National Academy of Sciences to use existing stormwater monitoring and other information and knowledge to report to the Congress by January 31, 1997"

Subsection (p)(2) establishes and describes a voluntary program. One past problem with stormwater regulation is its lack of scientific base. The NURP program found few if any problems from stormwater. The Phase I stormwater program has required the gathering of large amounts of data, which has not been adequately analyzed for the information it can provide as to whether and how stormwater should be regulated. This provision requires greater use of scientific expertise, including that of the National Academy of Sciences, which needs adequate time to analyze the newer data.

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By including the Soil Conservation Service, the bill recognizes that agriculture is the leading cause of water quality impairments in rivers, streams and lakes, ahead of urban runoff and storm sewers.[11] The 1985 Farm Bill, and the 1990 Farm Bill, and perhaps future Farm Bills will contribute to reductions of stormwater runoff. The U.S. Department of Agriculture estimates that conservation compliance plans for highly erodible land will have reduced erosion from a national average of 17.5 tons per acre in 1985 to 6 tons per acre by the end of 1994.[12] By including local and state governments, it recognizes them as partners in the planning, as they will be partners in the spending and implementation of projects.

"i) compiling a database of stormwater data to be available to the public,

"ii) analyzing stormwater data,

"iii) estimating the present danger or lack of danger of stormwater discharges to human health and the environment, using realistic risk assessment assuming average populations and fully stating uncertainties,

"iv) describing programs which the Academy would recommend for entities which want voluntarily to reduce pollution in the most cost-beneficial manner, estimating the economic costs and benefits to the human economy from such programs.

Despite 20 years of regulatory effort, insufficient data have been usefully complied into a database and thoughtfully analyzed.[13] With past studies not showing serious actual harm to human health, the economy, and the environment to justify a large regulatory program, the National Academy of Sciences would be delegated to do a thorough and reasonable risk assessment of the danger to actual and average populations. The National Academy of Sciences should do risk assessment and cost-benefit analysis in similar fashion to that contemplated by Senator Bennett Johnston's Amendment No. 1720 to the Senate's Safe Drinking Water Act Reauthorization Act of 1994 (S. 2019).

Because future projects would be voluntary, information must be gathered as to what future efforts would be cost effective, and reasonable for cities and states, as well as the federal government to undertake.[14]

"(B) The Congress authorizes $ _ billion[15] per year from Fiscal Year 1998 to 2002, to be spent for those projects which

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After the National Academy of Sciences Study, but well before the WQSs deadlines in either S. 2093 or the substitute to H. 3948, money will be authorized, and appropriated, to begin preventing, and cleaning up, stormwater pollution.

"i) are authorized by the local and state governments in the areas directly affected by the projects as well as by the Administrator, and for which local and state governments authorize 50% of the necessary total governmental expenditure,

There is more talk than action on partnership of federal, state, and local governments of flexibility. This program requires approval, and funds from all three levels of government. National, regional, state, and local planning committees would need to operate. If stormwater cleanup is a high priority, then many projects exist for which states and localities want to contribute 50% to the prevention or cleanup. Contribution from all three levels of government will help prevent both "pork barrel" projects viewed as important only by a few members of Congress, and projects not viewed as important at the state and local levels. Flexibility will be returned to this area of the Clean Water Act, because some projects will be extensive, and other geographic areas will not participate, at least for now.

"ii) prevent or reduce the discharge of particular pollutants in ways that will have the greatest benefit to human health and the economy for the least cost,

During a cooperative planning process, parties would study controlling stormwater pollution by prevention or reduction, and by non-structural means, including public education and community participation, as well as by structural means.

For many problem areas, one or a few pollutants or indicators may serve as representative for the cause of the real problem. Some pollutants may be high in volume, but low in toxicity or other characteristics that cause problems. Other pollutants may be low in volume, but cause, for example, serious shellfish kills which hurt the economy. If oil is the problem, oil refineries, city sweepers, and oil recyclers might bid for reduction of oil getting to the streams.

The stormwater program shall concentrate on costs and benefits, and recognize that most real problems, and real benefits, are reflected in human health and the economy. The Administrator may develop guidance or regulations for the implementation of the program which will achieve the greatest benefit to human health and the economy for the least cost, which will encourage at least partial solution of the worst problems first, and obtain the "most bang for the buck."

"iii) rely on private parties and governments (neither of which shall be preferred over the other) to enter closed bids for the reduction of amounts of the pollutants. Closed bids shall be accepted on the lowest cost per gram of pollutant, either for prevention of otherwise expected discharge of pollutants or reduction of present discharge of pollutants."

After local, state and EPA officials have determined there is a serious problem deserving of funding, they may develop a proposal for a project and put it out for bidding. Both private and public entities may bid, and for any reasonable amount of prevention or reduction of pollution. If in one watershed, erosion, stream sedimentation, and salinity are the problems, perhaps cities will bid for reduction of salt and sand use in the winter and more better street sweeping, while some farmers bid to reduce plowing at the edges of the streams, and other farmers on saline land bid to stop farming. If in another watershed copper is killing fish, perhaps mines will bid to cover abandoned mine tailings, and an automotive company will bid to replace copper brake shoes with a more expensive but more benign brake shoe.

A National Academy of Sciences analysis of regulations measuring cost-effectiveness by the cost per kilogram (kg) of PCBs found the cost-effectiveness of the alternatives analyzed varies by a factor of 200,000. 99.9% of the available control would come by certain regulations, while *other regulations, attempting to control the remaining 0.1%, would double the cost of regulation. The government "has declined to incur costs of $731 per kg to reduce risk through the control of PCBs in the diet, while it has incurred costs of over 100 times that amount to prevent the risks associated with releases from contaminated hydraulic fluids.*[16] With a voluntary program of bidding for pollution prevention and reduction, the cost of a given amount of environmental improvement will be much less than with command and control regulations.

The Administrator may develop guidance or regulations on how to evaluate prevention of otherwise expected discharge of pollutants. Some states may decide the voluntary program is insufficient to control, for example, new subdivisions or factories. States, of course, can adopt more stringent standards or requirements than this subsection.

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1. See also 55 FR 12,098 (March 21, 1991); NRDC v. EPA, ___ F.2d ___.

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1992 WL 117156; 57 FR 11,394 (April 2, 1992); and 57 FR 60,444 (Dec. 18, 1992).

2. See also 58 FR 61,146 (Nov. 19, 1993).

3. A Study of Nationwide Costs to Implement Municipal Stormwater Best Management Practices. American Public Works Association, Southern California Chapter 1992, and Cover Letter at page 2. EPA originally estimated that application costs for a large municipality would average $75,000. Id. at 5. The actual average cost has been approximately $760,000. Id. at 7, Table 1.

4. Id. at 1.

5. A February, 1994, study by Montgomery Watson for the National League of Cities and National Realty Committee conclude only 4-10 percent of water quality impacts result from urban runoff, as opposed to 20 to 40 percent sometimes reported. "Statement of Scott Tucker on behalf of the National Association of Flood and Stormwater Management Agencies before the Subcommittee on Water Resources and Environment, House Committee on Public Works and Transportation on the Reauthorization of the Federal Water Pollution Control Act, May 25, 1994, at p. 3.

6. U.S. Environmental Protection Agency. Results of the Nationwide Urban Runoff Program: Volume 1, Executive Summary at pages 9-6–9-8. December, 1983.

7. U.S. EPA, Unfinished Business: A Comprehensive Assessment of Environmental Problems (1987).

8. U.S. EPA, Unfinished Business: A Comprehensive Assessment of Environmental Problems, Report of the Cancer Work Group, Table 1 pages 4-10 (1987).

9. Webster's Third New International Dictionary (1967) at 1174.

10. 40 CFR § 122.1(b)(1) (1992).

11. U.S. EPA, The Quality of Our Nation's Water: 1992; March 1994. "[Agricultural stormwater discharges and return flows from irrigated agriculture" are not "point sources," and are not required to have permits. 33 U.S.C. § 1362 (14).

12. According to Sen. Patrick Leahy, "Cleaner Water? Farm Bill Can Help Too," ROLL CALL Environmental Policy Briefing, Monday, July 25, 1994. Leahy says the Conservation Reserve Program established in 1985 allowed the USDA to contract to take environmentally sensitive land out of production, use

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the Conservation Reserve Program for filter strips and to rebuild riparian zones, and improve wetlands.

13. "Historically, the Nation has made a meager commitment to the collection and analysis of toxics data; however, most of these efforts have been poorly designed from an experimental perspective and suffer from inadequate QA/QC and inconsistencies in sampling and analytical methods. The net result is that we have almost no useful instream toxics data upon which to base our decision-making." D. R. Wheeler, "Where is the Pendulum Now? Do We Really Know?," in Howard Holme, Ed., National Water Resources Regulation--Where is the Environmental Pendulum Now?, American Society of Civil Engineers, 1994; Kelly A. Cave, et al "Overview of Stormwater Monitoring Needs, at p. 6, in this volume.

14. National Science Foundation grants and EPA, under the national estuary program, have funded broad-based environmental and water quality studies for several major watersheds, including San Francisco Bay, the Delaware River, and Chesapeake Bay. These studies recommend pollution control programs very different and much less expensive than those under current 402(p). William Whipple, Jr., et al, "Drawing Conclusions as to Environmental Regulation," in Howard Holme, Editor, National Water Resources Regulation--Where is the Environmental Pendulum Now?, American Society of Civil Engineers, 1994.

15. The number of dollars is left blank for this Engineering Foundation paper. The amount to be spent is obviously a policy and political question. Many cities may think other urban needs are more serious than the needs to clean up stormwater, and can say so to their member or members of Congress. Lobbyists for water and environmental interests may support spending tens of billions, or conceivably hundreds of billions of dollars per year to clean up stormwater. Not to vote for a specific amount of money for the problem, but to rely on an unfunded mandate, invites a terrible decision to be made.

16. A.M. Freeman III, "Risk Evaluation in Environmental Regulation," at 47, 59, 64, in Wesley A. Magat, Reform of Environmental Regulation (1982).

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SESSION V: Policy & Institutional Issues of NPDES Monitoring

DISCUSSION

Stormwater Permitting - An Industrial Experience
P. Charles Beck

Coors has been in business for 175 years. Built first industrial waste treatment plant in Colorado. Have classified operations for permitting purposes as:

- Heavy industrial permit - brewing, can Manufacturing, abandoned landfill
- Light industrial permits
- Gravel mining

BMPs currently applied:

- Housekeeping processes
- Covered trash bins have been effective
- Covered storage
- Valves on drains to fuelling areas
- Roof drains and drains from some other possible spill areas go directly to the treatment plant

Concerns:

- Regulatory redundancy and bureaucracy
- Cost to implement is $250,000 vs. EPA estimate of $25,000
- Program goals not well defined
- Program support not enthusiastic
- Will numeric standards be mandated?
- Will structural controls be mandated?

Recommendations:

- Air control arena provides insight into improving stormwater regulation program
- Enforceable stormwater quality algorithm is needed

Strategies for Using NPDES Storm Water Data
William Swietlik, William Tate, Robert Goo and Eric Burneson

Municipal Permits

- Current regulations allow a municipality and the permit writer to jointly work out a sampling program for the local area.
- Examples of good monitoring programs: Santa Clara County,CA; Austin, TX; Charlotte, NC; Montgomery County, MD.
- Charlotte, NC, has developed an in-stream rating system based on concentration ranges. Action levels were defined (no action, watch, action). A correlation matrix was developed between pollutants and sources. These suggest the most likely sources of pollution - if they are detected in monitoring program.
- Montgomery County - permit application is focused on bio-assessment and habitat analysis. (Editor's note - Montgomery County is looking at citizen involvement in some of the simpler aspects of the monitoring program). These data will be used in long-term trend analysis (similar to Ohio).

Industrial Permits

Group Applications

- TSS is highest concentration (50% of sites had concentrations greater than the NURP mean).
- High metals concentrations
- Many of the high constituent concentrations come from industries that conduct activities outdoors, or have exposed materials stockpiled outdoors.

Uses of Industrial Data

- Identify pollutants of concern
- Target BMPs
- Identify high risk industrial sectors
- Arrive at permit monitoring provisions - if second year data show a decrease in concentrations, monitoring can be dropped.

Future Direction - Municipal

- Flexibility
- Three regulatory factors - costs, tool availability, purpose

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- Watershed planning, long term tracking of results, environmental indicators
- Phase II MS4s and Phase I MS4 reapplication - reflect experience gained from Phase I.

Future Direction - Industrial

- Assess effectiveness of P3 and GPs
- Assess potential for environmental impacts
- Watershed permitting and waste load allocation
- Data for second rounds
- BMP effectiveness evaluation

Questions/Comments

Question: When will EPA come to grips with the definition of "maximum extent practicable (MEP)?

Answer: Agency has tried to provide guidance, but it's a tough problem. Sort of letting municipality and permit writer come to agreement on what constitutes MEP for the particular municipality. Sections 301 and 402 of the Clean Water Act do not allow relief from attaining water quality standards. The reauthorization bills now before Congress may define MEP.

Question: How is the quality of data collected by industry addressed by EPA?

Answer: EPA recognizes that there may be some question about the accuracy of the data, but considers it acceptable for identifying pollutants of concern.

Stormwater Monitoring: Local Municipal Perspectives
Doug Harrison

California municipalities have been under permit for the last three years and are in the process of negotiating Round II. They have been monitoring for the last 3 years and will use this information in renegotiating the monitoring provisions in permit renewals.

Monitoring program results indicate that we are not reducing pollutant loads from urban runoff. Monitoring info is also not telling us what to do. The present NPDES monitoring programs are taking too few samples to be statistically significant in terms of determining differences and/or changes in quality (monitoring does not ensure compliance, yet it has shown that water quality has not been improved).

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Identification of performance of control mechanisms, documentation of impacts, documentation of water quality improvements is required by EPA regulations, but monitoring results are indicating that we cannot determine these things.

The EPA mandate used to be to reduce pollution to the MEP. A new aspect to the EPA mandate is that urban runoff must meet WQS in receiving waters.

Unless stormwater programs can demonstrate success (improved environment) to the public, the public will cease to fund it.

We need a national strategy for stormwater management.

Permit writers are too independent in determining content of stormwater permits.

To show with 80% probability a 20% pollutant reduction in storm water will require Fresno to increase present monitoring budget by a factor of 4. Present program provides a 15 percent probability that they can detect a 20% change.

Monitoring costs about $1.5 million/5 years, yet, according to their consultant, this will not provide statistically significant results.

Conclusions

- Must. document uncertainty in the data.
- Agree with Mike's (Cook) prioritization, but emphasis is on his lowest priority, pollutant reduction.
- Our monitoring programs are not supporting management decisions.
- Need Congressional help to set the national management strategy.
- Need to get away from end-of-pipe measurement.
- Need to change the presumption that it is easy to identify stormwater quality problems.

How Congress Should Act on Stormwater
Howard Holme

Congress should rewrite the statute to require a reasonable program, subsidized by the federal government, allowing municipalities to solve real water quality problems.

The requirement of water quality standards (WQS) must be repealed, recognizing that WQS are impossible and unnecessary to meet. Present requirement would require 10% of the national GNP.

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Human health is the highest priority for WQ management; EPA estimated less than 1 death per year related to point or non-point source discharges. (Editor's note - this is probably not a good statistic).

Stormwater pollution control should be a voluntary program.

Private entrepreneurs should bid to reduce pollution or pollutants.

Congress should recognize the need for cost-effective water quality management.

<u>Questions/Comments</u>

Question: Proposal is interesting, but contrary to current mind of Congress. Also, how will successful bidders be monitored to insure they spend the money and achieve promised results?

Answer: This would need to be worked out, but thinks it would be more cost-effective than command and control.

Comment: (Holme) Now we debate whether there should be federal subsidies; shouldn't we pay to fix our own problems?

Question: How is ecological health included in your proposal?

Answer: If Congress deems it necessary, then just add this provision to the statute.

Question: Ohio data base contradicts the conclusion that stormwater has not affected the environment. Maybe we are not using the right tools to identify the problems.

Answer: A valid criticism, but current WQ act is still chemically oriented in identifying problems and not addressing that problem. Time is needed to develop the appropriate tools.

Question: Given the fact that the present monitoring is not answering the desired questions, does EPA intend to change its rules and regulations regarding monitoring?

Answer: Maybe the wrong type of monitoring was selected. If a municipality thinks its monitoring program is not accomplishing its purpose, then change the program.

Question: Swietlik (EPA) indicated that there is flexibility in the monitoring program. How do we educate permit writers to interpret the regs in a similar fashion?

Answer: This is a problem and requires an education program. There is a gap in the information and guidance that EPA can give them.

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Comment: (on Harrison's talk) As a professional engineer, there is a requirement to maintain a standard of practice in technical programs for pollution control, but the public also has a role. It is necessary to have the public involved in monitoring violations and support of stormwater management programs. Mr. Harrison seems to feel that there is not enough money to carry out the program, therefore we need public volunteers to gather WQ samples.

Comment: Much of the country is doing permit application monitoring, not compliance monitoring. Compliance monitoring is a different animal and is oriented at determining progress in meeting requirements of the WQ Act. (Editor's note - inference is that maybe this is where we switch to biological monitoring). Data on the effectiveness of the management program is what is needed.

Comment: New Zealand (Aukland) has determined from bio-assessment that shellfish are affected by urban runoff. The process is then to move toward educating the public (who must approve funding of these programs) on the problem, and then moving initially toward mitigation of these problems by going directly into BMPs to reduce pollution.

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PARAMETERS TO REPORT WITH BMP MONITORING DATA

By Ben R. Urbonas, M. ASCE*

ABSTRACT

This paper presents an argument for standardization of the physical, chemical, climatic, geological, biological, and meteorological parameters being reported along with the data acquired by various investigators on the performance of structural stormwater Best Management Practices (BMPs) used to enhance stormwater quality. Also, a standard minimum list of such parameters is suggested. Such a list is needed if we want to have a meaningful exchange of data among the various studies being conducted throughout the world. Transferability of performance results and consistency, or lack of it, in the performance of various BMPs has been an ongoing problem. A mutually agreed upon minimum list of reporting parameters that can be used to relate the performance of BMPs to some, or all, of these parameters could begin to address this problem. Over time such standardization will conserve the resources being expended by various field investigations and may eventually lead to improvements in the selection of, and the design of, various BMPs.

INTRODUCTION

Much data have been collected over the past 10 to 20 years on the performance or "efficiency" of many structural stormwater quality BMPs. Most existing data relate to the performance of detention basins (i.e., detention basins that drain out completely after a storm runoff end, sometimes called "dry pond"), retention ponds (i.e., ponds that have a permanent pool of water and retain at least part of one storm's runoff after its runoff period ends, sometimes called "wet pond") and wetlands. Less data are available on field effectiveness of other types of BMPs. However, this data and/or its reporting lacks consistency. In addition, many of the reported results do not show clear mathematical relationships between the performance of similar BMPs among various sites in which they were investigated. One of the reasons may be that

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sufficient parametric information about each site has typically not been reported along with the performance data to permit systematic analysis of data collected under a variety of field studies, or to relate these data to a set of physical, climatic, geologic, or hydrologic conditions.

What we have now is a variety of independent interpretations with very little attempt to relate to other investigations that may have occurred in the past or may be occurring concurrently. Some of these interpretations may make a lot of sense while others leave us wondering and questioning what was studied, what was found, and why? More importantly, we cannot answer with any degree of confidence what role various site parameters play in the performance of any particular BMP.

As an example for a retention pond, is it more important to know the *pond size vs. inflow event volume* ratio when designing for the removal of Total Suspended Solids (TSS) or Total Phosphorous (TP), or is it more important to know the *surface area of the pond vs. tributary watershed area* ratio, or is another set of parameters more important? Such questions can only be answered by systematic and consistent BMP monitoring activities, wherever they may take place. Without these we will never be able to develop reliable, field tested, selection and design guidance for structural BMPs, guidance that we need to use these BMPs with confidence.

When we examine what occurs at a retention pond, there are two distinctly separate phases of sedimentation. The first takes place during storm runoff when settling occurs under turbulent conditions. The other takes place during the quiescent conditions between storm runoff periods. In addition, between runoff events biological and chemical processes can remove or remobilize suspended and dissolved constituents in the water column.

In the TSS removal example discussed above, the settling of solids under quiescent conditions is a function of particle density, particle size and the fluid's viscosity, which in turn is a function of temperature. According to Dobbin (1944) and Camp (1946), particle settling under dynamic inflow conditions is dependent on the unit surface hydraulic loading (i.e., Q/A) and the measured distribution of TSS particle settling velocities and critical shear stress, which in turn is a function of flow velocity and depth. There is also evidence (Grizzard et al; 1986) that TSS and other constituent removal efficiencies can be significantly affected by the initial concentration of the constituent. Laboratory and field data using stormwater show that it is easy to remove 80 to 90 percent of TSS from urban runoff when its initial concentration is high (e.g., > 400 mg/l) and difficult to remove even 20 percent when the initial concentrations are low (e.g., < 20 mg/l).

There are a number of key parameters that need to be obtained and reported whenever BMP performance is monitored. Identifying all such parameters at this time is not possible. We can add to the list as we learn more about the passive treatment mechanisms and the performance of structural BMPs. However, an initial list is

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suggested for a variety of BMPs that are currently or may be field tested in the future for effectiveness. They need to be reported in all study reports, data transfer reports, and other literature, along with performance data such as the inflow and outflow event mean concentrations (EMCs), the percentages of removal of each constituent, the flow rates and the volumes entering and leaving each structural BMP facility being investigated.

As municipalities and industries in United States of America begin to operate under the federally mandated National Pollutant Elimination Program's separate stormwater discharge permit system, we can expect a profound increase in the amount of stormwater monitoring data being collected and reported. Much of it will be associated with the performance of various BMPs. This data will be collected in a variety of ways, using different monitoring and reporting techniques, manual sampling, automatic sampling, different constituent detection levels, etc. The selection of the techniques used at each site will be determined by local conditions, budgets, expertise of the investigators, and other factors impossible to predict in advance. Some level of consistency in how this data and the type BMP parameters being reported will be needed if we ever hope to make any sense of this data or hope to draw repeatable quantitative conclusions. This will be a particular challenge when trying to draw conclusions relative to how this data relates to various BMP's and tributary watershed design parameters.

It is hoped that the consistent use in the professional literature of a minimum set of standard parameters will result in more reliable tools for the selection of structural BMPs, and in better design tools than we have today. In developing this list, various potential physical, biological and chemical processes were considered for several types of BMPs . Although this list is extensive, every attempt was made to keep it as brief as possible. This does not mean, however, that other site specific parameters should not be measured or reported.

It is also recommend that additional parameters be carefully evaluated before adding them to this list. It is not the intent to limit this initial list or to keep out other potential parameters of merit. It is suggested that before adding to this list consider that the complexity of finding meaningful empirical relationships expands exponentially with each new parameter. Also, we need to be sure that any new parameter is not already on this list, either as part of another parameter or within a grouping of the parameters on the present list. For example, it is not necessary to report the tributary impervious watershed area if the total watershed area and its percent of total imperviousness are reported.

REPORTING CONSTITUENTS AND THEIR REMOVALS

The way that we report data on the constituents in the water column and their removal rates is dictated by whether we have a detailed study report or a paper summarizing the study. The former merits much more detail. Also, should data be reported as event mean concentrations for each storm or should they be reported as a set of discrete sample data obtained at different times during a storm? There is a need to have some level of consistency in how we handle this issue.

Data and Study Reports

Typically, literature reports the constituents being monitored, their removal efficiencies and associated flows. Sometimes the constituents are reported as EMCs entering and leaving the BMP facility, while at other times data are reported for individual discrete samples taken throughout the runoff event, even though discrete samples are often composited into a single EMC. For consistency, it is recommended that stormwater BMP data be reported as paired inflow and outflow EMCs for all the events sampled, along with the event's volume of runoff (inflow and outflow if different) and percent constituent removal rates during each event.

The collection and reporting of discrete sample data taken at various times during runoff events is not discouraged by the above recommendation. It is, however, very expensive to test each discrete sample for a number of constituents, and many stormwater data collection efforts elect to test only the flow weighted composite sample to find the storm's EMC. If budgets permit, however, much understanding can be gained through the collection and analysis of discrete water quality samples throughout the runoff hydrograph. For constancy, the reporting of storm composite EMCs in published literature is recommended. However, discrete sample data should be made available to other investigators upon request as ASCII or data base files, along with the organization and format of these files.

Inconsistencies also occur in the literature in reporting removal efficiencies. To cope with this, it is recommended that the percent removal (*PR*) for any constituent be calculated and reported for each monitored event using the inflow and outflow loads. If the facility records less surface outflow than inflow, as can be the case when infiltration/percolation occurs, the outflow loads should be reported for the surface component based on the measured outflows, and for the subsurface component based on the estimates of the water infiltrated/percolated, into the ground. This should prevent the impression that infiltration/percolation actually eliminates constituents, instead of, as sometimes happens, transferring them to the groundwater flow regime. Equation 1 is suggested as the basic equation for calculating the percent removal rate of any sampled constituent.

$$PR = \frac{V_{in} \cdot EMC_{in} - V_{out} \cdot EMC_{out}}{V_{in} \cdot EMC_{in}} \cdot 100 \qquad (1)$$

in which,
PR = percent constituent load removed,
V_{in} = storm runoff volume inflow into the BMP facility,
EMC_{in} = event mean concentration of inflow volume,

V_{out} = storm runoff volume outflow from a into the BMP,
EMC_{out} = event mean concentration of outflow volume,

Reporting of constituent concentrations in dry weather inflows and outflows, if any, can reveal much about the true performance of a BMP. Many on-site BMPs do not experience dry weather flows and the reporting of the percent constituent removal efficiencies for storm events is sufficient. However, if dry weather flows are present, they sometimes can have a very significant effect on the actual constituent removal rates that take place over an extended period of time (Urbonas et al, 1994). To help us understand how any BMP being studied is affected by dry weather flows, it is recommended that constituent concentrations in dry weather flows be obtained and reported in sufficient numbers to provide averages and their coefficients of variation.

Report Summaries and Published Summary Papers

Summaries of monitoring studies and published papers often cannot include all the data that were collected. As a result, the information has to be reduced to fit the available space. Again there is no consistency in how this is done, and it is suggested that, as a minimum, summary reports and published summary papers report the constituent EMC data as monitoring period (or seasonal) averages for both the inflow and outflow, along with the inflow (and outflow if different) volume averages and numbers of EMC data points (i.e., storm events sampled) for each parameter, along with each average's coefficient of variation (CV). These data need to be accompanied by the long-term average percent removal rates for each constituent reported as the arithmetic mean of individual removal rates. Calculate these using Equation 2. The arithmetic, instead of the flow-weighted, mean is suggested to avoid the problem of a single runoff event, with a very large runoff volume, overwhelming the reported average removal rates. The author has observed that, under typical data sets, the arithmetic and the flow-weighed removal rate averages are similar. On the other hand, a single, very large storm can disproportionately affect the flow-weighted average.

$$PR_{av} = \frac{\sum_{i}^{n} PR_i}{n} \qquad (2)$$

in which, PR_{av} = Average % removed, all monitored events, single constituent,
n = number of events for which percent removals were calculated,
PR_i = % removed for the i_{th} event sampled.

BASIC SEDIMENTATION EQUATIONS

Much of the performance effectiveness attributed to BMPs currently focuses on the removal of TSS from runoff. This is definitely not always the case. Local concerns, such as those in watersheds tributary to Chesapeake Bay and the watersheds in the State of Florida suffering from groundwater depletion, may dictate that the removal of nutrients is of greatest concern, or, as is the case for the watershed

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draining to San Francisco Bay, the removal of copper, soluble and total, may be of most interest. Nevertheless, the selection of the parameters being suggested is based on the principles for the removal of TSS and other constituents. The reduction in the toxicity of some of the constituents was also considered in developing the recommended list.

The TSS removal process is much more complex than can be explained using simple sedimentation equations. Nevertheless, these equations provide some of the mathematical basis for identifying many of the physical parameters that should be looked at, especially when considering the design of facilities to remove particulates and the constituents that adhere to them.

Newton's Sedimentation Law For Spherical Particles:

Newton proposed the following equation to describe the settling velocity of a particle in a fluid:

$$V_s = \sqrt{\frac{4}{3} \cdot \frac{d_p \cdot g \cdot (r_p - r_v)}{C_D \cdot r_v}} \quad (3)$$

in which,
- V_s = settling velocity of a given particle size in m/s
- d_p = diameter of the particle in m
- r_p = specific gravity of the particle,
- r_v = specific gravity of the fluid,
- g = gravitational acceleration in m/s²
- C_D = drag coefficient, a function of Reynolds Number R_n, which in turn is a function of the fluid's temperature.

Basic Suspended Solid Settling in Turbulent Flow:

Geyer (1954) suggested a relationship to describe the sediment fraction that can be removed in a pool of water under the dynamic conditions that can occur as water enters the pool at one end and overflows through an outlet at the other end. This relationship, Equation 4, relies on the pool's hydraulic surface loading rate, namely the flow-through rate divided by the pool's surface area.

$$R_d = 1.0 - \left[1.0 + \frac{1}{n} \cdot \frac{V_s}{Q/A}\right]^{-n} \quad (4)$$

in which,
- R_d = fraction of the inflow solids removed under dynamic conditions,
- V_s = settling velocity of a given particle size in m/s (ft/sec),
- Q = flow through rate in cubic m³/s (ft³/sec),

A	=	surface area of the permanent water pool in m^2 (ft^2),
n	=	turbulence, or short-circuiting, constant,
	=	1.0 for poor performance, high sort-circuiting potential,
	=	5.0 for very good performance, low short-circuiting potential,
	=	∞ for ideal performance.

As n approaches infinity, Equation 4 reduces to:

$$R_d = 1.0 - e^{-kt} \quad (5)$$

in which,

k	=	V_s/h , sedimentation rate coefficient in /s units,
h	=	average depth of the pond in m (ft),
t	=	V/Q , residence time in the pool in seconds
V	=	volume of the pool in m^3

GENERAL PARAMETERS TO CONSIDER FOR ALL BMPS

There are a number of general parameters that should be recorded and reported, regardless of the type of BMP being tested. Some of these can be used to assess the aquatic environment and the toxicology of the constituents being monitored. Others, such as temperature, give the investigator an idea of the fluid's density and viscosity, both of which influence the settleability of solids. Table 1 lists a number of such general parameters. All of them can be measured in the field and, except for V_{SD}, are relatively inexpensive to obtain.

RUNOFF PARAMETERS

Since storm runoff is a function of the tributary watershed area and its imperviousness, always report the *Tributary Watershed (A_T)*, its *Total Percent Imperviousness (I_{IT})* and the *Percent of the Total Imperviousness that is Hydraulically Connected (I_{IC})* to the storm conveyance system. Often not reported in the literature is information about storm runoff peaks, runoff volumes or storms, and base flows associated with BMP facilities. Figure 1 illustrates storm runoff events as a time series of hydrographs, which information can be summarized using a probability distribution graph shown in Figure 2. To help us find relationships between runoff distribution data at a variety of sites being monitored and the performance of these BMPs, it is recommended that, as a minimum, runoff data (and outflow data if different) be summarized as suggested below for *Runoff Volume*, *Storm Runoff Duration* and *Storm Runoff Inter-Event Time* parameters as follows:

TABLE 1. GENERAL PARAMETERS TO REPORT FOR ALL BMPs

Inlet and Outlet	Plan, profile and details, including dimensions and elevations of the inlet and outlet works. Include inflow baffles and outlet trash racks, if any.
Temp •	Water temperature of influent, effluent and possibly the pond itself. Summarize this data as monitoring season averages, along with their coefficients of variation.
V_{SD}	Settling velocity distribution of the sediments in stormwater determined from a number of settling column tests.
Alkalinity & Hardness	Affect the solubility and the toxicity of metals and of other constituents. To be measured and reported as the Event Mean Concentration (EMC) of the facility influent and effluent.
Conductivity •	Provides a surrogate indicator of ionic activity in the water column, which may indicate the availability of toxic forms of metals to aquatic life. Reporting *dissolved* metals along with *total* metals data provides an indicator of potentially available toxic forms.
pH •	Affects the solubility and toxicity of metals and other constituents.
•	Indicates that these parameters are to be measured in the field and reported as the mean of the measured values.
Solar Radiation	Reported daily from the nearest first-order U.S. Weather station, only for retention ponds, wetlands and other biologically active treatment water quality facilities. Summarize this data as the mean of daily averages for each monitoring season and their coefficients of variation.
Maintenance	Provide type and frequency of maintenance such as dredging of sediments, harvesting, mowing, removing and replacing filter media, etc.
Facility Description	Full description of the BMP, including layout, typical cross-section and profile, inlet and outlet details, vegetative cover, etc.

<u>Runoff Volume Parameters During Monitoring Season:</u>

V_R = Volume of the average runoff event in watershed mm (in)·

V_{R50} = Volume of the 50th percentile runoff event in watershed mm (in)·

CV_{VR} = Coefficient of Variation in the volumes of runoff events ($_{SD-R}/V_R$),

in which V_{SD-R} = Standard deviation of Runoff volumes,

V_B = Volume of the seasonal dry weather base flow in watershed mm (in),

Q_P = Average runoff peak rate in m^3/s (ft^3/sec),

CV_{QP} = Coefficient of Variation of flow peaks.

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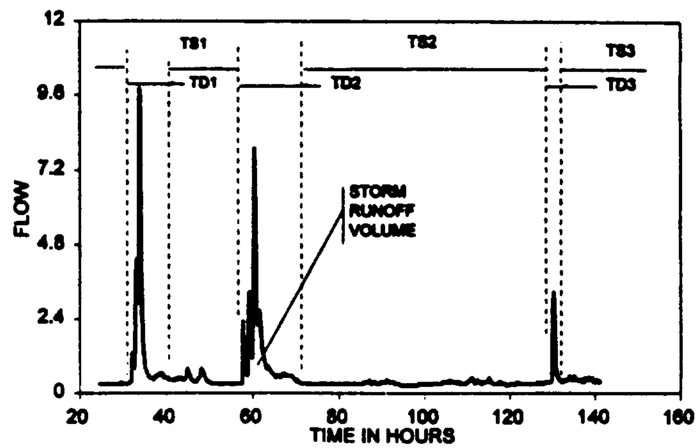

Figure 1. Time series of storm hydrographs, their duration and inter-event times.

Time Variable Parameters of Storms During the Monitoring Season:

Storm Runoff Inter-Event (Separation) Time:

T_S = Average separation period between the end of a storm runoff hydrograph and the beginning of the next one, in hours,

T_{S50} = The 50th percentile of storm runoff event separation periods, in hours,

CV_{TS} = Coefficient of Variation in storm runoff event separation periods (T_{SD-S}/T_S), in which T_{SD-S} = Standard deviation of storm runoff event separation periods.

Storm Runoff Duration:

T_D = Average duration of storm runoff in hours,

T_{D50} = The 50th percentile value of storm runoff duration in hours,

CV_{TD} = Coefficient of Variation in storm runoff duration (T_{SD-D}/T_D), in which T_{SD-D} = Standard deviation of storm runoff duration.

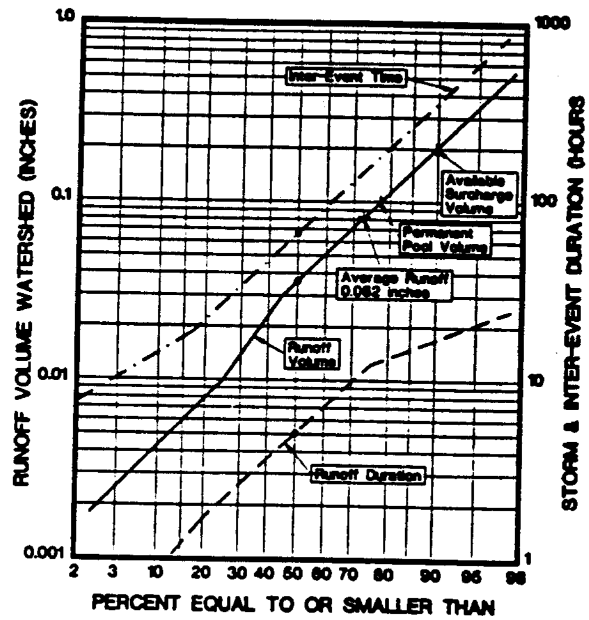

Figure 2. Example of cumulative probability distribution of Surface Runoff, Storm Separation and Inter-Event Time for one BMP site (After Urbonas et al, 1994).

PARAMETERS FOR RETENTION PONDS

Figure 3 is a plan view of an idealized stormwater retention pond used as a structural BMP. Retention ponds such as this always have some surcharge detention storage above the permanent pool water surface.

There are several pollutant removal mechanisms at work within a retention pond. These include sedimentation during runoff events and between runoff events, other physical processes, chemical processes and biological processes. As a result, more information needs to be reported for these types of facilities than for facilities that remove pollutants primarily though physical processes. Also, keeping these points and Equations 3 through 5 in mind, the following set of parameters emerge as needing to be reported with retention pond removal efficiency data.

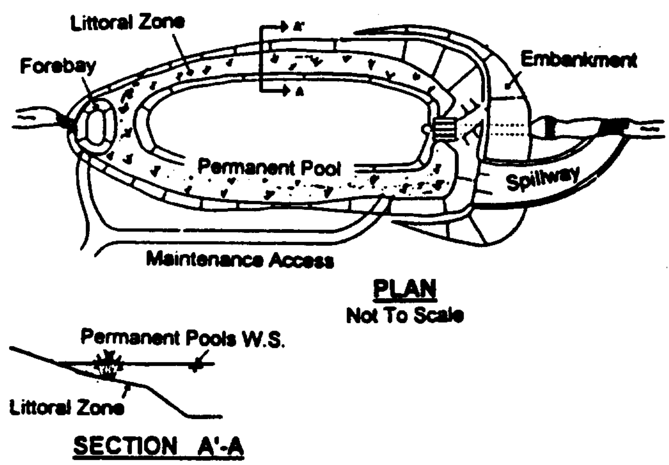

Figure 3. Plan of an Idealized Retention Pond. (After UDFCD, 1992)

Surface Area and Pond Layout Parameters:

A_P = Surface area of the permanent pool in m^2 (ft^2),

A_L = Surface area of the littoral zone (zone ≤ 0.5 m (1.5 ft) deep) in m^2 (ft^2),

A_D = Surface area of the top of the surcharge detention basin in m^2 (ft^2),

L_P = Length of the permanent pool or flow path in m (ft),

L_D = Length of the surcharge detention basin in m (ft),

A_F = Surface area of the forebay in m^2 (ft^2),

L_F = Length of the forebay in m (ft).

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Basin Volume Parameters:

V_P = Volume of the permanent pool in m^3 (ft^3),

V_D = Design volume of the surcharge detention basin above the permanent pool's water surface in m^3 (ft^3),

V_F = Volume of the forebay in m^3 (ft^3).

Emptying Time Parameters:

T_E = Time needed to empty 99% of V_D assuming no inflow takes place while the surcharge pool is emptying, in hours, and

$T_{0.5E}$ = Time needed to empty the upper one-half of V_D assuming no inflow takes place while the surcharge pool is emptying, in hours.

PARAMETERS FOR EXTENDED DETENTION BASINS

Figure 4 shows the plan view of an idealized extended detention basin. Such basins employ sedimentation as their primary pollutant removal mechanism. As a result, Equations 3, 4 and 5 apply to extended detention basins, but have to be viewed somewhat differently than for a retention pond. In a retention pond, sediments that settle below the overflow outlet level are essentially trapped within the permanent pool and are less likely to be discharged through the outlet. The trapped sediment continues to settle to the bottom of the pond even after the surcharge volume is drained off. In an extended detention basin stormwater empties through an outlet located on the bottom. As the sediments settle to the bottom they concentrate within the lower levels of the ever shrinking pool and discharge through the outlet. Unless they are scoured out, only the sediments that deposit on the bottom can be trapped within the basin.

The design for extended detention basins thus requires much longer drain times to permit the sediments to settle to the bottom of the basin. Current state-of-practice suggests that the emptying time be set at 24 to 48 hours for a volume equal to the average runoff event expected to occur at the design site. Current practice also suggests that extended detention basins be designed to have two levels. The lower level basin is filled frequently by the predominant numbers of small runoff events, while the upper basin is inundated only few times a year. This two layer design significantly improves the upper basin's usability for other community uses.

The list that follows reflects most of the parameters of importance for an extended detention basin. Many of the same parameters that were recommended for retention ponds are repeated.

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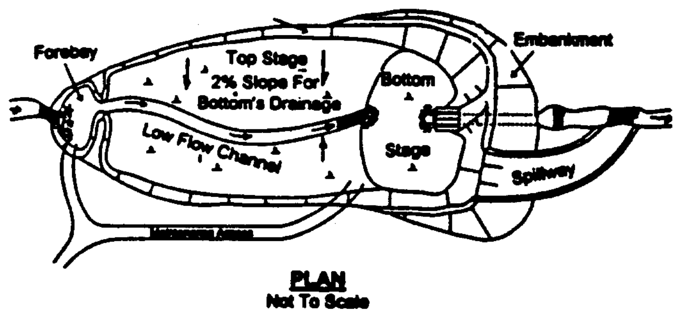

Figure 4. Plan of an Idealized Extended Detention Basin. (After UDFCD, 1992)

Surface Area and Plan Layout Parameters:

A_D = Surface area of the extended detention basin in m^2 (ft^2),

L_D = Length of the extended detention basin in m (ft),

A_B = Surface area of the bottom stage (i.e., lower basin) in m^2 (ft^2),

L_F = Length of the forebay in m (ft).

Basin Volume Parameters:

V_D = Total Volume of the extended detention basin in m^3 (ft^3)

V_B = Volume of the Bottom stage only of the basin in m^3 (ft^3)

V_F = Volume of the Forebay in m^3 (ft^3)

Time Variables:

Use the same *Emptying Time* parameters as defined for the retention pond.

PARAMETERS FOR WETLAND BASINS

Figure 5 depicts an idealized wetland basin. Some wetland basins are similar in their operation to retention ponds while others resemble extended detention basins. The difference between the two is whether or not the wetland basin has standing water or a wetland meadow as its bottom. The pollutant removal mechanisms are probably similar to those found in retention ponds and in detention basins, except that stormwater comes in contact with wetland flora and fauna. This contact and the physical structure of the wetland provide pollutant removals through adsorption and biochemical processes and possibly through reoxygenation of the sediments and detoxification of the water column, processes that may or may not be available in retention ponds, and that are not available in detention basins.

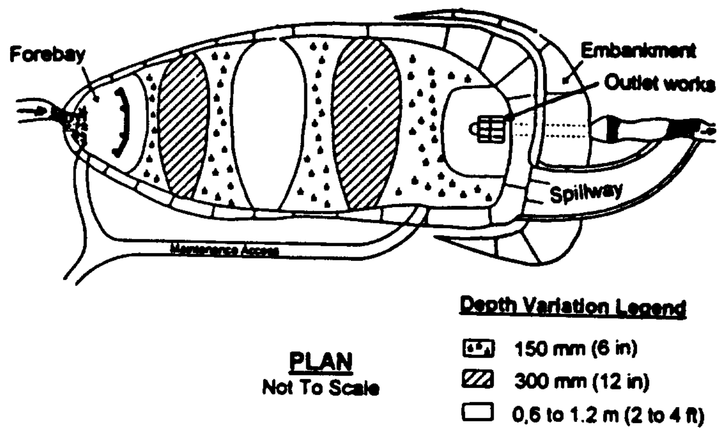

Figure 5. Plan of an Idealized Wetland Basin. (After UDFCD, 1992)

In addition to the parameters of Equations 3, 4 and 5, each performance monitoring program should report parameters that are peculiar to the wetland studied. Most currently available wetland monitoring data rarely contain such information, often not even reporting many of the parameters commonly being reported for other BMPs. Because the quantification of wetland performance as a BMP is relatively new, very little information can be found in the literature and it is difficult to suggest parameters to report when reporting the performance data of wetland basins. Table 2 and the list that follows it suggest the parameters that appear to be most important, many of which are identical to those recommenced for retention ponds.

TABLE 2. ADDITIONAL GENERAL PARAMETERS TO REPORT FOR WETLANDS

Type of Wetland	Cattail marsh, northern peat land, meadow, palustrine, southern marshland, hardwood swampland, brackish marsh, high altitude riverine, freshwater riverine, mixed (include types), constructed or natural, etc.
Rock Filter?	Is there a rock filter media present in the wetland bottom?
Dominant Plant Species	Lists the dominant plant species in the wetland and the age of these plants (i.e., time since their original planting or replanting).

<u>Surface Area and Layout Plan Parameters:</u>

A_P = Surface area of permanent wetland pool, if any, in m^2 (ft^2),

A_M = Surface area of the meadow wetland, if any, in m^2 (ft^2),

$P_{0.30}$ = Percent of permanent pool less than 0.30 m (12 in) in depth,

$P_{0.60}$ - Percent of the permanent pool more than 0.60 m (24 in) in depth,

A_S = Surface area of the surcharge detention basin's top in m^2 (ft^2),

L_S = Length of the wetland surcharge/detention pool or flow path in m (ft),

A_F = Surface area of the forebay in m^2 (ft^2),

L_F = Length of the forebay in m (ft).

<u>Basin Volume Parameters:</u>

V_P = Volume of the permanent pool, if any, in m^3 (ft^3),

V_D = Design volume of the surcharge/detention basin in m^3 (ft^3),

V_F = Volume of the forebay in m^3 (ft^3).

<u>Time Variables:</u>

Use the same *Emptying Time* parameters as defined for the retention pond.

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PARAMETERS FOR WETLAND CHANNELS

Channels can be designed to have a wetland bottom which are designed to flow very slowly. Figure 6 shows a profile for such a channel. When properly designed, the channel's bottom is covered by wetlands, with only the sideslopes having terrestrial vegetation. The flow velocity is controlled by transverse berms, by check dams or by an outlet at the downstream end of a given channel's reach. In the last case, the channel is essentially a long and narrow wetland basin.

The pollutant removal mechanisms in wetland bottom channels are similar to those found in wetland basins, except that contact time of stormwater with the wetland vegetation is likely to be less. Because of the flowing channel nature of this BMP, the following parameters, in addition to those in Tables 1 and 2, should provide the information needed to compare the performance of different installations:

V_{2-yr} = Average channel velocity during a 2-year runoff event in m/s (ft/sec).

A_D = Surface area of the wetland bottom in square m^2 (ft^2).

L_D = Length of the wetland channel in m (ft).

Prt = Describe any pretreatment provided ahead of the channel (e.g. detention).

Time Variables.

There are no *Emptying Time* parameters to report for wetland channels.

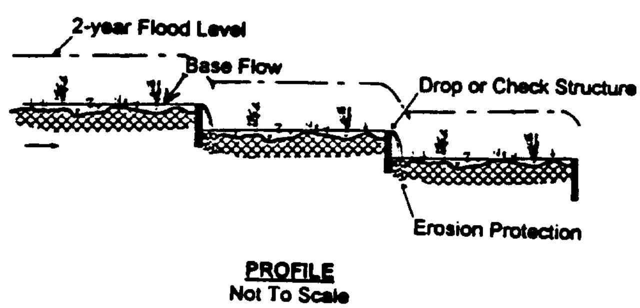

Figure 6. Profile of an Idealized Wetland Bottom Channel. (After UDFCD, 1992)

PARAMETERS FOR SAND FILTERS

Sand filters can be installed as basins or as sand filter inlets. Figure 7 illustrates an idealized filter basin and Figure 8 does the same for a filter inlet. Typically, these installations will have a detention basin or a retention pond (or tank) upstream of the filter to remove the heavier sediment and, if properly designed, some of the oil and grease found in stormwater. However, such a pretreatment basin is not always present. All of the parameters required for a *Retention Pond* or for an *Extended Detention Basin* should also be reported along with the information about the sand filter whenever the filter is preceded by a pre-treatment basin. For example, a filter inlet is often equipped with an underground tank which helps to remove some of the sediment, oil and grease before stormwater is applied to the filter. Such a tank is similar to a retention pond and all of the parameters associated with a retention pond, such as volume, surface area, length, surcharge volume, etc. should be reported.

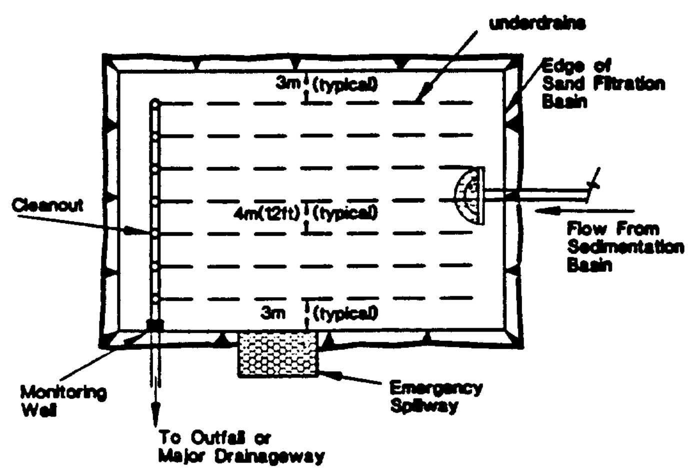

Figure 7. Plan of an Idealized Sand Filter Basin. (After UDFCD, 1986)

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In addition to the parameters of the pond or basin associated with the filter, provide the following:

- Dimensions of the installation.
- Depth of various filter material layers.
- Type of filter media, its median particle size (i.e., D_{50}) and its Coefficient of Uniformity.
- Maintenance frequency.
- All associated drainage and flooding problems attributed to the installation because of its configuration size, maintenance practices, etc.

Time Variables:

Use the same parameters for *Emptying Time* as defined for the retention pond.

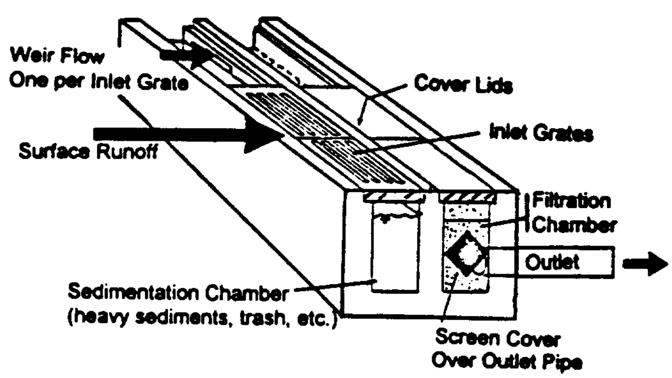

Figure 8. An Idealized Sand Filter Inlet. (After Shaver, 1993)

PARAMETERS FOR OIL, GREASE AND SAND TRAPS

An oil, grease and sand trap is an underground tank, similar to the one illustrated in Figure 9. It is nothing more then a special configuration of a retention pond. As a

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result, all parameters listed for a *Retention Pond* should be reported for these installations. Typically these installations have a forebay and an outlet basin. In addition to reporting the parameters for a pond, provide the *dimensions of the installation, details of its design (including skimmers, sorbent pillows, lamella plates, baffles, etc.) and the maintenance provided during the testing period.* Because these traps are much smaller than a surface pond, the flow-through velocity is of concern because it can cause trapped oil, grease and sediment to be remobilized and flushed out of the trap. As a result, provide the *average flow velocity that can be expected to occur in this device during a 2-year storm*, which velocity can be used as an index for comparing the performance among a variety of installations.

Time Variables:

Use the same *Emptying Time* parameters as defined for a retention pond.

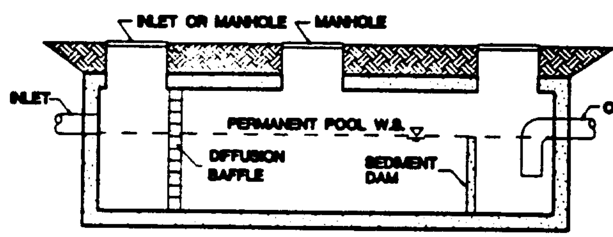

Figure 9. An Idealized Oil, Grease and Sand Trap (After Neufeld, 1994).

PARAMETERS FOR INFILTRATION AND PERCOLATION FACILITIES

An idealized percolation trench is illustrated in Figure 10. For percolation trenches and for infiltration basins report all of the parameters suggested for the *Extended Detention Basin.* In addition, report the following:

- Depth to high groundwater and to impermeable layers below the infiltrating surface of the basin, or below the bottom of the percolation trench.

- The hydraulic conductivity of soils adjacent to percolation trenches and the saturated surface infiltration rates of soils underlying infiltration basins.
- Dimensions of the installation.
- Maintenance needs and associated drainage and flooding problems attributed to the installation.
- Failures to empty out the captured water completely within the design emptying time.

<u>Time Variables:</u>

Use the same *Emptying Time* parameters as defined for a retention pond.

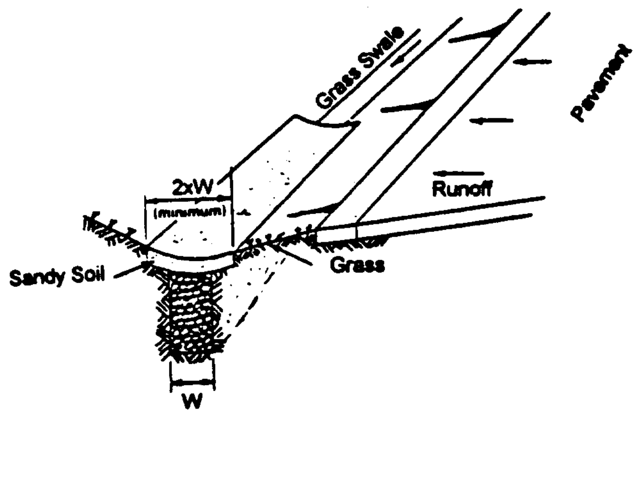

Figure 10. An Idealized Percolation Trench. (After Urbonas & Stahre, 1993)

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SUMMARY AND RECOMMENDATIONS

In summary, there is a great need for consistent reporting of various BMP parameters along with field testing data on their performance. Table 3 lists these parameters. It is recommended that all agencies and organizations that undertake field studies of BMP performance be encouraged to include in their reports and report summaries the information suggested in this paper. Only through a concerted effort by stormwater professionals to report the suggested minimum list of parameters about each installation, or some other list that the research community deems more appropriate, parametric relationships may be discovered that will allow us to refine and optimize the design tools for structural BMPs.

FURTHER REVIEW COMMENTS TO ASCE

A paper that presented the concepts and recommendations made in this paper is also being published by the American Society of Civil Engineers, Water Resource Planning and Management Division's Journal. Anyone wishing to comment on this topic and these recommendations is invited to write to the ASCE Journal's services. All comments are welcome as this topic deserves wide debate and discussion.

ACKNOWLEDGMENTS

The author acknowledges the many professionals that contributed to the development of this paper. The initial and pre-final drafts were distributed to approximately 40 individuals, many of who have contributed significantly to the field of stormwater management over the last 25 to 30 years. A special thanks goes to all those that responded with their comments and suggestions. As a result, the recommendations being made in this paper reflect the suggestions, opinions and the experience of many individuals and not only those of the author. Special acknowledgment goes to the following for their specific and extensive review comments and suggestions: Eric Strecker, John Warwick, Betty Rushton, Jim Wulliman and Harry Torno.

TABLE 3. SUMMARY OF REPORTABLE BMP SITE PARAMETERS.

Parameter	Ret. Pnd	Ext. Det. Bsin	Wet-land Bsin	Wet-land Chn'l	Sand Filter	Oil/ Sand Trap	Infilt. & Perc.
Tributary Watershed Area - A_T	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Total % Trib. Watershed is Impervious - I_{IT}	Yes	Yes	Yes	Yes	Yes	Yes	Yes
% of Impervious Area Hyd. Connected - I_{IC}	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Gutter/Sewer/Swale/Ditches in Watershed?	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Avarage Storm Runoff Volume - V_R	Yes	Yes	Yes	Yes	Yes	Yes	Yes
50th Percentile Runoff Volume - V_{R50}	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Coeff. Var. of Runoff Volumes- CV_{VR}	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Av. Daily Base Flow Volume - V_B	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Average Runoff Inter-Event Time - T_S	Yes	Yes	Yes	Yes	Yes	Yes	Yes
50th Percentile Inter-Event Time - T_{S50}	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Coeff. Var. of Inter-Event Times - CV_{TS}	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Average Storm Duration - T_D	Yes	Yes	Yes	Yes	Yes	Yes	Yes
50th Percentile Storm Duration - T_{D50}	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Coeff. Var. of Storm Durations- CV_{TD}	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Water Temperature - *Temp*	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Alkalinity, Hardness & pH	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Sediment Settling Velocity Dist. - V_{SD}	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Type & frequency of maintenance	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Inlet & Outlet dimensions & details	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Solar Radiation	Yes	NO	Yes	Yes	NO	NO	NO
Volume of Permanent Pool - V_P	Yes	NO	Yes	NO	Yes	Yes	NO
Perm. Pool Surface Area - A_P	Yes	NO	Yes	NO	Yes	Yes	NO
Littoral Zone Surface Area - A_L	Yes	NO	NO	NO	NO	NO	NO
Length of Permanent Pool - L_P	Yes	NO	Yes	NO	Yes	Yes	NO
Detention (or Surcharge) Vol. - V_D	Yes	Yes	Yes	NO	Yes	Yes	NO
Detention Basin's Surface Area - A_D	Yes	Yes	Yes	NO	Yes	Yes	Yes
Length of Detention Basin - L_D	Yes	Yes	Yes	NO	Yes	Yes	Yes
Brim-full Emptying Time - T_E	Yes	Yes	Yes	NO	Yes	Yes	Yes
½ Brim-full Emptying Time - $T_{0.5E}$	Yes	Yes	Yes	NO	Yes	Yes	Yes
Bottom Stage Volume - V_B	NO	Yes	NO	NO	NO	NO	NO
Bottom Stage Surface Area - A_B	NO	Yes	NO	NO	NO	NO	NO
Forebay Volume - V_F	Yes	Yes	Yes	NO	Yes	Yes	Yes
Forebay Length - L_F	Yes	Yes	Yes	NO	Yes	Yes	Yes
Wetland Type, Rock Filter Present?	NO	NO	Yes	Yes	NO	NO	NO
% of Wetland Surface at $P_{0.3}$ & $P_{0.6}$ Depths	NO	NO	Yes	Yes	NO	NO	NO
Meadow Wetland Surface Area - A_M	NO	NO	Yes	Yes	NO	NO	NO
Plant Species and Age of Facility	Yes	Yes	Yes	Yes	NO	NO	NO
2-year Flood Peak Velocity	NO	NO	NO	Yes	NO	Yes	NO
Depth to groundwater or impermeable layer	NO	Yes	Yes	NO	NO	NO	Yes

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Constituents and Methods for Assessing BMPs

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Abstract

The purpose of this paper is to recommend the utilization of consistent storm water monitoring techniques so that data collected on the effectiveness of individual best management practices (BMPs) will not only be useful for a particular site, but will also be useful for comparing studies of similar BMPs in other locations and other types of BMPs. The data collected may then be useful for assessing factors (such as settling characteristics of inflow solids and physical features of the BMP) that might have led to the performance levels achieved. This paper presents a list of constituents that are recommended for analysis of samples collected as a part of studies assessing the effectiveness of urban storm water BMPs. It also discusses other considerations that affect data transferability, such as effectiveness estimations, statistical-testing, etc.

Introduction

Many studies have been completed which have assessed the ability of storm water treatment BMPs (e.g., wet ponds, grass swales, storm water wetlands, sand filters, dry detention, etc.) to reduce pollutant concentrations and loadings in storm water. However, in attempting to review and summarize the information gathered from these individual BMP evaluations it is very apparent that inconsistent study methods and reporting make assessment difficult. Often the studies included the analysis of different constituents and utilized different methods for data collection and analysis. These differences alone contribute significantly to the range of BMP effectiveness reported. This makes assessing what other factors may have contributed to the variation in performance almost impossible.

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As an example, in a review of the use of wetlands for storm water pollution control (Strecker et. al., 1992), a summary of the literature was prepared regarding the performance of wetland systems and the factors that led to pollutant removals. The literature was inconsistent with respect to the constituents analyzed and the methods used to gather and analyze data. There are a number of pieces of information that, if collected and recorded, would have improved the ability to evaluate the effectiveness of storm water wetlands as BMPs and facilitated the transfer of that knowledge into better design practices. Urbonas (1994) summarized the information that should be recorded regarding the physical, climatic, and geological parameters which likely affect the performance of a BMP. This paper presents a suggested list of constituents for analysis along with recommendations for reporting data, methods of reporting pollutant removal efficiencies, a brief discussion of statistical approaches to selecting the number of samples needed, methods for including detection limit data, sample collection considerations, and the need for dry weather assessments.

Constituents for Assessing BMP Performance

The Nationwide Urban Runoff Program (NURP) (EPA, 1983), which included monitoring of land use runoff and BMP performance at over 28 cities nationwide, adopted consistent data collection methods and analytical parameters. Results from the NURP program could then be used to evaluate similarities and differences in pollutant concentrations in urban storm water from different and similar land uses and could be used to explain what might be causing these differences. The following pollutants were adopted by NURP as "standard pollutants characterizing urban runoff:"

TSS	Total suspended solids
BOD	Biochemical oxygen demand
COD	Chemical oxygen demand
TP	Total Phosphorus
SP	Soluble phosphorus
TKN	Total Kjeldahl nitrogen (as N)
$NO_2 + NO_3$	Nitrate + nitrite (as N)
CU	Copper
PB	Lead
ZN	Zinc

Because of the difficulty in obtaining representative samples, oil and grease was not included. On a less consistent basis, NURP also monitored for other pollutants including other metals, dissolved metals, semi-volatile organics, volatile organics, pesticides, and herbicides.

Since NURP, there have been a number of studies which continued to assess pollutant concentrations in storm water runoff. These included the Federal Highway Administration's highway runoff program (Driscoll et al., 1990) and some selected studies done in a few locations. These studies typically were not consistent with the standard NURP protocols. Based upon the 1987 amendments to the Clean Water Act, EPA recently required operators of municipal separate storm drainage systems that served populations of over 100,000 to collect flow-weighted composites at a minimum of five stations to characterize residential, commercial, and industrial runoff quality. Only a few additional parameters have been identified as "problems" in storm water based upon these post-NURP studies (this despite the improved analytical methods that have become available for conducting laboratory analyses). In addition, NURP focused primarily on residential and commercial land uses, while NPDES testing has included industrial land uses which were suspected of having a greater probability of having more pollutants present. However, there has not been a comprehensive review by EPA or others of the newly collected information to assess the results of requiring the analysis of over 130 constituents, including priority pollutants. This type of review is needed. EPA's requirements included monitoring three storms at selected stations. This number of storms is only useful for identifying potential problem pollutants. Statistically, it is not enough data to perform regional or other factors analyses of urban storm water concentrations, but could provide useful information on rates of detection.

The choice of constituents to include as "standard pollutants" is a subjective one. As an example, some would argue that cost should be a primary consideration; others would say that it should not. To include a parameter in the recommended list of monitoring constituents the following factors were considered:

- The pollutant is one that has been identified as prevalent in typical urban storm water at concentrations that could cause water quality impairment.
- The analytical test is one that can be related back to potential water quality impairment.
- Sampling methods for the pollutant are straight forward and reliable for a moderately careful investigator.
- Analysis of the pollutant is economical on a widespread basis.
- The pollutant is one where treatment is a viable option.

Not all of the pollutants recommended fully "meet" all of the factors listed above; however, the factors were considered in the recommendations. When developing a list of pollutant analyses for an individual BMP evaluation, it is important to consider the upstream land use activities. The parameters recommended below are generally present and of concern in "typical" urban storm water.

Table 1 presents a list of suggested standard constituents for assessing the effectiveness of BMPs. The table includes a typical cost (Portland, Oregon) for each of the tests.

Lab Analyses	Cost	Detection Limit
Conventional		
TSS and TDS	$24	1 mg/l
BOD5	$31	3 mg/l
COD	$15	
Total Hardness	$15	
Nutrients		
TKN (as N)	$25	0.3 mg/l
(NH_3 - N)	$15	0.3 mg/l
Total phosphorus (as P)	$20	0.05 mg/l
Ortho-phosphate (as P)	$15	0.05 mg/l
Nitrate + nitrite (NO_3 + NO_2 - N)	$15	0.1 mg/l
Total Metals		
Cd (cadmium)	$20	0.0002 mg/l
Pb (lead)	$20	0.001 mg/l
Cu (copper)	$20	0.001 mg/l
Zn (zinc)	$20	0.001 mg/l
Dissolved Metals		
Cd (cadmium)	$20	0.0002 mg/l
Pb (lead)	$20	0.001 mg/l
Cu (copper)	$20	0.001 mg/l
Zn (zinc)	$20	0.001 mg/l
Total Cost Per Sample	$350	

Table 1. Recommended Standard Analytical Tests for Urban Storm Water BMP Assessments

Presented below is a discussion by group of pollutants that are recommended to be included in a base list.

Total Suspended Solids (TSS). The term "suspended solids" is descriptive of the organic and inorganic particulate matter which is of a size and type that allows the particles to stay suspended in water. The solids load in a water body is influenced by a number of factors including but not limited to: particle sizes, stream flows, climate, geology, and vegetation of each drainage system. The conditions under which suspended solids are considered a pollutant is a matter of definition. In general, suspended solids are considered a pollutant when they significantly exceed natural concentrations and have a detrimental effect on water quality and/or beneficial uses of the water body.

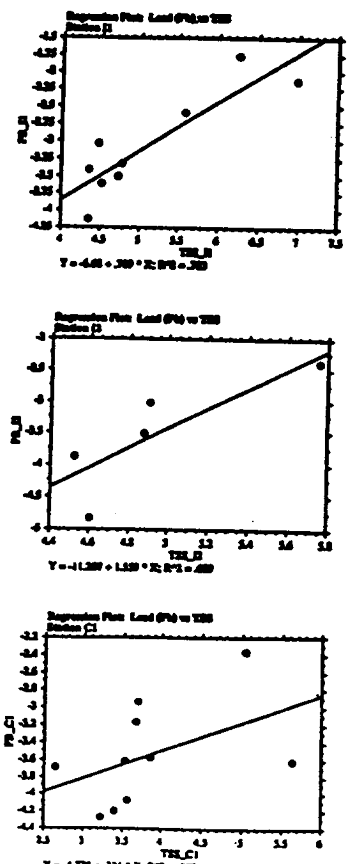

Figure 1. Natural Logarithm Concentration (mg/L) Regression of Total Lead (Pb) vs. Total Suspended Solids (TSS) for Stations I1, I2, and C1 (Portland, Oregon)

Suspended sediments are often used as a surrogate for other contaminants which bind or adsorb easily with fine particulate matter, including heavy metals. Although TSS is often highly correlated with other parameters, it is most often not a strong enough correlation to eliminate the need to address other parameters specifically. Figure 1 is an example of Total lead vs. TSS relationships found in the NPDES monitoring in Portland, Oregon at two industrial stations and a commercial station. The amount of lead that can be explained by the TSS concentration ranges greatly and is only statistically significant for one of the stations. Figure 2 shows pooled data from all ten stations monitored in Portland, Oregon and from the seven stations that were from piped systems. Although the relationship is statistically significant, it does not explain a significant amount of the variability. However, TSS is one good indicator of pollutant removal efficiency and should be included in any evaluation of BMP performance.

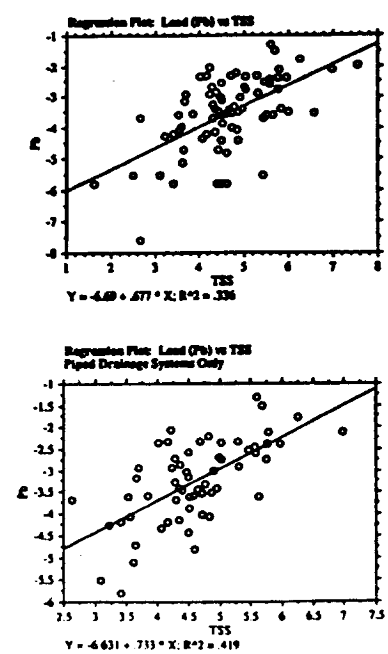

Figure 2. Natural Logarithm Regression Plots of Total Lead (Pb) vs. Total Suspended Solids (TSS) for Pooled Data from Portland, Oregon Monitoring Stations

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Many BMPs rely on sedimentation as the primary pollutant removal mechanism. It is recommended that samples also be analyzed for some measure of the expected settling rate of TSS. The performance of a BMP that relies on sedimentation and even filtering can be greatly effected by the particle sizes and densities present in the influent. If the influent TSS is characterized by small particle sizes, and therefore slow settling velocities, it will be much more difficult to treat. The settleability of influent solids has not been adequately addressed in performance comparisons, and may be one of the significant reasons that performance varies so highly from similar BMP to BMP. For consideration, the particle size distribution utilized in Sartor and Boyd (1972), as shown in Table 2, might be an appropriate gage of the "treatability" of storm water. As Table 2 indicates, these distributions vary considerably from City to City and likely from site to site. Another potential measure of the treatability would be settling column tests, as discussed by Urbonas in this session, or those discussed by EPA in their manual on combined sewer overflow control (EPA, 1993a).

Size Ranges	Milwaukee	Bucyrus	Baltimore	Atlanta	Tulsa
>4,800 μ	12.0%	– %	17.4%	– %	– %
2,000–4,800 μ	12.1	10.1	4.6	14.8	37.1
840–2,000 μ	40.8	7.3	6.0	6.6	9.4
246–840 μ	20.4	20.9	22.3	30.9	16.7
104–246 μ	5.5	15.5	20.3	29.5	17.1
43–104 μ	1.3	20.3	11.5	10.1	12.0
30–43 μ	4.2	13.3	10.1	5.1	3.7
14—30 μ	2.0	7.9	4.4	1.8	3.0
4—14 μ	1.2	4.7	2.6	0.9	0.9
>4 μ	0.5	—	0.9	0.3	0.1
Sand %, 43–3,800 μ	92.1	74.1	82.1	91.9	92.3
Silt %, 4–43 μ	7.4	25.9	17.1	7.8	7.6
Clay %, <4 μ	0.5	—	0.9	0.3	0.1

Note: μ = microns
Source: Sartor and Boyd, 1972

Table 2. Particle Size Distribution of Solids
Selected City Composites

The advantage of particle size tests is that they are much more cost-effective. Settling column tests to determine the range of particle settling velocities are labor intensive. Using a settling test with only one settling time may not reveal the true differences with regard to settling characteristics among inflows to different BMPs.

Oxygen Demand. Oxygen demand refers to the amount of oxygen that will be consumed by biological or chemical reactions involving organic compounds. The decomposition of biodegradable materials by natural soil and water bacteria draws upon the dissolved oxygen resources of a water body. This process is countered by natural re-aeration processes that occur in all water bodies to varying degrees. Significant reductions in dissolved oxygen concentrations can result when the demand rate exceeds the rate of replenishment through re-aeration. In general, moderately high dissolved oxygen content is necessary for the maintenance of healthy aquatic ecosystems. The relationship of oxygen-consuming discharges to the amount of dissolved oxygen in a receiving water body, therefore, is fundamental to the maintenance of environmental quality in natural water bodies. However, the tests available for assessing oxygen demand are not straightforward indicators of potential problems.

Biochemical Oxygen Demand (BOD). The 5-day BOD test provides an indirect measure of the quantity of biologically degradable organic matter in water in terms of the amount of oxygen required by microorganisms to oxidize it to carbon dioxide and water. The BOD test is quite variable. A number of factors can affect results, including the quality of the seed culture utilized in the test. The BOD test can also be inhibited by toxicants in the sample, which may react differently once the runoff mixes with the receiving water. The levels of BOD that are normally found in urban storm water are near detection limits for the BOD test. Therefore, they are subject to wide variation.

Chemical Oxygen Demand (COD). The COD test provides a more rapid measure of oxygen demand. The test is used to measure the organic content of the sample. The consumption of oxygen from an introduced strongly oxidizing chemical agent is measured by this test. As a result, it typically measures appreciably higher levels of oxygen demand than will be produced by biological decomposition because it oxidizes some organic compounds that are not biodegradable, and may also react with inorganic compounds as well. In urban storm water, for example, COD levels are typically found to be about 8 to 10 times greater than BOD levels. COD measures a "maximum possible," but not probable, oxygen demand.

COD and BOD have been monitored relatively frequently in urban runoff studies. Both tests are imperfect measures of the potential for urban runoff to cause oxygen depletion of receiving waters. However, both tests are indicators of the potential for oxygen depletion and are recommended for inclusion on the base list. It is also recommended that dissolved oxygen be measured on a "grab sample" basis, to indicate if the BMP may be having an effect on oxygen levels.

Nutrients. Nutrients are necessary for the growth and support of biota in natural water systems. Excessive quantities can result in the over-stimulation of biological growth and the creation of objectionable water quality conditions (eutrophication). Some forms of nutrients can also be toxic (e.g., ammonia). In general, the most important nutrient factors causing an acceleration in algal production are nitrogen compounds and phosphorus.

Nitrogen. Nonpoint sources of nitrogen include lawn fertilizers, leachate from waste disposal in dumps or sanitary landfills, atmospheric fallout, nitrite discharges from automobile exhausts and other combustion processes, natural sources such as mineralization of soil organic matter, and farm-site fertilizers and animal wastes. Many water treatment methods have no significant effect on nitrate removal from water (Dunne and Leopold, 1978).

Three forms of nitrogen have been analyzed extensively in storm water runoff water quality studies. These are nitrite plus nitrate ($NO_2 + NO_3$), ammonia nitrogen (NH_3), and total Kjeldahl nitrogen (TKN). The latter, named after the analytical test procedure, provides a measure of ammonia and organic nitrogen forms that are present. The first ($NO_2 + NO_3$) provides a measure of the inorganic nitrogen. There is usually very little nitrite in storm water. Nitrate (NO_3) is very mobile and is usually difficult to treat utilizing storm water BMPs. Ammonia nitrogen can be toxic to aquatic life. It can be assessed for toxicity to aquatic life with data on pH and temperature. These three forms of nitrogen are those that characterize nitrogen forms that are important to conducting receiving water assessments. Therefore these three forms of nitrogen are recommended for analysis, and it is recommended that they be consistently reported based upon their mass of nitrogen (as N).

Phosphorus. Phosphorus is used by algae and higher aquatic plants and may be stored in excess of use within plant cells. With decomposition of plant cells, some phosphorus may be released immediately through bacterial action for recycling within the biotic community, while the remainder may be deposited with sediments.

Phosphorus enters waterways from many of the same sources as nitrogen. Domestic sewage contains significant concentrations of phosphorus which is contributed by detergents and human wastes. Primary and secondary treatment processes normally remove only about 20 to 30 percent of this element from sewage (Dunne and Leopold, 1978). Fertilizers and the erosion of soils rich in phosphorus can also be a potential source.

Three forms of phosphorus have been somewhat routinely analyzed in storm water runoff water quality studies. These include total phosphorus (TP), soluble phosphorus (SP), and ortho-phosphate (OP). Ortho-phosphate indicates the phosphorus that is most immediately biologically available. Soluble phosphorus includes both the ortho-phosphate and a fraction of the organic phosphorus. Most all of the SP is usually OP, however. Total phosphorus includes phosphorus in the forms that may not be as readily biologically available plus the forms discussed above. TP and OP are recommended for inclusion in a monitoring program, as they characterize both the total and bioavailable forms of phosphorus. All forms should be reported as mass of phosphorus (as P).

Metals. Heavy metals such as copper, lead, and zinc are naturally released in very small quantities by the weathering of exposed soils and mineral deposits, corroding metal surfaces, decomposing paints, and certain corrosion-control compounds. Heavy metals tend to have comparatively low solubilities and are often mobilized by forming soluble complexes with humic materials or by becoming attached to clay particles. Heavy metals have been identified consistently as the most significant toxics found in urban storm water and often exceed water quality criteria for aquatic life.

These metals are present in the biosphere as trace elements and are micronutrients necessary for plant and animal growth. Heavy metals are of concern because elevated concentration levels of soluble forms in natural water bodies can produce toxic effects in biota. Sources include domestic and industrial point-source discharges, urban storm water runoff, and direct atmospheric deposition. In this paper, copper (Cu), lead (Pb), zinc (Zn), and cadmium (Cd) have been recommended for inclusion in a monitoring program because storm water runoff water quality studies conducted at many urban locations have indicated that these metals are almost always present, and are at concentrations which tend to be elevated, relative to other heavy metals. They also can be used as surrogates for other heavy metals, as they tend to display the range of transport characteristics for heavy metals. However, other heavy metals should be analyzed if there are known sources of significant quantities of these metals in influent flows.

It is recommended that both the total and dissolved form of each be analyzed. Based upon EPA's recommendation, it is the dissolved fraction that should be compared to water quality criteria, with modifications to the criteria as noted in EPA (1993). To compare data to criteria, hardness should be measured for each sample. Too often metals data are compared to criteria using some hardness value not directly associated with the monitoring.

Total concentrations are valuable in assessing the overall reduction of the heavy metal in both soluble and particulate forms. There is a concern about the long-term bioavailability of these metals in sediments and sediment standards are beginning to be developed and implemented.

A third test that could be conducted is settleable metals. This test gives an indication of the metals that might be removable through sedimentation. The test merits will be discussed in the work session.

When conducting these tests, it is recommended that low detection limits be achieved. For copper, lead, and zinc, the detection limit should be 1 ug/l and for cadmium 0.2 ug/l. This will minimize problems with analyses that include below detection limit data, which can severely impact performance evaluations. Special "clean" procedures will be necessary to achieve low detection limits, both in the laboratory and in the field.

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Too often, BMP effectiveness for metals is estimated base upon data that is very near or below detection. This is troublesome when both the inflow and outflow concentrations are at or near detection, and effectiveness is based upon a storm by storm comparison of loads or concentrations. It is recommended that if both the influent and effluent concentration are within five times the method detection limit, the pollutant data pair not be considered in the effectiveness analysis if a storm by storm effectiveness method is used. If statistical characterizations of the inflow and the outflow concentrations are utilized to assess effectiveness and some of the data are below detection, appropriate techniques should be utilized. Driscoll et al. (1990) describes a method to address detection limit data. The setting of these values to 0 or ½ the detection limit or the detection limit, which is often done, will lead to an underestimation of the mean.

Oil and Grease. Oil and grease is a prevalent constituent in urban runoff and often exceeds discharge limits set by states (such as 10 mg/l in Oregon for industrial storm water permits). In a study of oil and grease concentrations in urban runoff in Richmond, California, Stenstrom et al. (1984) found that oil and grease concentrations in runoff from commercial properties and parking lots are about three times higher than from residential and open areas. The NURP program did not address oil and grease as a standard constituent. Accurately measuring oil and grease is very difficult, especially due to its affinity for coating sampling bottles and sampling tubes, and its highly nonuniform distribution in the water column (except in the most turbulent situations). Other tests include total petroleum hydrocarbons, which measure the petroleum based fraction of oil and grease. Other sources of oil and grease include animal and vegetable. For BMPs which are designed to address oil and grease, it is suggested that some multiple within a storm grab sample analyses would be appropriate. For most BMPs, it is recommended that the parameter be optional. If completed, the TPH evaluation is the most appropriate measure to gage effectiveness of a BMP at reducing man-induced sources of petroleum oil and greases.

Pesticides/Herbicides. Pesticides and herbicides are regularly detected in urban runoff. However, the number of constituents usually detected is low and most often at levels below available criteria. In Portland, Oregon (WCC, 1993a) the frequency of detection of pesticides, herbicides was less than 1 percent of all the pesticides and herbicides tested. However, the city has noted locations where pesticide concentrations in sediments are high. This could indicate that the problem with pesticides and herbicides might be due to misuse or dumping, rather than a general storm water problem. Although it is possible that pesticides accumulate in sediments from low concentrations in storm water, some regional assessments of the effectiveness of source control measures (education, identification and elimination of dumping problems) are needed. The Alameda County, CA monitoring program (Cooke and Lee, 1993) has recently identified that the pesticide Diazinon may be a primary cause of toxicity at very low concentrations (below 8140 method detection limits) of *cerodaphrin dubia* in receiving streams in the south bay area of San Francisco. More research is needed to further define the level of this problem in

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relation to the instream biota, rather than test organisms. Other regional assessments have identified Diazinon as a pollutant which may be impairing water bodies. At this time, I would not recommend including the pesticide in a standard list, but focused research studies on the magnitude of the problem and the effectiveness of BMPs on these pesticides should be performed. Due to the low values at which these constituents can cause problems, it will be difficult to assess BMP performance on a wide-scale basis. For example, it may be more appropriate to eliminate or control the use of Diazinon rather than research BMP effectiveness.

Volatile and Semi-Volatile Organics. These pollutants have not generally been detected at a high frequency and in quantities that exceed available criteria [with the exception of Polynuclear Aromatic Hydrocarbons (PAHs), which are discussed separately]. In the recent City of Portland and Eugene sampling programs (WCC, 1993a and 1993b) detection rates were less than 2 percent of all the tested constituents and below all available criteria. These parameters are not recommended for general analysis unless the BMP effectiveness study is being considered in an industrial area suspected or known to have elevated levels of organics.

Polynuclear Aromatic Hydrocarbons. The carcinogenic properties of PAHs has generated increased interest in the study of their sources, transport, fate, and aquatic toxicity. Major sources include the combustion of fossil fuels, uncombusted petroleum products (fuels, etc.), and natural and man-caused fires. PAHs have recently been analyzed utilizing detection levels that are significantly below those achieved utilizing the standard semi-volatile organic scans (WCC, 1993a and 1993b; Cooke and Lee, 1993). These tests (GC-MS methods at the nanogram per liter level) have shown that PAHs in storm water are above human consumption criteria by significant amounts (up to over 100 times). This has been documented in a number of studies. However, these tests are specialized (only a few laboratories provide this level of analysis) and expensive (about $500 to $600 per analyses). In addition, there are no criteria for aquatic life and toxicity identification evaluations performed in the San Francisco Bay Area have not identified PAHs as the source of toxicity in either developed land-use runoff or in stream stations. For these reasons, PAHs are not recommended for the standard list of constituents to be monitored. However, because of their carcinogenic nature and their tendency to bioaccumulate, new studies may identify potential long-term aquatic life impacts that may require reevaluation of this recommendation.

Data Reporting

There are some practical and technical considerations regarding data reporting which would facilitate data usefulness, including consistent formatting of data, the clear indication of QA/QC results, standard comparisons to water quality criteria, and utilization of consistent methods for estimation of pollutant removal effectiveness. It is recommended that all constituent concentration data be reported as event mean concentrations (EMCs).

<u>Data Formatting</u>. Table 3 is an example table format for reporting storm event EMCs. It indicates the date of the storm, the EMC value for each sampling point, the data that are estimates based upon QA/QC evaluations, method used for analysis, and detection limit achieved. Also included are summary statistics of the EMCs. These statistics should be based on use of the lognormal distribution. The NURP and FHWA studies (EPA, 1983; Driscoll et al., 1983) identified that the lognormal distribution is suitable for characterizing EMC distributions.

The inclusion of outlet data as a part of any paper or report will allow comparisons of typical outlet concentrations and may allow the determination of the lowest expected concentration from a particular type of BMP. For example, it may be that

Chromium (mg/L) Method EPA 7191 Receiving Water Quality Criteria **

Storm Event	Date Sample	R-1	C-1	I-1	I-2	M-1	M-2	Detection Limit
#1	9/23/92	0.034	0.016	0.031	[illegible]		[illegible]	[illegible]
#2	12/5/92	0.005		[illegible]	[illegible]	[illegible]		[illegible]
#3	12/16/92	0.004	0.004	[illegible]	[illegible]		[illegible]	[illegible]
#4	1/19/93	0.004	0.012	0.019	0.011	[illegible]	[illegible]	[illegible]
#5	3/14/93	0.005	0.006	0.005	0.017	0.004	0.007	[illegible]
#6								
#7								
#8								
	Median	0.006	0.008	0.014	0.008	[illegible]	0.004	
	COV	1.27	0.70	0.86	0.71	-	0.42	
	Mean	0.010	0.010	0.018	0.010	-	0.004	

Copper (mg/L) Method EPA [illegible] Receiving Water Quality Criteria **

Storm Event	Date Sample	R-1	C-1	I-1	I-2	M-1	M-2	Detection Limit
#1	9/23/92	0.081	0.130	0.071	0.016		0.019	0.001
#2	12/5/92	0.004		0.01	0.01	0.009		0.004
#3	12/16/92	0.011	0.016	0.037	0.03		0.009	0.004
#4	1/19/93	0.009	0.046	0.076	0.034	0.027	0.012	0.005
#5	3/14/93	<0.030	0.027	0.034	0.025	0.030	<0.030	0.004
#6								
#7								
#8								
	Median	0.013	0.040	0.037	0.021	0.017	0.013	
	COV	2.03	1.11	0.97	0.54	-	-	
	Mean	0.030	0.060	0.054	0.024	-	-	

Results expressed as mg/L (ppm) unless otherwise noted. COV is the Coefficient of Variation. ** Criteria are hardness dependent.
"nd" means none detected at or above the detection limit listed. If no value is shown, the lab analysis was not performed.
Summary statistics are based upon the assumption that the sample of EMCs is lognormally distributed.
Italicized values are considered estimates due to QA/QC review but are included in the calculations.

Table 3. Example Data Reporting Table from Eugene NPDES Monitoring Summary Report (WCC, 1993b)

wet ponds may only be able to treat to some minimum concentration range at the outlet and the "effectiveness" is greatly impacted by the inlet concentrations.

Quality Assurance/Quality Control (QA/QC). All monitoring studies should include a QA/QC program. The results of the QA/QC program should be reported in monitoring study reports and summarized in papers. It is especially important to discuss when data are characterized as estimates due to QA/QC results and when detection limits were affected. Too often this information is not included.

Comparisons to Water Quality Criteria. Another method to gage effectiveness could be to monitor how the BMP effects the number of times that criteria are exceeded in both the inflow and the outflow, to assess how the BMP reduces (or does not reduce) the number of times water quality criteria are exceeded. For heavy metals analyses, it is recommended that hardness be collected for all storms monitored and that comparisons to criteria be made utilizing the dissolved fraction with the computed aquatic criteria as modified by EPA (1993). Table 4 presents an example presentation of metals exceedances for data collected in Portland, Oregon (WCC 1993a).

Estimation of Pollutant Removal Effectiveness

BMP pollutant removal effectiveness estimations are not straightforward. Martin and Smoot (1986) discussed the following three types of methods to compute efficiencies:

- The first method employs the efficiency ratio (ER), which is defined in terms of the average event mean concentration (EMC) of pollutants from inflows and outflows, thus:

$$ER = 1 - \frac{\text{Average outlet EMC}}{\text{Average inlet EMC}}$$

- The second method is based on the summation of loads (SOL) of pollutants removed during the monitored storms, thus:

$$SOL = 1 - \frac{\text{Sum of outlet loads}}{\text{Sum of inlet loads}}$$

- The third method of determining efficiency was developed by Martin and Smoot (1986). This method defines the ratio as the slope of a simple linear regression of inlet loads and outlet loads of pollutants. The equation for the regression of loads (ROL) efficiency is thus:

$$\text{Loads in} = \beta \cdot \text{Loads out}$$

where β equals the slope of the regression line, with the intercept constrained at zero.

Station	Storm	Date	Total Hardness (mg/l as CaCO3)	Cadmium conc. (mg/l)	Cadmium criteria (mg/l)	Chromium conc. (mg/l)	Chromium criteria (mg/l)	Copper conc. (mg/l)	Copper criteria (mg/l)	Lead conc. (mg/l)	Lead criteria (mg/l)	Nickel conc. (mg/l)	Nickel criteria (mg/l)	Silver conc. (mg/l)	Silver criteria (mg/l)	Zinc conc. (mg/l)	Zinc criteria (mg/l)
R1	# 1	5/7/91															
	# 2	8/9/91	37	nd	0.0013	0.002	0.77	0.008	0.007	nd	0.023	0.002	0.61	0.0002	0.0007	0.020	0.050
	# 2a	10/16/91															
	# 3	10/22/91	45	nd	0.0016	0.002	0.90	0.007	0.008	0.004	0.040	0.002	0.72	nd	0.0010	0.014	0.059
	# 4	12/5/91	29	nd	0.0010	0.003	0.63	< 0.005	0.006	< 0.025	0.017	nd	0.50	nd	0.0009	< 0.030	0.041
	# 5	12/18/91	38	nd	0.0013	0.002	0.79	< 0.005	0.007	< 0.065	0.024	nd	0.63	nd	0.0008	0.012	0.052
	# 6	1/10/92	37	nd	0.0013	nd	0.77	0.005	0.007	nd	0.023	nd	0.61	0.0003	0.0007	< 0.010	0.050
	# 7	9/24/92	31	nd	0.0019	nd	0.67	0.008	0.006	nd	0.019	nd	0.53	nd	0.0005	0.020	0.043
	# 8	10/30/92	55	0.0007	0.0020	0.015	1.06	0.046	0.010	0.300	0.039	0.013	0.86	nd	0.0015	0.300	0.071
	# 9	11/19/92	25	nd	0.0008			nd	0.005	nd	0.016			nd	0.0004	0.020	0.036
	# 10	1/19/93	26	nd	0.0009	0.001	0.58	0.004	0.005	nd	0.015	nd	0.45	nd	0.0004	0.020	0.037
R3	# 1	5/7/91	7.0	nd	0.0002	nd	0.21	0.008	0.002	nd	0.005	0.001	0.16	nd	0.00005	0.087	0.013
	# 2	8/9/91															
	# 2a	10/16/91	34	nd	0.0012	0.002	0.72	0.036	0.006	< 0.010	0.021	0.005	0.57	nd	0.0006	0.130	0.047
	# 3	10/22/91	13	nd	0.0004	0.002	0.33	0.008	0.003	0.008	0.006	0.005	0.25	nd	0.0001	0.080	0.021
	# 4	12/5/91															
	# 5	12/18/91	6	0.006	0.0002	nd	0.17	< 0.003	0.001	< 0.065	0.002	nd	0.13	nd	0.00003	0.037	0.011
	# 6	1/10/92	5.9	nd	0.0002	nd	0.17	0.003	0.001	nd	0.002	nd	0.13	nd	0.00003	[illegible]	0.011
	# 7	9/24/92	8.8	nd	0.0003	nd	0.24	0.013	0.002	nd	0.004	0.002	0.18	nd	0.00006	[illegible]	0.015
	# 8	10/30/92	11	nd	0.0001	nd	0.28	0.004	0.002	nd	0.005	0.002	0.22	nd	0.00009	[illegible]	0.018
	# 9	11/19/92	8.9	nd	0.0003			nd	0.002	nd	0.004			nd	0.00006	[illegible]	0.015
	# 10	1/19/93	6.3	nd	0.0002	nd	0.18	0.036	0.001	0.008	0.002	nd	0.14	nd	0.00001	[illegible]	0.011
C1	# 1	5/7/91	3	0.0004	0.0001	0.001	0.11	0.005	0.001	nd	0.001	0.001	0.08	nd	0.0000	0.104	0.007
	# 2	8/9/91															
	# 2a	10/16/91	43	0.0013	0.0015	0.003	0.07	0.046	0.008	< 0.010	0.020	0.011	0.09	0.0002	0.0010	1.000	0.057
	# 3	10/22/91	12	0.0008	0.0004	0.005	0.31	0.016	0.002	0.002	0.006	0.004	0.24	nd	0.00011	0.340	0.019
	# 4	12/5/91	1.9	0.0004	0.00004	0.002	0.07	< 0.005	0.0004	< 0.025	0.001	< 0.010	0.08	nd	0.000004	[illegible]	0.004
	# 5	12/18/91	5	0.0003	0.0001	0.002	0.15	< 0.005	0.001	< 0.065	0.002	0.002	0.11	nd	0.00002	0.094	0.009
	# 6	1/10/92	4.1	0.0003	0.0001	nd	0.13	0.008	0.001	< 0.010	0.001	nd	0.10	nd	0.00002	0.066	0.008
	# 7	9/24/92	5.4	nd	0.0001	0.001	0.16	0.110	0.001	0.001	0.002	0.002	0.12	nd	0.00003	0.130	0.010
	# 8	10/30/92	3.4	nd	0.0001	nd	0.11	0.004	0.001	0.004	0.001	0.002	0.08	nd	0.00001	0.064	0.007
	# 9	11/19/92	5.8	nd	0.0002			nd	0.001	nd	0.000			nd	0.00003	[illegible]	0.010
	# 10	1/19/93	3	0.0008	0.0001	nd	0.10	0.008	0.001	0.002	0.001	nd	0.07	nd	0.00001	0.070	0.006

Results expressed as mg/l, unless otherwise noted.
Shaded, bold face type indicate acute criteria exceedances. Acute criteria shown is for Cr (+3). Cr (+6) criteria is 0.016 (mg/l).
The "nd" symbol means none detected at or above the indicated value and represents the method detection limit.

Table 4. Example Comparison to Water Quality Criteria

The ER and SOL methods assume that the monitored storms include samples that are representative of all storms that occur. The SOL method assumes that enough samples were collected such that any significant input loads or output loads were not missed. They are different in that one gages effectiveness in terms of concentration reduction, while the other gages effectiveness in terms of load of pollutant removed. The ROL method assumes that the treatment efficiency is the same for all storms.

Urbonas in this session suggested one should utilize an efficiency measure based upon storm pollutant loads into and out of the BMP on a storm by storm basis. This would weight the effectiveness considering that all storms are "equal" in computing the average removal. Similarly one could utilize concentrations on a storm by storm basis.

One factor that complicates the estimation of the effectiveness is that for wet ponds and wetlands (and other BMPs where there is a permanent pool), comparing effectiveness on a storm by storm basis neglects the fact that the outflow being measured may have no or only a limited relationship to the inflow. In analysis of rain gages utilizing SYNOP (EPA, 1989), if a basin where sized to have a permanent pool equal to the average storm, about 60 to 70 percent of the storms would be less than this volume. Therefore, storm to storm comparisons are probably not valid. In cases like this, it is probably more appropriate to utilize statistical characterizations of the inflow and outflow concentrations to evaluate effectiveness or, if enough samples are collected (i.e., almost all storms monitored), to utilize total loads into and out of the BMP.

Sample Collection Techniques

This topic deserves much more attention than this paper can possibly address. The collection of the sample alone is likely the largest source of variation in reported removal efficiencies. Questions and concerns such as how well mixed are the flows, placement of intake tubes, the effects of peristaltic pumps and pumping of a sample from up to 15 feet or more below the sampler, and how they affect what gets into the sample bottle. Another question is how often are sub-samples collected as a part of the flow-weighted composite? Sartor and Boyd (1972; and Boyd, personal communications) contemplated some post sampling/pre-analysis techniques to address some of these issues. They felt that a more representative sample for comparisons would be 1) to avoid collecting surface scum in the sample and 2) to perform a 20-minute settling to remove the settleable solids that were probably not collected representatively (due to settling that probably occurs in the intake tube). Then effectiveness comparisons could be made on the remaining "more representative" samples. The easily settleable material could still be analyzed separately.

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BMP Evaluations – Statistical Considerations

There are several types of BMP evaluations that may be conducted. First, the standard evaluation of a single BMP, testing input and output; second, the evaluation of multiple BMPs within a basin; and third, the evaluation of a BMP with multiple inlets (where it might be impossible to evaluate the BMP utilizing input/output). For the second and third, the only practical method of evaluation may be a downstream analysis of before and after implementation of BMP(s). This will require that a rigorous statistical approach be applied in selecting the number of samples to be collected to assure detection of a given level of change. As an example of the number of samples required to detect a "true" difference, Table 5 presents an analysis of two of the NPDES monitoring stations where 10 flow-weighted composited samples were collected. The Fanno Creek station is a large (about 1,200 acres) residential catchment, while the M1 station is a smaller (about 100 acres) mixed land use station. An analysis of a variance-based test was utilized to determine how many samples would need to be collected to detect a 5%, 20%, and 50% change in the mean concentration at the station. The test was performed considering an 80% probability that the difference will be found to be significant, with a 5% level of significance (Sokal and Rohlf, 1969). The results are shown in Table 5. This analysis does not consider potential seasonal effects on the collection of data as a factor. Even so, quite a large number of samples would be required to detect a 5% to 20% difference in concentrations. There are numerous examples in the literature where differences of these levels are reported based upon much fewer samples than indicated by this analysis. This indicates the need to be more rigorous with regard to statistical testing of reported effectiveness estimates. To detect larger changes, the number of samples becomes reasonable. The mixed land use catchment in Portland is currently being studied for the effectiveness of the implementation of a number of source controls and other controls that do not lend themselves to input/output testing. Examples include maintenance changes (catch basin cleaning, street sweeping), education (business and residences), tree planting, etc. Post-BMP monitoring will be conducted along with qualitative evaluations.

Other Considerations

There is a need to conduct dry weather analyses between storms on BMPs with dry weather flows. It may be that pollutants captured during storms are slowly released during dry weather discharges.

Biological assessments such as those discussed by Eric Livingston in this conference should be explored as an alternative to just utilizing chemical measures of effectiveness. Long-term trends in receiving water quality, coupled with biological assessments, would likely be a much better gage of the success of the implementation of BMPs, especially on an area-wide basis.

Monitoring Site	Parameter	Number of Samples Required to Detect the Indicated % Reduction in Site Mean Concentration* 5%	20%	50%
R1 - Fanno Creek Residential	TSS	202	14	4
	Copper	442	29	6
	Phosphorus	244	16	4
M1 - NE 122nd and Columbia Slough Mixed Use	TSS	61	5	2
	Copper	226	15	4
	Phosphorus	105	8	3

*80% certain of detecting the indicated % reduction in mean of the EMCs.

Table 5. Analysis of Sample Sizes Needed to Statistically Detect Changes in Mean Pollutant Concentrations from 2 Stations in Portland, Oregon

Summary and Recommendations

There is a great need to have consistency with the constituents and methods utilized for assessing BMP effectiveness. This paper has presented only some of the consistency issues. It is recommended that researchers who undertake BMP effectiveness studies consider the recommendations suggested here or some other recommendations developed based upon further analysis of this subject. EPA should require studies receiving federal funding to conduct BMP effectiveness studies which utilize standard methods as suggested here to improve data transferability.

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SESSION VI - BMP Monitoring for Data Transferability

DISCUSSION

Parameters to Report with BMP Monitoring Data
Ben Urbonas

Efficiency Calculations - should report long term removal as mass in minus mass out over the season, rather than event by event.

All federally funded BMPs should be required to enter data into a public database like GLIN (Great Lakes Information Network, operates on INFONET) or EPA CIESIN.

- Include estimates of error associated with measurements.
- Include whether the facility is on-line or off-line. Include event size captured by facility if it is designed to bypass larger flows.
- The volumes and EMCs of the by-passes, if monitored or estimated, would allow a better estimate of total annual or seasonal removals attributed to the BMP. Can address this by measuring the composite inflow and the co-mingled outflow of treated and bypassed flows. Thus, each event's effectiveness is reported in total.

Measure rates of sediment accumulation, sediment volume and grain size in detention facilities.

Residuals management should be part of the evaluation. This information is useful for solid waste concerns (nice to have), but is not necessary for BMP assessments.

Water balance must be included in BMP evaluation.

Measure settling velocity of influent using settling column test (nice to have).

Report percentage of flow included in calculation of event EMCs. Report percentage of total storm volume and annual flow included in the EMC calculation.

Include construction cost and O&M cost for the facility (This is nice to have, but not a technical issue.)

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Safety should be included in the BMP evaluation; keep a record of accidents, etc. (nice to have).

Keep record of O&M practices on the site (must have).

Questions/Comments

Question: Should standardization take place through ASTM, ASCE or some formal organization?
Answer: We are not ready to propose a mandatory program.

Question: There are a number of other areas where standardization would be useful, such as monitoring. Should the Council (or ASTM, or ASCE, etc.) work on these others?
Answer: Might be useful.

Question: When talking about efficiency you use arithmetic averages. How about long-term efficiencies over several events?
Answer: Good point - I need to look at my equations. (Post-conference response: Suggest using arithmetic averages of removal efficiencies and not flow-weighted ones to avoid being overwhelmed by the effects of one or more very large, atypical, events.)

Question: The parameter list seems quite long. Shouldn't we separate it into must have and nice to have categories?
Answer: Most of the parameters defined in the paper are "must haves" for BMP assessments.

Comment: Class parameters into "must have" and "nice to have." Need to define some criteria for differentiating between: 1) extended detention ponds with a permanent pool; 2) "wet pond", which has a biological component in littoral vegetation and permanent pool; and 3) wetland.

Question: How about including measurement error (error estimates)?
Answer: Very good point.

Question: Shouldn't we also report if a facility is on-line versus off-line?
Answer: Yes.

Comment: We should have a simple procedure for measuring settling velocity distribution. (Editor's note: Hans Brombach, a German consultant, is working on such a device, and the CSO people have been using one for some time).

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Comment: The residuals management aspect of a facility, such as the disposition of sediments removed from a pond, should also be reported.

Response: This is nice to have, but not necessary for evaluating the performance effectiveness of a BMP. Residuals management is a problem that must be addressed at all BMP sites.

Comment: We should also report the water-balance aspects of a facility. This may help to interpret the volumes reported and any losses in storage.

Response: Good point - this is suggested indirectly in the paper and should be one of the descriptive parameters.

Question: Shouldn't we be reporting the inflow and outflow hydrographs?

Answer: That is a good idea, however, storm volume is the operative term when we try to come up with a minimum list.

Question: We often sample and report only a portion of the storm event - don't we also need to have some idea of the total event (and total annual) flow?

Answer: This is also a good point. I presume that is the case in such evaluation studies.

Constituents and Methods for Assessing BMPs
Eric Strecker

Recommendations:

- Adopt consistent constituents as a minimum
- Adopt consistent reporting techniques
- Produce a monitoring methods manual

TOC in conjunction with BOD is a good indicator of total organic hydrocarbons. Use as surrogate for individual tests. (Editor's note - another individual believes that TOC is a better way of measuring organic carbon content - if values are high, then one can look at specific organic compounds further. This is one place where it would be good to consult with the analytical chemists).

The low-detection methods recommended for pesticides are not always necessary. Use of a gas chromatograph-mass spectrometer is suitable for most purposes.

Sample some simple conservative parameter to help you do a mass balance and calculate the error in your measurements.

Should list standard methods for each constituent. Also need to get some help from the chemists in setting these parameters. Need to pay particular attention to concentrations at or near the detection limit - likely not accurate.

Provide guidance on how to report data near or below the detection limits.

If BOD is measured, need to do ultimate BOD and K determination.

For ponds with multiple inflows, might use storage equation with stage and outflow volume to compute inflow (but what about computing quality and mass load in?).

Report rainfall intensity of storm events used in BMP assessment.

Use a coulter counter for the determination of solids.

Report age of BMP and maintenance practices to assist with understanding long term behavior.

Lithium chloride can useful as a tracer to verify weir or channel discharge stage curves.

Should not ignore how BMPs affect the quality of the groundwater.

Fecal Coliform or pathogens should be considered as an addition to the parameter list.

Analytical methods that indicate partitioning of metals should be considered.

May need to modify Standard Methods to work better for stormwater.

Transpiration should be part of the water balance in wetlands.

Questions/Comments

Comment: A vital part of your monitoring program is good specifications for your analytical chemistry labs. It is also a good idea to use blanks, spikes, etc. for quality control, and in fact our laboratories welcome this.

Comment: (Post-Conference Comment by Strecker) Recommend that BOD be dropped as a constituent. It is extremely difficult to sample, especially when drain time is measured in periods of days, and of little practical value in stormwater. Surrogates such as TOC or COD can be used.

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Time-Scale Toxic Effects in Aquatic Ecosystems

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Abstract

Although the general effects of stormwater on receiving systems are well described, the relationship between loading/concentration changes during stormwater runoff events and time-scale toxicity, which would support improved modeling and prediction of stormwater effects, is poorly defined. In fact, there are few studies that clearly assess the effects of episodic change in contaminant concentration on individuals, populations, or communities of organisms. To effectively assess these time-scale effects, it is necessary to connect multiple factors, including physical, chemical and biological/ecological characteristics of receiving systems and their watersheds conditions, which affect receiving system biota. The interactions between flow and toxic contaminant concentration in stormwater runoff events, and the measurement of toxic effect is the focus of this paper.

Introduction

When monitoring receiving water trends associated with wet-weather events, including stormwater runoff, there are reasonably predictable changes in water quality but much less predictable changes in receiving water ecosystems produced by toxic contaminants in the stormwater. The changes in water quality are produced by mechanisms that operate on land surfaces as well as in the stream channel affecting both physical (habitat) and chemical (water quality/contaminant concentration) conditions. The result is a powerful mechanism for change in aquatic ecosystems. Although aquatic organisms are adapted to life in a changing environment, stormwater flow events, particularly

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in urban areas, are often very different than those found in more natural settings. In addition to increased flow volume, and changes in the unit hydrograph (e.g. higher slope ascending and descending limbs with higher peaks) the presence of toxic contaminants will reduce the capacity of aquatic organisms to function in areas changed from natural conditions. Unfortunately, although the general effects of stormwater on receiving systems are well described, the relationship between contaminant loading and time-scale toxicity, which would support improved modeling and prediction of stormwater effects, is poorly defined. In fact, there are few studies that clearly assess the effects of episodic change in contaminant concentration on individuals, populations, or communities of organisms. To effectively measure these time-scale effects, it is necessary to consider the full range of factors that affect receiving system biota. The interactions between flow and toxic contaminant concentration, and the measurement of toxic effect is the focus of this paper.

Stormwater Characteristics

A key characteristic of stormwater events is rapid change in physical and chemical conditions in the receiving system. Pre-storm conditions usually find the receiving system at a stable flow with low contaminant concentrations, although contaminant presence and concentration may vary based on land use and the presence of industrial, or other effluents. The primary determinant of overall stormwater event characteristics is rainfall. The rainfall required to change receiving system conditions will vary based on land use and watershed conditions. The sequence of events has been well described. Rainfall in excess of interception, infiltration, and storage will run off. Runoff increases the volume of flow in the receiving system, which can be described in terms of a time discharge relationship - the runoff hydrograph. Storm intensity and watershed conditions determine the rising limb slope, the peak, and recession limb characteristics. Contaminant concentrations will vary following a pattern that is hydrograph related. Since contaminant concentrations may be zero, or at very low background concentrations, the transient change may be of several orders of magnitude. Usually, contaminant concentrations will rise and then fall, with the changing concentrations associated with how and when the contaminants are delivered to the receiving system and the dilution produced by increased flow volume. A commonly recognized contaminant maxima is associated with the first flush that carries contaminants stored on land or other surfaces, but other peaks in concentration may occur when critical hydraulic conditions are reached and contaminants in the stream bed are re-suspended. Thus a storm flow may produce one or more high concentration transients during a single event, each transient present for only a short time, potentially a few seconds to several minutes.

Stormwater events also have characteristics common to all discharges of contaminants into receiving waters. These characteristics include source specificity, loading/concentration relationships, and seasonal influences. Source specificity will typically define the contaminant type and the delivery mechanism. Contaminant types are conservative (unchanging) and non-conservative (defined half-life or degradation rate). The addition of both conservative and non-conservative contaminants to the receiving system can create secondary effects such as 1) storage of conservative contaminants increasing potential environmental, and organism, exposure concentration, 2) the breakdown of non-conservative contaminants altering environmental conditions (e.g. dissolved oxygen depletion) or 3) production of new contaminants as parent compounds decompose or are altered (e.g. photolysis). The delivery mechanism will vary based on source (e.g. point or non-point) Point sources of stormwater, such as combined sewer overflows or storm sewer outfalls can be characterized and related to expected receiving system conditions upstream and downstream of the discharge location. Non-point sources of stormwater are by their very nature diffuse and will have characteristics associated with the flow path and associated land use.

Loading/concentration relationships for stormwater runoff deserve some review. The determination of loading begins with an analysis of concentration, then a mass discharge is calculated from analyzed concentrations and measured discharge flow. Loading effects can be related to receiving system dilution capacity. A small load may produce a high concentration in a small stream where dilution capacity is limited. Thus in upper reaches of a watershed the greatest concern for time-related change may be for stormwater related concentration transients with minimal attention paid to loading when loads are small. Because loading may produce biological or ecological consequence while the instream concentration remains low because of receiving stream dilution capacity, there may be more concern in the lower watershed may be for stormwater related contaminant loading. In reality, as suggested by Schlosser and Karr (1981), both loading and concentration are important issues when considering stormwater runoff effect.

Seasonal concerns are associated with both what organisms are present and changing background environmental conditions. The species present during a storm event will determine the general susceptibility of receiving system communities to stormwater. Species presence and abundance is expected to change naturally through the seasons due to normal growth and development, and organism movement. Suscepubility to the changes produced by stormwater will be determined by the presence of sensitive life stages or the presence in migratory species. Seasonal change in environmental conditions will find differences in temperature, base flow (general dilution capacity), and other physical and chemical conditions.

In summary, stormwater event characteristics are reasonably predictable. There will be time-related changes in flow and corresponding time and flow related changes in receiving system water quality. To illustrate these general characteristics an example is provided from the Copper Slough, near Champaign,

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Illinois. The Copper Slough receives urban runoff and the discharge from a sewage treatment plant. Figure 1 illustrates the effect of a stormwater event on receiving system water quality, tracking changes in temperature, pH, conductivity, and dissolved oxygen. Although event characteristics alone are important, it is essential to view the stormwater event in the context of the receiving system. Figure 2 provides a summary of receiving system conditions before, during, and after the same stormwater event. Figure 1 clearly shows changes in water quality (pH and DO) and the effects of dilution (specific conductivity). Figure 2 shows storm event effects on the natural diurnal variation in stream conditions, indicating that a single storm event may alter natural conditions for some time after a stormwater runoff event.

Species and Community Adaption to Disturbance

Aquatic organisms are adapted to changing conditions in streams. In fact, disturbance is thought to play a major a role in ecosystem maintenance and controls the character of most (if not all) natural systems (Sprugel, 1985; Gerritsen and Patten, 1985; Harper, 1977; Doyle, 1981). This is particularly true for streams where changes in flow, and related habitat, are common. Disturbance can be defined as a greater than expected magnitude of variance (lower than expected predictability) occurring for a time span related to a specified level of analysis (Gerritsen and Patten, 1985). As watersheds develop the general result is an increase in variance in receiving system conditions. Disturbance classes can be developed based on a series of state variables, and change vectors (Gerritsen and Patten, 1985; Fontaine, 1983; Odum, 1985; Odum, 1979).

Because streams are constantly changing (seasonally as well as with storm events), defining disturbance in stream ecosystems is difficult because there is a constant "expectation" of change. A challenge to ecologists, particularly stream ecologists is the full characterization of disturbance variables and vectors rather than simply identifying system state or condition at some point in time and/or space. Finally, it is important to recognize the full influence of time when considering disturbance in stream ecosystems. Connell and Sousa (1983) have suggested that one must study a biotic system for a length of time equal to the life history of the longest lived organism in the system, in order to understand system dynamics. In fact, that time span may be too short to fully understand factors that contribute to ecosystem dynamics. Gerritsen and Patten (1985) suggest that the Connell and Sousa (1983) concepts can be extended to include one complete turnover of biotic (population numbers, biomass) or abiotic (nutrients) elements. If both organism life history and turnover are considered in analysis, disturbance may be classed as: 1) a change in state caused by a) removal of organisms by an external factor (e.g. toxicity); b) by the addition of organisms that displace indigenous flora and fauna (e.g. the Zebra mussel); or c) by changes in the physical structure of the system; or 2) as a change in inputs (increase or decrease) of biotic or abiotic materials (Sprugel, 1985; Gerritsen and Patten, 1985).

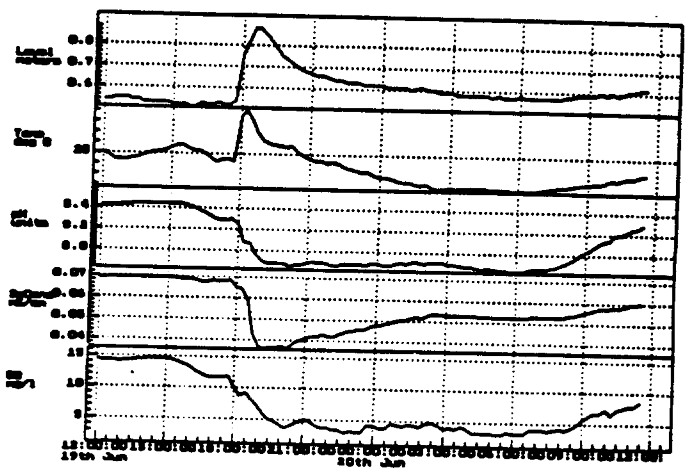

Figure 1. Twelve hour record of a single storm event.

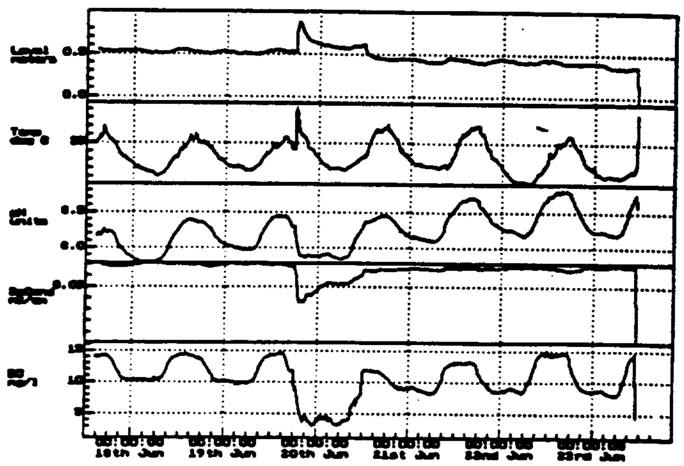

Figure 2. Six day record of stream water quality with storm event on Day 3

What are the implications of these theories on disturbance in streams affected by stormwater. First, a recognition that disturbance plays a role in the natural function of systems receiving stormwater suggests that stormwater, and storm effects, are important to the maintenance of stream ecosystems and regulation should not be developed to "eliminate" stormwater. Next, it is possible to develop a better understanding of variables and vectors that relate storm events to organism and community ecology. Experiments, field manipulations, and assessments involving organisms (including toxicity testing), species life history and interactions, and/or element turnover must go beyond a simple identification of state and condition to address time-related issues in receiving systems. Finally, it will be necessary to fully define disturbance. In a stormwater context that will require identification of what actually constitutes a disturbance in receiving systems affected by stormwater runoff. Further, the definition must consider both physical and chemical factors and develop a solid relationship between those factors and organism presence and receiving system community structure and function.

A Synthesis of Time-Scale Effects

When viewed from an ecological perspective the effects of a single storm may produce: 1) no effect (e.g. if the event produces no change, or changes produced have no consequence to organisms or the receiving system community), 2) short-term effects (e.g. change is disruptive, but disruptions are local and recovery mechanisms exist for rapid restoration of system state or condition), or 3) long-term effects (if change disrupts natural dynamics, producing a new stable state that resists return to pre-storm conditions. In reality, it is seldom that a single storm event produces severe environmental impact. Stormwater runoff effects are usually cumulative, produced over a long time span that includes a combination of storm-related change and large scale alterations of the watershed.

Typically the greatest environmental concern associated with stormwater runoff is toxicity. Toxicity is produced by both contaminant concentration, and the duration of the exposure to a given contaminant concentration. When considering the acute toxicity produced by stormwater runoff, the primary mechanism of effect can be defined by the concentration/time relationships for contaminants, and time related toxicity is typically associated with a single event. When considering chronic toxicity produced by stormwater runoff, the primary mechanism of effect is related to the fate and exposure concentration of contaminants introduced to the receiving system.

We do know that single stormwater events can produce chemical toxicity. Examples of event specific toxicity are given in Figure 3 and 4. In Figure 3, toxicity is determined using a microtox assay of samples collected at different times during a stormwater runoff hydrograph. The results indicate changing toxicity at different stages of the hydrograph. In Figure 4, toxicity is determined using a longer term toxicity test (in this case a 24-hour bioassay using rotifers).

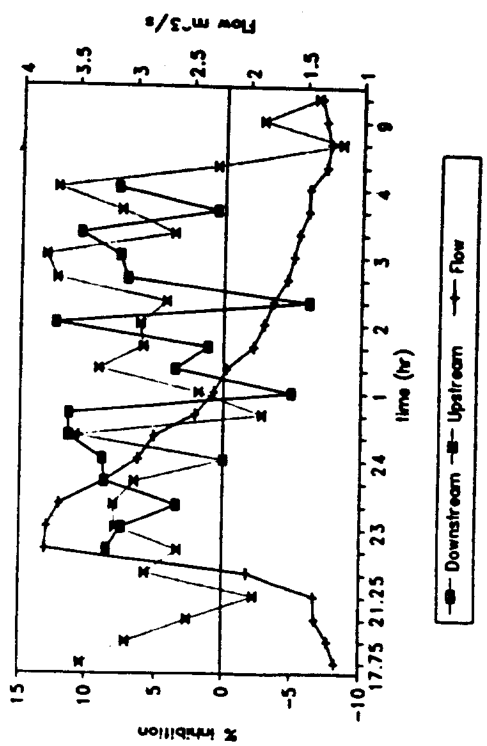

Figure 3. Microtox assay results on samples collected during a storm event.

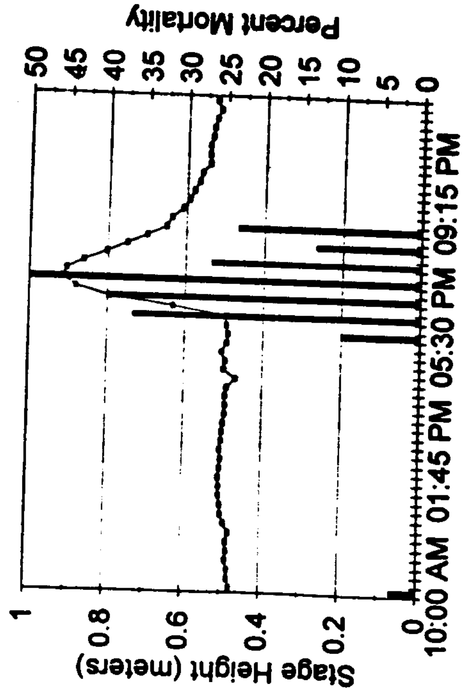

Figure 4. Rotifer 24 hr toxicity measured in samples collected during a storm event.

The results from this testing reveal a slightly different stage-related toxicity. A major cause of this apparent change in toxic effect is that the time of exposure to stormwater related contaminants is near the expected natural exposure time for the microtox assay, and well in excess of natural exposure times for the rotifer assay. A valid question that might be asked is are these toxicity results meaningful? We have measured toxicity, but assigning importance to indications of toxicity is very difficult because the link between acutely toxic events and long-term, or chronic, effect is still uncertain.

To get a handle on potential chronic toxicity we must turn to any of a number of studies have demonstrated "impact" from stormwater, particularly urban runoff (Whiting and Clifford, 1983; Garie and McIntosh, 1986; Willemsen et al., 1990; Bascombe et al., 1990; Milne et al., 1992). In these studies, measurements are usually made of water column, and sometimes sediment, contaminant concentrations along with assessments of receiving system state and condition. A link to chronic toxicity is suggested in many of these studies, and elevated environmental concentrations of contaminants have been related to stormwater loading. The major difficulty in these assessments is that it is difficult to separate stormwater effects from other watershed influences, and, by their nature, these assessments connect multiple events, which may differentially affect receiving system condition. In watersheds changed from their natural state, effects observed may be more from global causes, such as watershed disruption, than from specific factors, such as single or multiple storm event changes to the receiving system, either physical or chemical. Further, we simply do not know enough about the connection between episodic event effects to adequately develop a comprehensive assessment of chronic effects that are specifically stormwater related.

Where are we left in this analysis? A synthesis of time-scale effects produced by stormwater is possible. In a single event, there will most likely be two periods when concentration of contaminants is highest. The first is associated with the first flush, the second associated with the resuspension of previously deposited contaminants. During an event, the concentration and time of exposure of the first flush contaminants may or may not produce measurable toxicity. Nonetheless, the addition of contaminants to the receiving system may have long term consequences. If the contaminant is conservative, it is possible that it will accumulate, and exposure concentrations may reach levels that produce chronic, and possibly even acute, toxicity in target organisms. If a contaminant is non-conservative, its degradation products may extend the effect of a storm event by causing environmental change well beyond the unit hydrograph. It is also possible that degradation byproducts may produce chronic toxicity, or acutely toxic concentrations may be produced some time after the event that added the primary contaminant to the receiving system. In addition, physical disturbances caused by the storm event may increase toxic effects. For example scour or dislocation of organisms may increase their susceptibility to toxic contaminants.

The challenge to developing a reasonable, and scientifically accurate, analysis of time-scale effects will be the development of an effective measurement program that identifies specific stormwater effects, and sorts these effects from the range of other changes that may naturally occur, or be present because of watershed development.

Measurement of Time-Scale Effects

To address the issue of measurement of time-scale effects it is necessary to select actual metrics for measurement. The testing approaches, and test systems, available for these measurements can be selected from a range of physical or chemical measurements, and biological measurements that can be made at the various levels of the biological/ecological hierarchy (Herricks and Schaeffer, 1985; Herricks, 1992). The principal challenge is connecting any measurements made to stormwater runoff. A useful starting point for establishing connections is the identification of both cause and effect through an organized measurement/assessment program. One of the more common cause and effect relationships is that illustrated in the typical dose/concentration response curve commonly developed from toxicity testing, Figure 5. We have identified three regions of response that provide a basis for identifying cause and effect. In the first region no effect is measured, or effects are indeterminant because at this "low" stress/disturbance level although change may be observed in lower levels of the hierarchy (e.g. biochemical responses) change is not disruptive and the capacity of the organism to maintain function produces a flat response at higher levels of the hierarchy. In the second region, the magnitude of the stress increases and a threshold in response is observed. In this region toxicity may be observed as a graded response or a progressive change in community structure and function that can be related to increasing stress dosage. Low doses will be associated with chronic toxicity while high doses will be associated with acute toxicity. If the dose/concentration remains low, organisms can acclimate and the best response measures for community-level assessment will be associated with changes in function. Later in the second region, as dose increases, more profound effects are observed that gradually increase in severity. Dose/concentration levels exceed chronic effect levels leading to acute toxicity while the increased stress/disturbance levels produce responses that are effectively measured using structural metrics (e.g. replacement of sensitive by more tolerant species). At even higher dosages, we find that even tolerant species affected so the response observed is a change in both structure and function. Responses may be magnified because functional redundancy (the capacity of one species to replace the functional role of another species) is lost with progression through the second region. In the final region, measurement of response may be problematic. The high dosage produces such profound effects that responses are limited (e.g. further structural change is minimal and the spectrum of functional responses is reduced to a single response, death.

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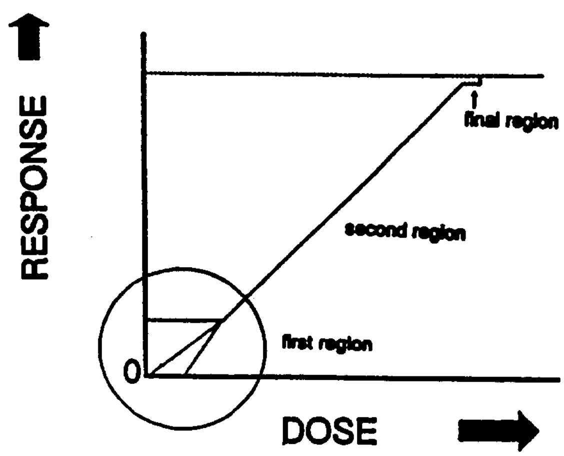

Figure 5. Dose (or Concentration) Response Curve.

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The progression of response can also be related to disturbance. The onset of change occurs as the variability of environmental conditions exceed the capacity of the receiving system to adjust to change. With increasing frequency of disturbance, the capacity of the receiving system is further diminished and the ability to cope with additional change is further reduced. Depending on the antecedent state of the receiving system, even a short duration low magnitude disturbance, such as a stormwater runoff event, can lead directly to stages three and four particularly in highly developed watersheds.

Clearly, the effects of stormwater runoff can be complex, ranging from short duration changes in contaminant concentration to long term modification of physical, chemical, and biological habitat conditions. This range of potential effects suggests that the measurement approach, and test systems used, to assess stormwater runoff must have characteristics that allow effect analysis over a range of temporal and spatial scales, which accommodate all levels of the biological/ecological hierarchy. The following characteristics of test systems are needed to effectively and efficiently assess the effects of stormwater runoff.

1. The time scale for the response must match the time scale of the exposure. For stormwater runoff, this means that the ideal test systems must have the capacity to respond to transient changes in contaminant concentration. Continuous monitoring results suggest that the shortest duration for transient concentration change is on the order of seconds with duration measured in minutes.

2. The test system must have response characteristics that track the transient changes in contaminant concentration during a stormwater runoff event. Because each stormwater event can produce a complex set of concentration, duration, and frequency of exposure conditions, an ideal test system must have both rapid response characteristics and some level of independence from exposure history to provide an accurate measure of constantly changing effects.

3. The ideal test system must also have the capacity to measure the effects of a single stressor, as well as integrate the effects of multiple physical, chemical, and/or biological stressors. The nature of stormwater runoff events suggest that it is unlikely that a single stressor will be the primary cause of an observed response during the entirety of a wet weather event although a community response is likely to be the sum of the response of different species to different single stressors. An ideal test system must have the capacity for effective monitoring transients of a single stressor with the ability to exclude other stress types, or the capacity to integrate responses for a range of stressors while maintaining the ability to discriminate between multiple stressor effects on a single, or multiple, response(s).

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4. The test system must have the capacity to assess an impact, or provide a measure, or measures, that have relevance to an ecological system or at least high hierarchical level effect. The ideal test system will provide measures that correlate highly with observed damage or impact.

In addition to these characteristics specific for stormwater runoff analysis, test systems must also meet other criteria that are applied in either experimental or descriptive analyses that often constitute what is considered Quality Assurance or Quality Control (QA/QC) elements or activities, Table 1. To meet these criteria, it should be evident that more than one test system will be required for stormwater runoff effect analysis. In fact a test battery, concurrent application of multiple test systems, will be required for effective measurement of stormwater runoff effects.

Test Systems

To provide a useful summary for the review of test systems that may be useful in developing a suitable test battery, a table was developed that examined test system types in relation to identified criteria for test system selection (Herricks, et.al. 1994), Appendix A. A critical issue in the selection of test systems, measures, and metrics is the development and implementation of a QA/QC program that meets the stormwater runoff and general testing criteria. Unfortunately, it is not possible to apply QA/QC protocols commonly used in ecotoxicology. For example, where testing is carried out on collected water samples, standard QA/QC procedures can be applied to sample collection and analysis. These procedures can include inclusion of field and analytical blanks, and replicate testing of toxicity. Where *in situ* tests are involved, it is not possible to implement a similar QA/QC program. It is simply not possible to truly replicate field conditions, or provide experimental controls. Further, the evaluation of test systems as a measure of stormwater runoff effect may follow no accepted standard methods because, in fact, the evaluations are a part of the development of new methods. For *in situ* measurements and field assessments it is possible to develop adequate reference samples from unaffected areas, and develop robust experimental designs that incorporate, where possible, standard methods and incorporate effective QA/QC procedures. Addressing the characteristics and criteria in the test system selection process establishes a basic QA/QC program. In addition, reference toxicant testing can be used to assess changes in sensitivity of different batches of organisms used in laboratory studies or field deployments.

Implications for Monitoring and Regulation

Virtually any living system can be used in a bioassay (Schaeffer and Herricks, 1993) but not all test systems are appropriate for the determination of time-scale toxicity. Not all living systems will respond in the same manner to the same contaminant, nor can the response from a single individual necessarily be

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Accuracy	Ability to predict actual effects of a contaminant (e.g. minimize false positives and false negatives). In practice, the ability of the test to produce a dose-response curve is evaluated, and to make predictions that are consistent with other measures.
Precision	Ability to produce low variation in the analysis of identical samples.
Sensitivity	Ability to measure low concentrations with acceptable precision.
Variability	Inherent variability of the test system should be known, or easily estimated. Schaeffer and Cox (1986) suggest that variability should be expressed as coefficient of variation that can be classified as low <10%, medium <20%, high <30%, very high >30%
Controls	Test systems must provide adequate opportunity for controlled experimentation or have an adequate reference data base of performance to assist in assessing effect
Specificy	Test system should have a known specificity for contaminants. This specificity can be based on either response or chemicals. Response specificity refers to whether there is a specific uniform response to a dose, or a broad scale, non-uniform response. Chemical specificity refers to whether the test response is limited to a few or to a broad range of chemical types.
Convenience	The test system should have an ease of performance, which includes facilities and equipment requirements as well as procedures.
Cost	Fixed and unit costs associated with the analysis should meet accepted targets developed in the monitoring program.
Technical Requirements	Qualifications and training required for test performance must be specified.
Previous Application	Information on previous test system applications in similar or different systems at other sites by different investigators.

extrapolated to other members of the same species, other communities of organisms, or to the ecosystem (Herricks, 1993). Thus a major requirement for monitoring time-scale toxicity is selection of test systems, and assessment approaches, which 1) respond to a contaminants typical of stormwater runoff, 2) respond in the time/concentration pattern that is appropriate to the event or the condition produced by stormwater discharges, and 3) provide a basis for extrapolating effects to determine the risk of environmental damage.

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The test systems available can include any biochemical, physiological, or behavioral response that can be measured experimentally, or a range of structural and functional population, community, or ecosystem parameters that can be monitored for change (Appendix). We will argue that any monitoring program for stormwater runoff effects must use a battery of test systems combined with a careful assessment of receiving system physical and chemical conditions. Further, since test system/battery applications to episodic toxicity measurement are limited, we have come to realize that the initial test system selection process should start with the evaluation of test systems that respond effectively to episodic event toxicity. Following the well developed hazard assessment procedures, we suggest that the initial phase of this evaluation should focus on screening tests with future analysis emphasizing predictive and confirmatory level testing. This implies that the program of measurement for time-scale toxicity should be ongoing and iterative, eventually developing a stormwater runoff effect analysis protocols that fully meet the need for realistic testing, follow QA/QC requirements and provide the foundation for regulation.

With regard to regulation, care must be taken when extrapolating existing toxicity testing data, or the use of standard toxicity testing methods, in regulatory programs. In fact, it may be inappropriate to apply existing standard acute or chronic toxicity testing procedures because these procedures inadequately, if not inaccurately, address concentration/time exposure relationships typical of stormwater runoff. The regulation of stormwater runoff should be established on sound scientific principles, meeting criteria for test system selection set out above.

Acknowledgements

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Appendix - Table 1. Evaluation of Test Systems Against Wet Weather Criteria.

Test System	Response induction time (hours)	Response observation time (hours)	Response measurement time (hours)	Tracking capability	Stress effect integration	Ecological relevance Response: General	Ecological relevance Response: # in (Table 3)	Previous application to wet weather events
Biochemical Responses								
MFO	Duration of exposure needed for induction unclear	~24.0	~24-30	M	L	No relationships established (L)	1,3	No
Cholinesterase activity	< 1.0	~1.0	~2-3	M	L	Related to mortality (M)	1,3	No
Stress Proteins								
heat shock (HSP)	< 1.0	~1.0	Lack of standard procedure	M	M	Limited data ?	5	No
specific stress proteins	Duration of exposure needed for induction unclear	~24.0	~24-36	M	L	Equivocal data (L)	5	No
Whole Organism Bioassays								
Lethality	V	V	< 0.1	L	H	H	1,3,4,5	Yes
Bioaccumulation	V	V	Dependent on sample number and type of substance > 4	L	M	M	1,3,5	Yes
Behaviorally Based Sub-lethal Tests								
Preference avoidance	< 0.5	< 0.5	< 0.5	H	M	M	5,7	No
Shell valve closure in bivalves	< 0.5	< 0.5	< 0.5	H	M -> H	L	5	No
Locomotion in invertebrates	< 0.5	< 0.5	< 0.5	M	M	M	5,7	No

Table continues

Test System	Response induction time (hours)	Response observation time (hours)	Response measurement time (hours)	Tracking capability	Stress effect integration	Ecological relevance Response General	# in (Table 3)	Previous application to wet weather events
Physiologically Based Sub-lethal Tests *Basic physiological functions*								
Heart rate	< 0.5	< 0.5	< 0.5	H	M	L	5	No
Respiration and ventilation rate	< 0.5	< 0.5	< 0.5	H	M	L	5	Yes
Muscular movement	< 0.5	< 0.5	< 0.5	M	L	L	5	Yes
Bioluminescence	< 0.5	< 0.1	< 0.1	H	M	L	5	Yes
Systems Integrating Physiological Function								
Feeding rate	V - OLH	6d	2d	L	H	M	1,3	No
Scope for growth	V - OLH	6d	3d	L	H	M	1,3	Yes
Whole body condition indices	?	d - w	h - d	L	H	L	4,5	No
Population and Community Responses								
Colonization (Expt. Bioassay)	NR	d - w	d - w	M	M	M - H	7	Yes*
Artificial streams (Manipulation)	V - RD	d - w	d - w	L	H	H	1,3,4,5,7	Yes*
Enclosures (Manipulation)	V - RD	d - w	d - w	L	H	H	1,3,4,5,7,9	No
Bioassessment	V - RD	h - w	d - w	L	H	H	1 - 9	Yes

Key: SH - short; LO - long; L - low; M - moderate; H - high; V - variable; RD - response dependent; d - days; w - week; OLH - organism life history dependent; * primarily in laboratory settings

Table 1 Continued. Evaluation of Test Systems Against Wet Weather Criteria.

Appendix - Table 2. Evaluation of Test Systems Against General Selection Criteria.

Test system	Accuracy WW event	Accuracy Ecological effect	Precision repeatability	Precision reproducibility	Sensitivity	Specificity to WW events	Specificity chemical or contaminants	Convenience/Cost	Technical requirements	Tier/Level
Biochemical Responses										
MFO	?	?	< 20%	22.3 - 29.6%	EPSS	?	PAHs	M/M	H	P/P
Cholinesterase activity	?	?	?	?	EPSS	?	carbamate insecticides	M/M	H	P/P
Stress Proteins										
Heat shock (HSP)	?	?	?	?	EPSS	?	general	M/M	H	P/P
Specific stress proteins	?	?	?	?	EPSS	?	metals	M/M	H	P/P
Whole Organism Bioassays										
Lethality	?	L	< 20%	30%	EPSS	?	general	H/L	L	S&P-/P&S
Bioaccumulation	?	M	40% organics 20% metals	30%	EPSS	?	metals organics	M/M	M	C/C
Behaviorally Based Sub-lethal Tests										
Preference avoidance	?	?	?	?	EPSS	M?	general	L/H(*)	H	P/P
Shell valve closure in bivalves	T ?	?	< 30%	?	EPSS	H	general	M/M	H	C/P
Locomotion in invertebrates	T ?	?	?	?	EPSS	M	general	M/H	H	P/P
Physiologically Based Sub-lethal Tests *Basic Physiological functions*										
Heart rate	T ?	?	?	?	EPSS	M	general	L/H	H	P/P
Respiration and ventilation rate	T ?	?	< 30%	?	EPSS	M	general	L/H	H	P/P
Muscular movement	no data	?	?	?	EPSS	?	general	L/H	H	P/P
Bioluminescence	T ?	L	< 10%	< 20%	H	L	general	H/L	L	S/P

Test system	Accuracy WW event	Accuracy Ecological effect	Precision repeatability	Precision reproducibility	Sensitivity	Specificity to WW events	Specificity chemical or contaminants	Convenience/ Cost	Technical requirements	Tier/ Level
Systems Integrating Physiological Function										
Feeding rate	ND	M	< 30%	?	EPSS	M	general	M/M	M	P/C
Scope for growth	T	M	> 30%	?	EPSS	M	general	M/M	M	C/C
Whole body condition indices	ND	L	?	?	EPSS	L	general	M/L	L	P/P
Population and Community Responses										
Colonization	NA	H	20–50%	?	SS	M	general	M/M	M	C/C
Artificial streams	T/?	H	< 400%	?	M	L	general	L/H	H	C/D
Enclosures	T/?	H	< 400%	?	M	L	general	L/H	H	C/D
Bioassessment	?	H	< 400%	30	M	L	general	M/M	M	C/D

Key:

L - low
M - medium
H - high
LO - long

T - method available and tested
EPSS - endpoint and substance specific
SS - species specific
NA - not applicable
ND - not determined
? - unknown

Tier:

S - screening
P - predictive
C - confirmatory
M - monitoring

Level:

P - preliminary
C - classification
D - definitive

Table 2 Continued - Evaluation of Test Systems Against General Selection Criteria.

Appendix - Table 3. Integrative responses of impacts produced by toxic substances in ecosystems (after National Research Council, 1991)

1 Elemental Dynamics	inputs, internal transport, and losses of critical plants, animals, and biochemical compounds, including the flux of nutrients essential for primary production and secondary metabolism.
2. Energy Dynamics (physical)	energy exchange at geological and biological surfaces (e.g., radiation, sensible and latent heat fluxes, and evapotranspiration) and mixing processes (e.g. turbulence, convection, and advection).
3 Food Web (trophic dynamics)	the set of trophic relationships among species in a community/ecosystem. In its simplest form, the food web is an energy-flow diagram connecting each consumer to all species that it consumes. However, in its dynamic form, the concept also includes rates of consumption, preference of food items, and prey switching. A given food web may indicate which species are necessary resources for other species (e.g., a particular valued species), the amount of redundancy in community/ecosystem functions, and the degree to which particular consumers, termed "keystone" species may control the competitive processes among the species consumed.
4 Biodiversity	the number of taxa per unit area as represented by populations, guilds, or life forms, as well as the relative abundance of various taxa.
5. Critical Species	keystone, resource, and endangered species: keystone species are those that exert influences over other populations in their ecosystem out of proportion to their abundances; resource species are species that have energetic, economic, or aesthetic importance; endangered species are species in imminent danger of becoming extinct.
6 Genetic Diversity	genetic diversity represents the number and frequency of different genotypes within species.
7 Dispersal and Migration	movements of individuals within and between ecosystems that are crucial to the population's survival and the ecosystem's health, including colonization or dispersal between habitats as well as movements of individuals to different habitats for food, reproduction, overwintering, or protection from predators.
8. Natural disturbance	externally driven disturbances, unrelated to human activities, that have major impacts on ecosystem integrity by altering the species composition, trophic structure, or other important ecosystem developmental processes; these disturbances include wind storms, fires, and floods resulting from weather patterns. these disturbances are often essential to maintenance of certain ecosystems.
9 Ecosystem Development (successional processes)	developmental changes (successional stages) in species composition through time, mediated by biological-physical interrelationships, resulting in a defined ecosystem structure and function.

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Use of Sediment and Biological Monitoring

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ABSTRACT

Assessing the environmental effects of stormwater discharges presents many new and complex challenges. Unlike traditional point sources of pollution, these discharges are intermittent, creating temporally and spatially variable shock loadings to receiving waters. Consequently, traditional assessment techniques which rely solely upon sampling and characterization of the water column are ineffective in determining the environmental effects of stormwater discharges. This paper will discuss the need and rationale for alternative sampling and assessment procedures that provide a more ecologically-based manner of determining the environmental effects of stormwater discharges. Activities undertaken by the Florida Department of Environmental Protection in the past few years to develop biological community assessment and coastal sediment monitoring tools to evaluate stormwater discharges will be summarized. The development and use of a coastal and estuarine sediment assessment tool, based on the relationship between sediment aluminum and metal concentrations, will be reviewed. Similarly, the steps taken to develop and implement a riverine biological community assessment tool, based on comparisons between impacted sites and ecoregion reference sites, are reviewed.

INTRODUCTION

During the late 1970s, stormwater and other nonpoint sources (NPS) of pollution were identified as major contributors to the degradation of Florida's surface and ground water resources. To minimize stormwater pollutant loadings discharged from new land use activities, the Florida Environmental Regulation Commission adopted a statewide stormwater treatment regulation in February 1982. This rule, implemented cooperatively by the state's Department of Environmental Protection and

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five regional water management districts, establishes permitting procedures and, for various types of stormwater management practices, design criteria presumed to achieve a specified treatment level. This rule is one of numerous statutes and regulations that have been implemented during the past 20 years to minimize the detrimental environmental effects associated with the state's extremely rapid growth. Collectively, the individual laws and programs enacted during this period can be considered "Florida's Watershed Management Program" (Livingston, 1993).

An essential component of this watershed management program is monitoring, to evaluate environmental conditions and the program's environmental benefits. In the past, water quality management actions focused on traditional point sources of pollution, such as domestic or industrial wastewater discharges, making monitoring and evaluation relatively easy. These point sources typically discharge effluents of uniform, known quality at continuous design flows, making them relatively easy to assess, model and control. Point source assessments generally have relied almost solely upon water column chemistry monitoring. On the other hand, stormwater and other nonpoint sources of pollution, because of their intermittent, diffuse, land use specific nature, are highly variable in effluent quality and environmental effects. Of particular environmental concern is the cumulative impact on a water body from the numerous stormwater/nonpoint sources within a watershed. Traditional water quality monitoring and management efforts generally suffer from several deficiencies in understanding and managing stormwater/NPS pollution. These deficiencies include difficulty in:

1. Assessing intermittent, shock loadings of pollutants.
2. Assessing cumulative impacts of multiple sources.
3. Comparing water bodies and establishing priorities for management actions.
4. Distinguishing actual or potential problems from perceived problems.
5. Discriminating anthropogenic loadings from natural watershed loadings of metals and nutrients.
6. Establishing cost-effective ways to assess pollution trends and understand overall watershed pollution.

Most stormwater pollutants accumulate over time in sediments, not the water column. Therefore, assessment methods to determine the cumulative effects of watershed stormwater/NPS pollution sources on aquatic systems or to evaluate the effectiveness of management programs should include evaluation of sediments and the organisms that reside there and in other aquatic habitats. This paper will review the development and implementation of sediment and biological monitoring protocols in Florida which are being used to improve evaluation and management of stormwater and other intermittent pollution sources, along with traditional point sources.

ASSESSING SEDIMENT CONTAMINATION

Sediment quality is a sensitive indicator of overall environmental quality. Sediments influence the environmental fate of many toxic and bioaccumulative substances in aquatic ecosystems. Sediments tend to integrate contaminant concentrations over time and may represent long-term sources of contamination. Specifically, sediment quality is important because many toxic contaminants found in only trace amounts in water can accumulate to elevated levels in sediments. Sediment-associated contaminants can also directly affect benthic and other sediment-associated organisms since sediments provide benthic and pelagic communities suitable habitats for essential biological processes (e.g. spawning, incubation, rearing, etc.).

Sediments provide an essential link between chemical and biological processes. By understanding this link, environmental scientists can develop assessment tools and conduct monitoring programs to more rapidly and accurately evaluate the health of aquatic systems. Therefore, sediment quality data provide essential information for evaluating ambient environmental quality conditions in water bodies. Additionally, information about the amount and quality of sediments within stormwater systems, stormsewers and other stormwater conveyances can help trace pollution sources, prioritize areas for implementing control measures, and help to assure proper disposal of accumulated sediments.

FLORIDA'S SEDIMENT ASSESSMENT PROJECTS

Florida has an extensive coastline (approximately 11,000 miles) and an unusual diversity of estuarine types. Conditions in its many estuaries range from nearly pristine to localized severe degradation. Metals are of particular concern in terms of protecting and rehabilitating estuaries because of their potential toxic effects and because high metal concentrations can signal the presence of other types of pollution. Natural metal concentrations can vary widely among Florida estuaries presenting special difficulties in comparing estuarine systems statewide and in making consistent, scientifically defensible management decisions.

In the past, determining whether estuarine and coastal sediments were anthropogenically enriched with metals was a difficult process requiring comprehensive site-specific assessments. In 1983, staff from the Department's Office of Coastal Zone Management, in association with Dr. Herb Windom of the Skidaway Institute of Oceanography, began a nearly decade long effort to develop a practical approach for assessing metals contamination in coastal sediments. Projects undertaken include:

1. The Deep Water Ports Project, a survey of sediment quality in eleven major ports around the state, performed in 1983-84.
2. The Statewide Survey of Clean Reference Sites, a survey of sediment quality in many relatively isolated, unimpacted locations around the state, done between 1986 and 1991.
3. Ongoing surveys, some in conjunction with the National Atmospheric and Oceanic Administration, initiated in 1985 to survey sediment quality in estuaries throughout Florida.

From these projects an assessment procedure was developed which relies on normalization of metal concentrations to a reference element. In Florida,

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normalization of metal concentrations to aluminum concentrations in estuarine sediments provided the most promising method of comparing metal levels regionally. Other elements such as iron or lithium can also be used as normalizing elements for assessing estuarine and marine sediments. Development of this sediment assessment procedure required three components of monitoring to be addressed:

1. Refinement of sediment sampling protocols and laboratory analytical techniques to assure that sediment data is accurate and comparable.
2. Development of an interpretive technique to determine whether sediment materials are naturally occurring or from anthropogenic sources within a watershed.
3. Development of sediment quality assessment guidelines to help determine whether sediment bound pollutants are harmful to the environment.

Part 1. Collection of Sediment Samples: To ensure that the information used to develop the interpretive tool represented the diverse Florida sediments, uncontaminated sediments from around the state were examined for their metal content and the natural variability of metal/aluminum relationships was statistically assessed (FDER, 1988). Sediment samples from 103 stations in uncontaminated estuarine/coastal areas were collected and analyzed for aluminum and other environmentally and geochemically important metals. The areas sampled encompassed various sediment types ranging from terrigenous, aluminosilicate-rich sediments in northern Florida to biogenic, carbonate-rich sediments in southern Florida. These "clean" sites were selected subjectively, based upon their remoteness from known or suspected anthropogenic metal sources.

The following sampling procedures were developed and refined into a standard protocol:

1. Prior to field sampling, station locations were determined after studying local watershed information (land use, drainage patterns and systems, water depths, potential sediment deposition areas), navigation charts, and meeting with local government staff.
2. Stations were located using LORAN-C by latitude and longitude, compass bearings, and cross referenced to navigational charts. In 1991, the standard field protocol was changed and Global Positioning System (GPS) is now used to locate stations.
3. Upon arrival at the station, the boat was anchored and engines shut off. The location, time, date, weather conditions, and compass bearings (and GPS location) were recorded in a station log notebook along with water column physical parameters taken at the surface, mid-depth, and bottom.
4. Sediments were collected in replicate from the boat using a stainless 9X9" PONAR grab sampler. The grab was suspended from a hoist, acid washed and rinsed with deionized water before use, and rinsed with ambient water between grabs. A 10% HCl solution was used to acid rinse all utensils, the sampling grab, and spatulas used to process samples. Once the sampler was retrieved, it was carefully emptied into a clean, acid washed and rinsed tub. The top two cm of sediment were scooped from the top of the grab. Repeated grabs were made at the same site until enough material was collected for all analyses.

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5. Sediments were collected by using sediment coring tubes at stations where the water was too shallow for the boat, or where sensitive habitats (sea grass beds, corals) precluded use of the grab sampler. Acid washed and rinsed clear cellulose-acetate-butyrate core tubes with caps were used for each sample, with three replicate samples collected at each station. Core tubes were plunged into the sediment and the top capped. A diver retrieved the core tube by displacing the sediment around the core, putting on the bottom cap, and lifting the core tube. Cores were taken to the boat where they were transferred into containers using an acid washed extruding tool. The top 3-5 cm of the cores were packed in the collecting jar. Each replicate sample was a composite of the three cores.
6. Samples were transferred to glass jars or whirlpaks which have been precleaned to meet EPA specifications for organic and inorganic materials. Sample containers were labeled, then placed on ice.
7. Since 1991, several changes have been made to the FDEP standard field protocol including:
   a. A 12"X12" Kynar coated stainless steel "Young" grab is used to collect sediment. It is deployed in a similar fashion as the PONAR.
   b. In addition to acid washing, full strength acetone is used to rinse all gear prior to sampling and between all stations. This volatilizes any organic contaminants that might be on the sampler.
   c. The top two centimeters of sediment are scooped from the top of the sampler with an acetone rinsed sterile scoop. The sediment is then transferred to a stainless container, and homogenized using an acid washed, acetone rinsed, long handled stainless scoop.

Part 2. Laboratory Analysis of Sediment Samples: From 1982 to 1990, all FDEP sediment samples were analyzed by Savannah Laboratories and Environmental Services, Inc. (SLES) in Savannah, Georgia. From 1990 to the present, the Skidaway Institute of Oceanography (SIO) in Savannah analyzed sediments. Physical characteristics, such as grain size and percent organic matter, were determined for sediment samples which were then analyzed for nine metals (aluminum, arsenic, cadmium, chromium, copper, mercury, nickel, lead, zinc). Except for mercury, SLES analyzed metals using graphite furnace or flame atomic absorption spectrometer and analyzed organic compounds using gas chromatographic techniques. SIO analyzed metals by ICP (inductively-coupled plasma) mass spectrometry or by atomic absorption spectrometry.

Before analysis for metals, particular care was taken to totally digest the sediment samples using hydrofluoric, nitric, and perchloric acids as required by the project quality assurance plan. Total digestion of the sediment sample is essential when using the sediment assessment tool because of its normalization method to estimate metal contamination. Total digestion is strongly encouraged to produce comparable date for general environmental and trend monitoring of pollutants. FDEP conducted a laboratory intercalibration exercise, in which four laboratories participated, to assess the accuracy and precision of reported metals data from coastal sediments and from sediment reference materials (Schropp, 1992). Results of this exercise and an

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international intercalibration exercise (Loring and Rantala, 1988) both showed that sediment trace metal data from different laboratories may not be comparable if different sample digestion techniques are used.

Part 3. Distinguishing Natural vs. Anthropogenically Enriched Sediments: Once methods to reliably and accurately collect and analyze sediment samples were refined, the next step was to develop an interpretive tool to determine whether metals in sediments were natural or from human activities. To understand this assessment tool, one must generally understand the geochemical processes that govern the behavior and fate of metals in estuarine and marine waters. Natural estuarine sediments are predominantly composed of river-transported debris resulting from continental weathering. The solid debris is composed chiefly of chemically resistant minerals, such as quartz and clay minerals, which are the alteration products of other aluminosilicate minerals. The weathering solution also contains dissolved metals leached from the parent rock. Because of their low solubilities, however, the transporting solution (e.g., rivers) carries low amounts of metals. Most metals transported by rivers are tightly bound in the aluminosilicate solid phases. As a consequence, weathering causes little fractionation between the naturally occurring metals and aluminum.

In general, when dissolved metals from natural or anthropogenic sources come in contact with saline water, they quickly adsorb to particulate matter and are removed from the water column to bottom sediments. Thus, metals from both natural and anthropogenic sources ultimately are concentrated in estuarine sediments, not the water column. Since much of the natural component of metals in estuarine sediments is chemically bound in the aluminosilicate structure, the metals generally are immobile. However, the adsorbed anthropogenic or "pollutant" component is more loosely bound and may be more available to estuarine biota and may be released to the water column when sediments are disturbed (e.g., by dredging or storms).

The tool for interpreting metal concentrations in estuarine sediments is based on demonstrated, naturally occurring relationships between metals and aluminum. Specifically, natural metal/aluminum relationships were used to develop guidelines to distinguish natural from contaminated sediments for several metals commonly released to the environment from anthropogenic activities. Aluminum was chosen as a reference element to normalize sediment metals concentrations for several reasons:

1. After silicon, it is the most abundant naturally occurring metal;
2. It is highly refractory;
3. The relative proportions of metals and aluminum in crustal materials are fairly constant;
4. Its concentration is rarely influenced by anthropogenic sources.

Using the data from sediments collected and analyzed as part of the Statewide Survey of Clean Reference Sites, a metal to aluminum normalization method was developed (FDEP, 1988). At these sites, sediment metal concentrations generally are expected to express natural relationships with aluminum. Eight metals (As, Cd, Cr, Cu, Hg, Pb, Ni, and Zn) were tested to determine their relationship to aluminum with a set of graphical tools developed to assess trace metal contamination in a sediment sample. For example, Figure 1 shows that as aluminum concentrations in "clean" sediments increase, metals concentrations, in this case lead, also increase. Least squares regression analysis, using aluminum concentration as the independent variable and the concentration of the other metal as the dependent variable, were performed on log-transformed data and 95% prediction limits were calculated. Significant correlations were obtained for arsenic, cadmium, copper, lead, nickel, and zinc. The plotted regression lines and prediction limits provide the basis for interpreting metal concentrations in sediments.

To determine whether estuarine sediments are enriched with metals, a mean value of each metal (derived from replicate or triplicate samples) is calculated and points representing corresponding metal and aluminum values are plotted (Figure 2). The sediment is judged to be natural or metal enriched depending on where the points lie relative to the regression lines and prediction limits. If a point falls within the prediction limits, then the metal concentration is within the natural range. If a point falls above the upper prediction limit, then the sediment is considered to be metal-enriched. Before concluding sediment "enrichment", the accuracy of the analytical results should be confirmed, since an unusual point can be indicative of procedural errors. Since the results are interpreted with respect to the 95% prediction limit, some points from "clean" stations may plot outside the prediction limit. The greater the distance above the prediction limit, the greater degree of enrichment. An enrichment factor, which is the ratio of the measured metal concentration to its maximum expected concentration in natural sediments, can be calculated using the following equation (FDEP, 1994):

$$\text{Metal Enrichment Factor} = \frac{\text{Observed Metal Concentration } (\mu g/g)}{\text{Max Expected Natural Metal Conc } (\mu g/g)}$$

Applications of the Interpretive Tool: The effectiveness and utility of this sediment assessment tool has been tested in a variety of regional studies (Tampa Bay, Schropp et al., 1989; SE Atlantic and Gulf coasts, Hanson and Evans, 1991; Louisiana, Pardue et al., 1992). The results of these studies indicate that aluminosilicate minerals have a major influence on metal concentrations in natural sediments. The interpretive tool using metal and aluminum relationships allows results of sediment chemical analyses to be used for a variety of environmental information needs:

1. Distinguishing natural versus enriched metals concentrations in coastal sediments.
2. Normalizing metals to a reference element allows comparisons of metal concentrations among sites within a watershed.
3. Comparing investigative results from different watersheds. By normalizing metal concentrations to aluminum, an assessment of relative metal enrichment levels can be made, allowing watersheds to be ranked according to specific metal enrichment problems.
4. Tracking the influence of a pollution source.

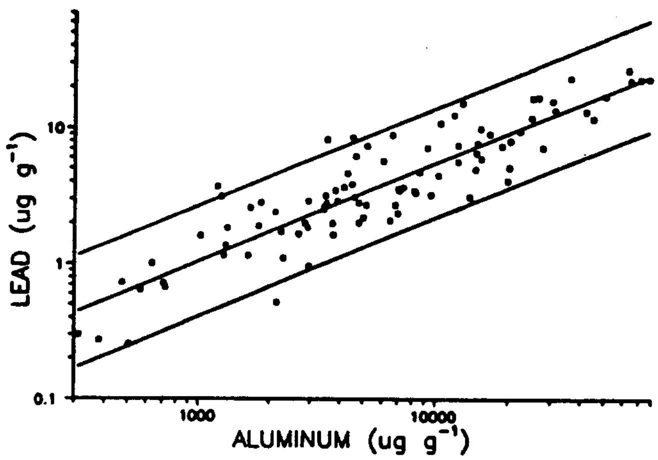

Figure 1. Lead/aluminum relationship from statewide "clean" sediments.

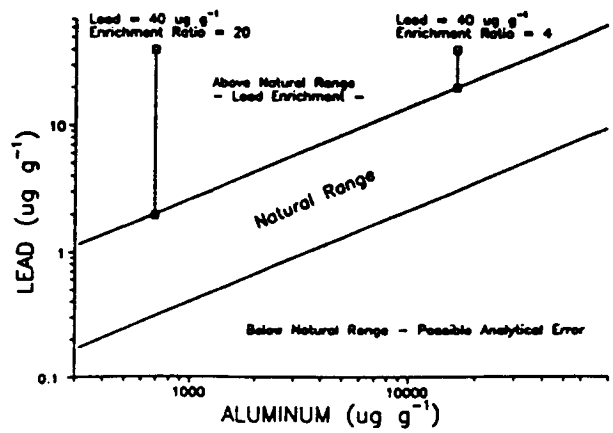

Figure 2. Interpretation of Lead data using lead/aluminum relationship.

5. Monitoring trends in sediment metal concentrations over time.
6. Determining sediment sampling or analysis procedural or laboratory errors.
7. Screening sediment data to promote cost-effective use of elutriate or other sediment quality tests.

Limitations of the Interpretive Tool (FDER, 1988): Funding limitations in Florida have prevented the collection and analysis of sediment samples from freshwater systems to evaluate if the tool can be used in those aquatic systems. However, such sampling is underway in Washington and previously was completed in Illinois. Use of this tool requires knowledge of local conditions and applying professional judgement. Consider the following points when using this interpretive tool:

1. The interpretive tool is useless without reliable data. Results from single, non-replicated samples should not be used. Ideally, sediment samples should be collected in triplicate. If budget constraints dictate analysis of only duplicate samples, the third sample should be archived. In the event of a disparity in the results of replicate analyses, the archived sample should be retrieved and analyzed to resolve the problem.
2. Sediment metals must be analyzed using techniques appropriate for saline conditions and capable of providing adequate detection limits. Because naturally-occurring aluminum and other metals are tightly bound within the crystalline structure of sedimentary minerals, the metal analysis method must include total digestion using HF, HNO_3, and $HClO_4$ acids. If aluminum is not completely released by a thorough digestion, metal to aluminum ratios may appear to be unusually high.
3. Natural concentrations of cadmium and mercury are very low and are near normal analytical detection limits. Because of this, analytical precision and accuracy are reduced and special care must be taken to obtain accurate laboratory results.
4. The data set is, to the extent possible, representative of various types of natural "clean" sediments found in Florida estuaries. Only in a few instances should aluminum concentrations exceed 100,000 ppm (10% aluminum). Any samples containing greater than 100,000 ppm aluminum should be examined carefully for evidence of contamination or analytical error.
5. Interpretation of metal concentrations, using these metal to aluminum relationships, must also consider sediment grain size, mineralogy, coastal hydrography, and proximity to sources of metals.

Part 4. Determining the Ecological Significance of Enriched Sediments: Sediment chemistry data alone do not provide an adequate basis to identify or manage potential sediment quality problems. After determining that sediments are anthropogenically enriched with pollutants, the next assessment step is to determine whether these sediment-bound pollutants are harmful to the environment. Biologically-based numerical sediment quality assessment guidelines (SQAGs) also are required to interpret the ecological significance of sediment chemistry data by providing a basis for assessing the potential effects of sediment-associated contaminants.

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MacDonald (1993) reviews the variety of approaches which have been devised to formulate sediment quality guidelines (SQGs). A suitable strategy for deriving SQAGs for Florida must recognize the limitations of the existing database to evaluate the potential biological effects of sediment-associated contaminants. Therefore, the strategy must address both the immediate requirement for defensible SQAGs and the long-term requirement for increased reliability and applicability of these guidelines (i.e., guidelines that account for the environmental characteristics that influence the bioavailability of sediment-associated contaminants).

To develop a tool to assess the potential ecological effects of sediment based contaminants, the FDEP, in association with MacDonald Environmental Sciences, reviewed eight approaches to derive sediment quality assessment guidelines that would be applicable to Florida coastal conditions and appropriate for the state's specific needs. Several criteria were established to objectively evaluate the approaches and select a relevant strategy to derive these guidelines. The primary selection factors were practicality, cost-effectiveness, scientific defensibility, and broad applicability to sediment quality assessment. This review indicated that each of the approaches has deficiencies that limit its direct application in Florida. For this reason, an integrated strategy for deriving numerical SQAGs was recommended for the state of Florida (MacDonald, 1993). This strategy provides relevant near term assessment tools and a basis to refine these guidelines as the necessary data become available.

Using the recommended approach, numerical SQAGs have been developed for 25 priority contaminants in Florida coastal waters (MacDonald, 1993) using a modification of the NOAA's National Status and Trends Program Approach (Long and Morgan, 1990). These guidelines, derived from numerous investigations of sediment quality conducted throughout North America, are based on a weight-of-evidence linking contaminant concentrations and adverse biological effects. In this respect, the guidelines represent a cost-effective response to a practical need for assessment tools. However, these guidelines are preliminary and will likely be refined with results from field validation and other related studies now underway in Florida and elsewhere in North America. The guidelines should be used with other interpretive tools to conduct comprehensive and reliable assessments.

Effects-based SQAGs provide a basis to assess the potential for biological effects associated with various contaminant concentrations. MacDonald (1993) derived no observed effects levels (NOELs) and probable effects levels (PELs) to define three ranges of contaminant concentrations: the probable effects range, the possible effects range, and the no effects range.

The probable effects range is the concentration range of specific sediment contaminants within which biological effects are usually or always observed (probable effects range ≥ PEL). Sediments with contaminant concentrations within the probable effects range *represent significant and immediate hazards to exposed organisms*. Sites with concentrations of one or more contaminants that fall within the

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probable effects range should be given the highest priority in implementing sediment quality management options. However, direct biological assessment is required at these sites to determine the nature and extent of effects that could be manifested.

The possible effects range is the concentration range of a specific sediment contaminant with uncertain adverse biological effects (NOEL < possible effects range < PEL). This range is likely to be dependent on factors, such as bioavailability, that may influence the toxicity of the substance. Sediment-associated contaminants *represent potential hazards to exposed organisms* when concentrations fall within this range. Sediments with contaminant concentrations within this range require further assessment to determine the biological significance of the contamination. In general, further assessment would be supported by biological tests designed to evaluate the biological significance of sediment-associated contaminants to key species of aquatic biota.

The no effects range of sediment contaminant concentrations where biological effects are rarely or never observed (no effects range ≤ NOEL). Sediments with concentrations of contaminants within the no effects range are *considered to be of acceptable quality* for those contaminants. In general, further investigations of sediment quality conditions within this range are relatively lower priority. However, biological testing may be required to validate the results of the initial assessment of the potential for adverse biological effects, particularly in sediments with low levels of total organic carbon, acid volatile sulfide, and/or other variables that could influence the bioavailability of sediment-associated contaminants.

A Framework For Assessing Site-specific Sediment Quality Conditions in Florida: MacDonald (1993) developed a framework for the Florida Department of Environmental Protection for future use of sediment quality assessment guidelines and related tools. This framework, which identifies essential considerations to address in conducting site-specific sediment quality assessment programs, consists of:

1. Collect Historical Land and Water Use Information
   - Land uses - current and historical; industrial, commercial
   - Infrastructure including stormwater systems
   - Pollution sources - point and nonpoint
   - Hydrology, physiography, ecology

2. Collect and Evaluate Existing Sediment Chemistry Data
   - Sediment deposition location, patterns, transport,
   - Sediment physical and chemical characteristics
   - Temporal and spatial variability, vertically and horizontally
   - Determine data reliability, acceptability, applicability

3. Collect Supplemental Sediment Chemistry Data
   - Determine contaminants, sampling locations
   - Delineate temporal and spatial variability in sediment contamination

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- Prepare and follow QA Plan for sampling, handling, and analysis protocols
4. Conduct Preliminary Assessment of the Potential for Biological Effects of Sediment-Associated Contaminants
   - Compare sediment contaminant concentrations to SQAGs
5. Evaluate Natural versus Anthropogenic Sources of Sediment-Associated Contaminants
   - Determine sources using the previously described sediment assessment procedure
6. Conduct Biological Assessment of Sediment Quality
   - Determine whole sediment toxicity
   - Conduct short-term bioassays, long-term microcosm studies, etc.
   - Develop site-specific SQAGs
   - Conduct biological community assessments
7. Implement Management of Sediment Quality
   - Evaluation factors include nature and severity of sediment contamination, potential for exposure of aquatic life, site or regional management goals, availability of remediation technology, costs, and public expectations.
   - Actions may range from none to continued monitoring to remedial actions such as removal and treatment of sediment contaminants or source control implementation.

This framework is designed to provide a consistent approach to assessing sediment quality in marine and estuarine areas. However, the framework is not intended to replace accepted sediment testing protocols such as developed for the ocean disposal of dredged material. Instead, it is intended to provide general guidance to support the sediment quality assessment process.

Applications and Limitations of the Recommended Sediment Assessment Approach: The sediment quality assessment strategy provides a consistent basis to evaluate sediment quality in Florida. While the SQAGs represent an integral element of this strategy, they should be used with other assessment tools to efficiently and cost-effectively evaluate ambient sediment quality conditions. In this context, these SQAGs may be used to:

- Interpret the results of sediment quality monitoring data to assess the potential adverse biological effects associated with concentrations of sediment-associated contaminants.
- Support the design of sediment quality monitoring programs by evaluating existing sediment chemistry data to rank areas and chemicals of concern allowing monitoring priorities to be more clearly and effectively identified.
- Identify the need for site-specific investigations to support regulatory or watershed management decisions, including source controls and the siting of regional stormwater management systems.
- Evaluate the hazards associated with increased levels of contaminants at specific sites.
- Facilitate multijurisdictional agreements on sediment quality issues and concerns by establishing site-specific sediment quality objectives that help define the

responsibilities of various levels of government in preventing and remediating sediment contamination.

These guidelines were established to provide a consistent basis for evaluating estuarine sediment quality in Florida. However, these guidelines are preliminary and, as such, have certain limitations on their application. Therefore, SQAGs:

- Are applicable to marine and estuarine waters only, not to freshwater systems.
- Should not be used in lieu of water quality criteria. However, they may be used to evaluate the effectiveness of regulatory programs and identify the need for more stringent regulations.
- Should not be used to define uniform values for sediment quality on a statewide basis (i.e., they should not be used as sediment quality criteria). Ambient environmental conditions may influence the applicability of these guidelines at specific locations;
- Should not be used as criteria for the disposal of dredged material and should not replace formal assessment protocols established for disposal of dredged material.
- Should not be used directly as numerical clean-up levels at severely contaminated sites (e.g., Superfund sites).
- Are designed to determine the potential for sediment-associated contaminants to induce biological effects. Direct cause and effect relationships should not be inferred when comparing chemical data to the recommended guidelines.
- Have been derived primarily from acute toxicity study results. Few data are available on the chronic responses of aquatic organisms to contaminants associated with sediments.
- Should be used with other assessment tools and protocols, such as the FDEP metals interpretive tool and the Green Book (EPA and ACE, 1991), to provide comprehensive evaluations of sediment quality.
- Were developed using information from various North American locations. These data may not be representative of the wide range of Florida sediment types. For this reason, caution should be exercised in using these guidelines, particularly in carbonate-dominated sediments in southern Florida.

Part 5. Using the Sediment Assessment Tools: MacDonald (1993) stresses the importance of combining the effects-based guidelines and the metals interpretive tool. MacDonald examines data on levels of sediment-associated lead from two geochemically distinct systems, Biscayne Bay and Apalachicola Bay, to illustrate the integrated sediment quality assessment framework. Figure 3 shows a summary of the available data (FDEP, 1994) on the levels of sediment-associated lead in the Miami area. The data, sorted by increasing concentration, were assigned sample numbers of 1 to 108. Evaluation using the SQAGs suggests that approximately 15% of the samples fall within the probable effects concentration range (exceed the PEL of 160 mg/kg). Another 20% of the samples fall within the possible effects range (between the NOEL and the PEL). Therefore, comparing sediment chemistry data with the numerical SQAGs suggests a relatively high probability of observing adverse biological effects. Further examination of these data using the metals interpretive tool (Figure 4) demonstrates that sediments from this area are clearly

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anthropogenically-enriched with lead. Roughly 90% of the samples exceed the 95% prediction limits established for clean sites. Concordance between the effects-based tool and the geochemically-based tool suggests that the Miami area should be a priority area for further investigations to evaluate sediment toxicity.

In Apalachicola Bay, roughly 20% of the samples had lead levels that exceeded the NOEL of 21 mg/kg (Figure 5). Comparison of the ambient lead levels in Apalachicola Bay with SQAGs suggests possible adverse biological effects at a significant number of sites. However, further evaluation using the metals interpretive tool indicates that aluminum-normalized lead level in Apalachicola Bay sediments is indicative of those measured in clean sediments in Florida (Figure 6). While the effects-based tool predicts the possibility of adverse effects at some sites, the geochemical tool demonstrates that lead concentration in Apalachicola Bay are naturally-occurring and, as such, should not be considered hazardous to aquatic organisms. This system does not require further investigations to evaluate the extent of sediment toxicity.

In 1994, the Sediment Research Group of FDEP released the *Florida Coastal Sediment Contaminants Atlas*, which describes the spatial extent of sediment contamination in Florida's coastal waterbodies. The *Atlas* presents the results of the previously mentioned FDEP coastal sediment surveys. In addition, the *Atlas* has been strengthened by inclusion of sediment data from the NOAA National Status and Trends Program, as well as sediment data produced by the Mote Marine Laboratory, an independent marine research facility located in Sarasota, Florida. The *Atlas* includes information on the eight metals and five classes of organic compounds - chlorinated hydrocarbons, polynuclear aromatic hydrocarbons (PAHs), polychlorinated biphenyls (PCBs), phenolic hydrocarbons, and aliphatic hydrocarbons. A Technical Volume accompanies this *Atlas* and provides ancillary information for users of this document. Although the Department was not able to fully assess sediment contamination along Florida's extensive coastline, it appears that the highest concentrations of contaminants in sediments are generally near urban centers. However, low to moderate levels of contaminants are common adjacent to many less developed coastal areas. Stormwater runoff appears to be the major cause of contamination of sites identified in the *Atlas*. Regional monitoring of contaminants in living resources and sediments, followed by sediment toxicity studies, is strongly recommended to keep a finger on the pulse of Florida's freshwater and marine ecosystems.

BIOLOGICAL COMMUNITY MONITORING

Since enactment of the Federal Clean Water Act, most efforts to preserve, maintain and restore water quality have relied upon and been directed by chemical and physical measurements of the water column. While this approach may be useful in assessing the effects of continuous point discharges, such as domestic or industrial wastewaters, it cannot accurately determine environmental impairments from intermittent sources such as stormwater or other nonpoint source discharges.

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Figure 3. Conc. of Pb in sediments of Biscayne Bay.

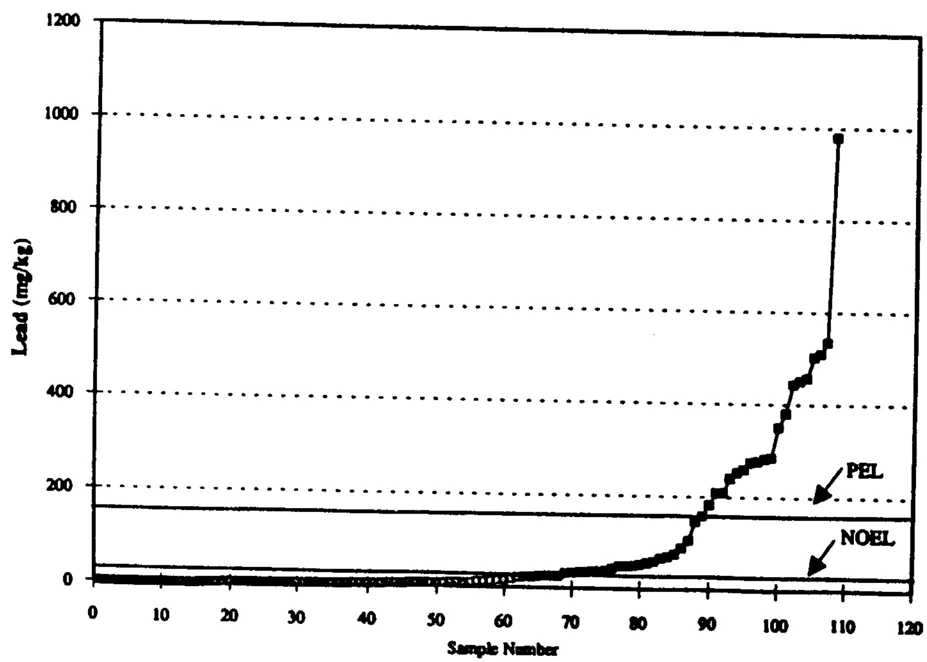


Figure 4. Alum. normalized conc of Pb in Biscayne Bay sediments.

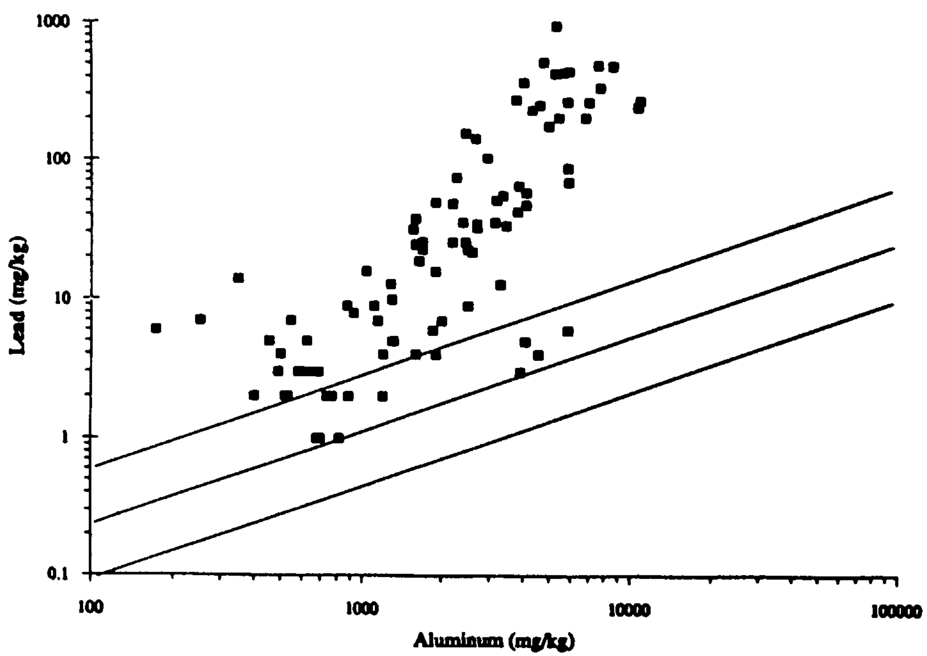


Figure 5. Conc. of Pb. in sediments of Apalachicola Bay.

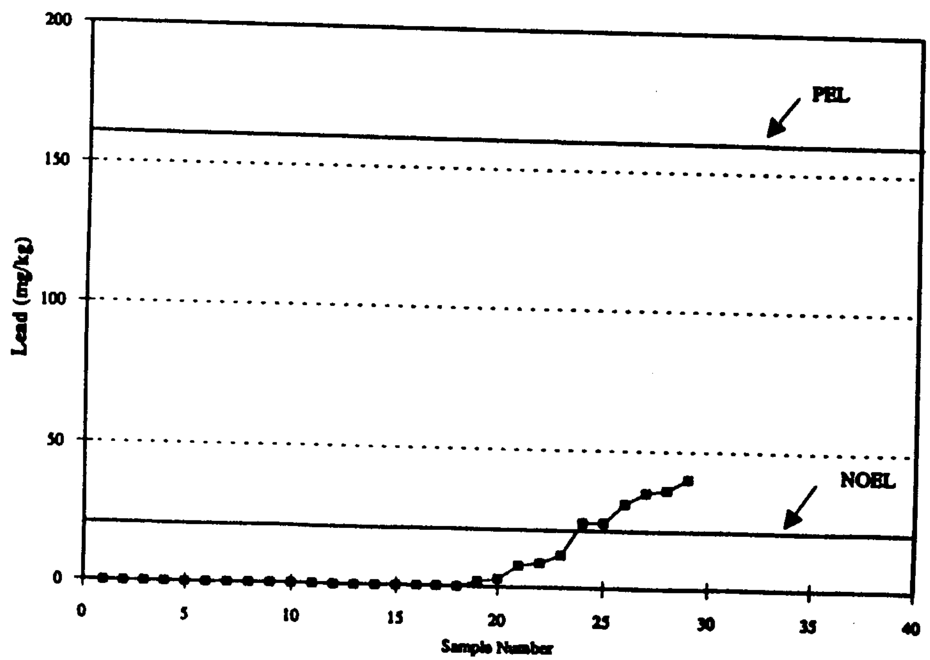
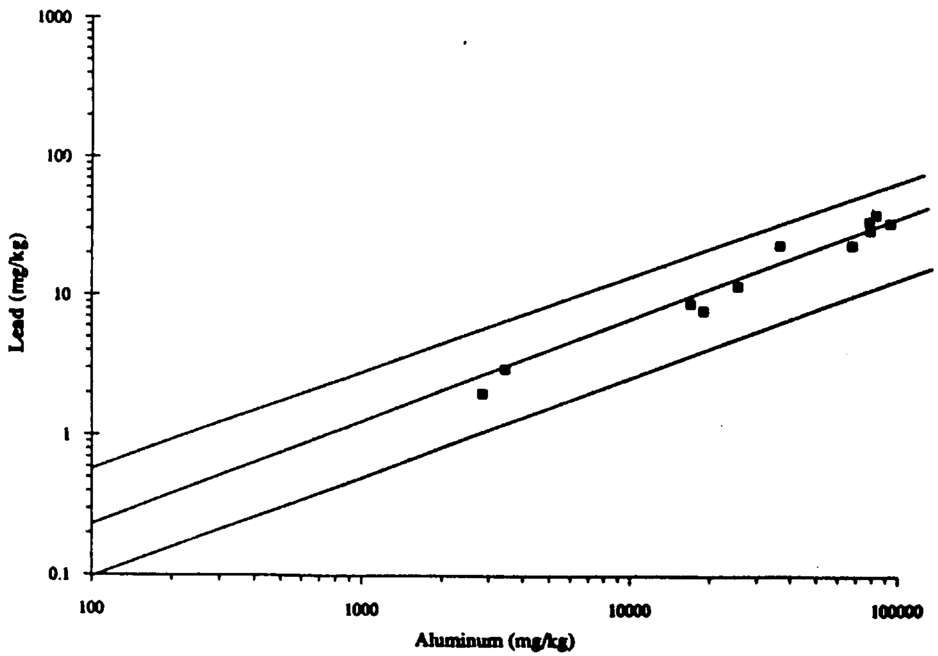


Figure 6. Alum normalized conc of Pb in Apalach Bay sediments.



Intermittent discharges create shock loadings to a water body with the ecological effects depending on complex interactions of many variables. Moreover, most stormwater pollutants become attached to sediment particles or settle quickly, exerting detrimental effects over a long period. Furthermore, stormwater discharges degrade habitat (eg, channel and bank erosion) and cause tremendous siltation, neither of which are detected by water chemistry sampling. Karr et. al. (1986) group environmental factors affecting most aquatic ecosystems into five major classes: chemical variables, biotic interactions, flow regime, habitat structure, and energy source. These factors interact to determine the integrity of water resources reflected by the resident aquatic life. Alterations to the physical, chemical, or biological process can adversely affect the aquatic biota and, therefore, the biological integrity of the water body. Monitoring methods integrating all five classes are necessary to accurately assess and manage surface water quality and aquatic life resources.

Inclusion of biological community monitoring allows a more holistic, systems approach that greatly enhances surface water quality assessment and management. While chemical data reflect short-term conditions that exist when a particular sample is collected, biological communities accurately indicate overall environmental health because they continuously inhabit receiving waters where they integrate a variety of environmental influences - chemical, physical and biological.

Biological assessment involves an integrated analysis of functional and structural components of aquatic communities. Bioassessments are best used to detect aquatic life impairments and assess their relative severity. Once an impairment is detected, additional chemical and biological toxicity testing can identify the causative agent and its source. Both biological and chemical methods play critical roles in successful pollution control and environmental management programs. They are complementary, not mutually exclusive, approaches that enhance overall program effectiveness.

Some advantages of bioassessments are:

1. Biological communities reflect overall ecological integrity (chemical, physical and biological).
2. Over time, biological communities integrate the effects of different stressors, providing a measure of fluctuating environmental conditions.
3. By integrating responses to highly variable pollutant inputs, biological communities provide a practical approach for monitoring stormwater/nonpoint source impacts and the effectiveness of best management practices.
4. Routine monitoring of biological communities can be relatively inexpensive, particularly when compared to the cost of assessing toxic substances.
5. The public is very interested in the status of biological communities as a measure of environmental health.
6. Biological communities offer a practical way to evaluate the habitat degradation typically associated with stormwater discharges.

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Determining Biological Integrity - Rapid Bioassessment Concept: Although the principal goal of the Federal Clean Water Act is to restore and maintain the chemical, physical and biological integrity of the nation's water resources, difficulties in defining an ecological approach to assessing biotic integrity has led regulatory agencies to rely primarily on chemical measurements. However, Karr and Dudley (1981) define biotic integrity as "the ability of an aquatic ecosystem to support and maintain a balanced, integrated, adaptive community of organisms having a species composition, diversity and functional organization comparable to that of the natural habitats within a region". This practical definition is based on measurable characteristics of aquatic communities and comparisons to a regional reference site thus providing a framework for bioassessments.

Recent advances in computer technology and, more importantly, in biological community assessment techniques makes bioassessments more practical. These advances include geographic information systems (GIS) and available digitized data bases, refined laboratory and field methods, development of standard assessment techniques, a practical and useful definition of biological integrity, and the regional reference site concept. These advances provide a framework to incorporate biological community assessments and "biocriteria" into surface water management programs.

In 1985, EPA conducted a survey to identify states that routinely performed biological assessments and to evaluate the field methods being used. A workgroup of state and EPA biologists was formed to review the existing methods and to refine protocols for monitoring benthic macroinvertebrates and fish. In May 1989, EPA published "Rapid Bioassessment Protocols for Use in Streams and Rivers" to which the reader is referred for a more comprehensive discussion of this topic.

The rapid bioassessment protocols (also known as community bioassessment protocols) advocate an integrated assessment, comparing habitat (physical structure and flow regime) and biological measures with empirically defined reference conditions. Reference conditions are established through systematic monitoring of actual sites (ecoregion reference sites) that represent the natural range of variation in "least disturbed" water chemistry, habitat, and biological condition. The concept of ecoregions and ecoregional reference sites is discussed in a July 1989 EPA publication "Regionalization as a Tool for Managing Environmental Resources".

With the publication of these two landmark publications, states began intensive work to refine the ecoregions and protocols to suit local conditions and needs. The state-of-the-art in this rapidly developing field continues to evolve into many more variations. The original authors of the documents strongly advocate customizing both ecoregions and the bioassessment protocols. The most important common element required in these efforts is the use of a scientific approach which can be defended.

Consequently, before this protocol can be used and biological community assessment programs implemented, state specific analyses must be undertaken. This presents many unique challenges, requiring special expertise, adequate funding and several years. For example, state specific subecoregions must be delineated, appropriate ecoregion reference sites selected and sampled, community bioassessment sampling and evaluation methods modified, appropriate biological community metrics selected, and each of these must be verified.

These techniques offer the best means of accurately assessing the impacts of stormwater and other nonpoint sources of pollution. The Florida Bioassessment Project was designed to address many of the above issues to develop a refined bioassessment protocol for use in Florida streams to document impairment from nonpoint sources of pollution and to determine the effectiveness of management programs.

THE FLORIDA STORMWATER/NPS BIOASSESSMENT PROJECTS

In 1990, the Stormwater/Nonpoint Source Management Section of the Florida Department of Environmental Protection began a multi-year effort to refine and enhance current biological community assessment methods. This work consists of four primary components: I. Delineating subecoregions and selecting reference sites; II. Developing standardized biological sampling and habitat assessment methods; III. Evaluating biological data to develop and verify biological metrics and an index of biotic integrity; and, IV. Developing or revising biocriteria. The rest of this paper will discuss program components I through III.

Four contracts, funded by EPA Section 104 (b)(3), 205(j)(1), and 319 grants, are the central focus of this effort:

1. Florida Regionalization Project, contracted to the EPA Environmental Research Lab and to ManTech Environmental Technology, Inc. of Corvallis, Oregon, and led by James Omernik and Glenn Griffith. The two primary tasks included subdividing Florida's three ecoregions into subregions, and selecting and verifying ecoregion reference sites. $160,000. (Component I).
2. Bioassessment for the Nonpoint Source Program, contracted to EA Engineering, Science, and Technology, whose project manager is Mike Bastian, and Tetra Tech, Inc., whose project manager is Mike Barbour. This project's objectives include reviewing and refining DEP's existing biological sampling and analysis procedures; development of standardized stream macroinvertebrate sampling and habitat assessment protocols; testing the protocols by collecting data at candidate reference sites; and, developing candidate biological metrics to quantify the biotic integrity of benthic macroinvertebrates. $236,000. (Components II and III).
3. Development of a Florida Index of Biotic Integrity, contracted to Tetra Tech and Mike Barbour. This project continues the statistical analysis of biomonitoring data being collected from the candidate reference sites and other sites. In particular, the metrics will be refined by further testing and verification of the recommended biological metrics. $122,500. (Component III).

4. Development of a Biological Data Base, contracted to Lori Wolfe Enterprises, a local computer programming firm. $28,500. (Corollary project).

Component I. Delineating Ecoregions and Selecting Reference Sites: Spatial frameworks can profoundly influence the effectiveness of research, assessment, and management of many water resource problems, especially those caused by stormwater and nonpoint sources. Traditionally, we have relied on spatial frameworks based on political boundaries, watersheds, hydrologic units, or physiographic regions. However, these units do not correspond to patterns in vegetation, soils, land surface form, land use, climate, rainfall or other characteristics that control or reflect spatial variations in surface water quality or aquatic organisms.

Effective water quality management programs must recognize the significance of land/water interactions, nonpoint sources, and regional variations in attainable water quality. Water quality assessments need a regional framework to:

1. compare regional land and water patterns;
2. compare ecological and habitat similarities and differences;
3. establish realistic, achievable chemical and biological standards;
4. assess the effects of all pollution sources within a watershed, especially intermittent discharges;
5. predict the effectiveness of management practices;
6. prioritize assessment and management efforts;
7. locate monitoring and special study sites; and
8. extrapolate site-specific information to larger areas.

Omernik (1987) proposed using spatial frameworks based on ecological regions (ecoregions) to assess the health of aquatic systems. Ecoregions are areas of relative homogeneity in ecological systems and relationships between organisms and their environments. Ecoregions usually are defined by patterns of homogeneity in a combination of factors such as climate, physiography, geology, soils, vegetation and dominant land uses. These regions also define areas within which there are different patterns in human stresses on the environment and different patterns in the existing and attainable quality of environmental resources. Ecoregions reflect similarities in the type, quality and quantity of water resources and the factors affecting them. Therefore, regional patterns of environmental factors reflect regional patterns in surface water quality.

Omernik (1987) originally identified 76 ecoregions in the conterminous United States including three in Florida. These ecoregions were useful for stratifying streams in Arkansas, Nebraska, Ohio, Oregon, Washington, and Wisconsin. They were used to set water quality standards in Arkansas, lake management goals in Minnesota, and to develop biocriteria in Ohio. However, in many states, the resolution of the ecoregions was of insufficient detail leading to collaborative projects involving states, EPA regions and the EPA Environmental Research Lab-Corvallis to refine ecoregions and delineate subregions.

Delineating regions or subregions typically involves compiling and reviewing relevant materials, maps and data; outlining the regional characteristics; drafting the regional and subregional boundaries; digitizing the boundary lines, creating digital coverages, and producing maps; and revising after review by state managers and scientists. To delineate subregions in Florida, aerial and satellite images, maps, and other documents were obtained describing environmental characteristics including physiography, geology, soils, climate, land use, vegetation, wetlands, and various biological communities. Analysis of this information led to the definition of the following ecoregions and subregions in Florida (Griffin et. al., 1994):

1. The Southeastern Plains Ecoregion, with three subregions - Southern Pine Plains and Hills, Dougherty/Marianna Plains, and Tifton Upland/Tallahassee Hills
2. The Southern Coastal Plain Ecoregion, with six subregions - Gulf Coast Flatwoods, Southwestern Florida Flatwoods, Central Florida Ridges and Uplands, Eastern Florida Flatwoods, Okefenokee Swamps and Plains, and Sea Island Flatwoods.
3. The Southern Florida Coastal Plain Ecoregion, with four subregions - Everglades, Big Cypress, Miami Ridge and Atlantic Coastal Strip, and Southern Coast and Islands.

Once ecoregions and subregions are delineated and field verified, ecoregion reference sites must be selected. An essential component of the management framework, these sites allow us to evaluate the environmental health of a locale by comparing it to a known reference site - a key concept in Karr and Dudley's definition of biotic integrity, which compares site evaluations to the aquatic community of "natural habitats within a region".

Reference sites must be carefully selected because they will be used for two purposes: (1) Benchmark for establishing regional biocriteria; and, (2) Control sites to which test sites will be compared. The two main criteria for selecting reference sites are that they be minimally impaired and that they represent the region's natural biological community. The ideal reference site will have extensive, natural, riparian vegetation; a diversity of substrate materials; natural physical structures; a natural hydrograph; a representative and diverse abundance of naturally-occurring biological communities; and a minimum of known, human induced disturbances or discharges. General guidelines for selecting reference sites are given in EPA (1989a).

To select stream subecoregion reference sites in Florida, the following steps were taken:

1. Using GIS techniques, information about the general characteristics of each ecoregion and subregion was analyzed to better understand representative conditions. Information reviewed included topographic maps, land use and soil maps, county highway maps, vegetational coverage maps, Landsat imagery, and the 1988 and 1990 Florida Water Quality Assessment 305(b) reports.
2. A set of stream sites with surface watersheds that appear relatively undisturbed and entirely within a subecoregion was chosen in which candidate reference sites were located. The actual number of sites per watershed is a function of the

apparent homogeneity or heterogeneity of the region, the size of the region, hydrologic characteristics, and the number of candidate sites available. Access is a major factor in selection of the final reference sites. The number of candidate sites per subregion varied, ranging from only eight in subregion 75C, the Central Florida Ridges and Uplands where relatively few streams are found, to twenty sites in subregion 75D, the Eastern Florida Flatwoods. A list of the candidate sites was developed that included the subregion, site number, stream name and location, major basin, county, GIS map name, watershed area, and other information.

3. Department and water management district biologists reviewed the information for each candidate site and then conducted site visits. This ground reconnaissance allowed staff to get a sense of the usefulness of the subecoregions, the characteristics that comprise reference sites in each region, the range of characteristics and types of disturbances in each region, and how site characteristics and stream types vary between regions. Using this process, sites were dropped that were found unsuitable because of disturbances not apparent on aerials or maps or because of anomalous situations while additional sites were identified.
4. Aerial reconnaissance was conducted to identify disturbances not observable from the ground, to get a better sense for spatial patterns of disturbances and geographic characteristics in each region, and to photograph typical characteristics, site locations, or disturbances.
5. Over 100 subecoregional candidate reference sites originally were selected by EPA and FDEP biologists. A thorough review process for each site to determine its representativeness and an analysis of available staff hours to conduct bioassessments was performed, reducing the number of sites to 83.

The distribution of reference sites varies among DEP districts as well as among subecoregions. The number of sites in the districts range from three to 30 while the number of subecoregion sites varies from six to 13. This information is summarized below:

Subecoregion	Reference Sites
65F Southern Pine Plains and Hills	8
65G Dougherty/Marianna Plains	6
65H Tifton Upland/Tallahassee Hills	8
75A Gulf Coast Flatwoods	3
75B Southwestern Florida Flatwoods	12
75C Central Fla Ridges & Uplands	8
75D Eastern Fla Flatwoods	10
75E Okefenokee Swamp & Plains	8
75F Sea Island Flatwoods	9

It is important to remember that reference sites represent the least or minimally disturbed ecosystem conditions. All of them have some level of disturbance which is a moving target because of ongoing human activity and natural processes. Since levels of impact are relative on a regional basis, the characteristics of appropriate reference sites will be different in different ecoregions and subregions and for different waterbody and habitat types. It is desirable, therefore, to have a large number of reference sites for each region to help define the different types of streams, to characterize the natural variability within similar stream types, and to clarify the factors that characterize the best sites from factors present in the lower quality sites.

Component II. Developing Standard Biological Assessment Methods: The technical objectives of this component included:

1. Review existing bioassessment protocols used by FDEP's "Point Source Fifth Year Inspection Program" as a template for proposed refinement of protocols for the NPS program.
2. Develop a standardized and cost-effective methodology to (a) collect and process benthic macroinvertebrates collected from Florida streams, and (b) to perform an assessment of habitat conditions.
3. Develop a Standard Operating Procedures Manual (SOP) as a quality assurance/quality control document to provide consistent, standardized methods for sampling freshwater benthic macroinvertebrates and evaluating habitat in rivers and streams.
4. In conjunction with the Ecoregionalization project, design a statewide standardized biological sampling and habitat assessment program to collect data for use in classifying reference streams and in developing the candidate measurements of biotic integrity.
5. Conduct a training program in which FDEP and water management district field biologists discuss and learn the new protocols.

One of the most important aspects of the community bioassessment procedure is the evaluation of stream habitat, which includes physical characteristics and water quality. Since conditions in the watershed determine conditions in the stream, habitat quality is dependent on land use, channel and riparian features as well as instream factors such as substrate types and velocity.

In 1991, the FDEP developed its first habitat evaluation methods (Frydenborg, 1991) based on EPA's Rapid Bioassessment Protocols document. The components of habitat evaluation are: (1) physical/chemical characterization, and, (2) habitat assessment. Physical/chemical characterization includes determining predominant surrounding land uses; identifying local watershed erosion, nonpoint, and point source pollution sources; estimating stream depth, width, high water mark, temperature, and velocity; noting stream alterations such as impoundment or channelization; estimating canopy cover; and evaluating sediment/substrate. Water quality parameters measured include pH, dissolved oxygen, conductivity, and secchi disk depth; and, noting water clarity, color, odors and surface oils.the measurement and observation of land use, riparian zone conditions, channel and substrate features and water quality. Habitat assessment includes evaluating water velocity, substrate

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and cover, channel conditions, bank stability and riparian zone vegetation based on their capacity to support a stable, well balanced benthic community.

Most of the technical objectives of Component II have been achieved (FDEP, 1994b). However, all SOPs continue to be reviewed. Using DEP training funds, DEP's biologists attend quarterly "Biocriteria Committee Meetings" where they participate in workshops, discussions, and field exercises to learn about the bioassessment protocols. Beginning in the summer of 1992, DEP biologists from the Tallahassee and district offices conducted bioassessments, following the procedures set forth in the SOP, at all of the candidate reference sites. Sampling at these sites, and at additional reference sites, has continued on a summer-winter sampling schedule.

Component III. Data Analysis, Development of Metrics and Index of Biotic Integrity: Framework for Habitat Assessments: An analysis of the reference site habitat data was undertaken to (1) characterize the expected or typical condition for habitat parameters in least-disturbed streams and (2) refine the existing habitat evaluation methods. Sites were classified by (1) the aggregate subecoregions (65, 75a, 75bcd, 75ef) identified with the biometrics; (2) their designation as part of a subset of subecoregional sites versus all sites; and, (3) by flow conditions at the time of sampling. It was determined by analysis of the biological data that the aggregate subecoregions were the most appropriate classification scheme to explain variability in the data. Statistical analysis of the data was used to identify the habitat features that have a limited amount of variability and could be used to define the typical condition. The typical conditions, based on one sampling event and only four sampling sites in two subecoregions (75ef), will be modified when the results of additional sampling events are evaluated.

Framework for Biometrics: Metrics allow the ecologist to use meaningful indicator attributes to assess the status of communities in response to perturbation. The definition of a metric is a characteristic of the biota that changes in some predictable way with increased human influence (Barbour et al., in review). By using multiple metrics to assess biological condition, the information available about the elements and processes of aquatic communities is maximized. The validity of an integrated assessment using multiple metrics is supported by the use of measurements of biological attributes firmly rooted in sound ecological principles (Karr et al. 1986; Fausch et al. 1990; Lyons 1992).

The development of appropriate metrics follows a determination of (1) taxa to be sampled, (2) the biological characteristics of reference conditions, and to a certain extent, (3) the anthropogenic influences being assessed. In many situations, multiple stressors impact ecological resources, and specific "cause-and-effect" assessments may be difficult. However, changes in individual metrics or suites of metrics in response to perturbation by certain stressors (or sets thereof) are important diagnostic assessment indicators. For this reason, use of a multimetric approach for evaluating nonpoint source effects upon the biota is a more powerful tool than traditional approaches to bioassessment.

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The basic approach to developing metrics is modeled after EPA's technical guidance for biocriteria (Barbour et al., in review). Candidate metrics are selected based on knowledge of aquatic systems, flora and fauna, literature reviews, and historical data. Candidate metrics are evaluated for efficacy and validity for implementation into the bioassessment program. Less robust metrics, or those not well-founded in ecological principles, are excluded as a result of this research process. Metrics with little or no relationship to stressors are rejected. Core metrics are those remaining that provide useful information in discriminating between good or poor quality ecological conditions. It is important to understand the effects of various stressors on the behavior of specific metrics. Metrics that use the relative sensitivity of the monitored populations to specific pollutants, where these relationships are well-characterized, can be useful as a diagnostic tool. Core metrics should be selected to represent diverse aspects of structure, composition, individual health, or processes of the aquatic biota. Together they form the foundation for a sound, integrated analysis of the biotic condition to judge the attainment of biological criteria. For a metric to be useful, it must have the following attributes: (1) relevant to the biological community under study and to the specified program objectives; (2) sensitive to stressors and provides a response that can be discriminated from natural variation; (3) environmentally-benign to measure in the aquatic environment; and (4) cost-effective to sample and to implement into water resource programs.

To select metrics for Florida streams, a two phase process was used which included an optimization phase, whereby the metrics are evaluated for their relevance and natural variability, and a calibration phase, which is necessary to determine the discriminatory power and sensitivity to perturbation. In the first phase, all potential metrics having relevance to Florida stream macroinvertebrate communities were identified. These metrics were classified into categories roughly corresponding to various elements and processes of the macroinvertebrate assemblage. Categories used for this metric classification corresponded to the following:

A. Richness measures, which signify the relative variety or diversity of the aquatic assemblage.
B. Composition measures, which provide information on the make-up of the assemblage and the relative abundance of particular taxa to the total community.
C. Tolerance measures, which relate to the relative sensitivity or tolerance of the assemblage and component populations to various types of perturbation.
D. Trophic measures, which are surrogates of more complicated processes, such as biotic trophic interaction, production and food source availability. Trophic metrics primarily are related to functional feed group designation and density, both difficult to evaluate. Therefore, these metrics are in an evolutionary status around the country and will continue undergoing refinement.

Selecting Candidate Metrics: From the biological data collected at the candidate reference sites in Summer 1992, a total of 47 metrics were calculated and entered into the data base. These parameters were analyzed using a number of statistical methods including covariate and autocorrelation analysis, analysis of variance, and cluster analysis. Two key graphical displays, scatter plots of physicochemical

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variables versus biological metrics and box-and-whisker plots, were relied on for evaluating site classifications and discriminatory power. All of the 47 metrics fit the condition of biological relevance since they represent elements and processes of the macroinvertebrate assemblage and are thought to change in a predictable fashion in response to perturbation. However, by evaluating the inherent variability within the reference site database, 35 candidate metrics were identified. A highly variable metric would not be useful because the discriminatory power would be diminished. Conversely, a metric that has a narrow variance within a maximum or optimal range for reference conditions would be a useful metric. Box-and-whisker plots of the sites classified by subecoregions were used to depict the natural variability of each metric.

Fourteen of the 35 metrics appear to be appropriate as candidate metrics from this initial evaluation (Table 1). These are the metrics that illustrate a relatively tight range of values among the various subecoregions and are at the high end of their range of values for the reference sites. Four of the metrics are from the richness measures and consist of the Number of Total Taxa, EPT Index, the Number ofChironomidae Taxa, and the Number of Crustacean plus Mollusc Taxa. The Shannon-Wiener Index, Percent Diptera, and Percent Crustaceans and Molluscs are from the composition measures. Candidate metrics from the sensitivity measures are the Florida Index, Percent Class 1 and Class 2 Individuals, the HBI, and Percent Dominant Taxon. Percent Collector-Gatherers, Percent Collector-Filterers, and Percent Shredders are representative trophic measures.

These 14 metrics were evaluated by using them as the basic candidate metrics with which to classify the sites, compare the efficiencies of the collecting gear, and test the discriminatory ability of the metrics. Through these additional analyses, some metrics may be eliminated. The resulting core metrics will then be used to develop an aggregation technique to evaluate the biological condition of the sites.

Metric Classification: Once candidate metrics were identified, analyses was performed to develop a classification system for Florida streams that would aggregate the streams into a small number of classes that could be managed and monitored with similar expectations. The classes should account for significant variation in the biological metric data with classes that do not contribute to the variation explained separated from those that do. Classification analysis was done with the dip net data.

Two classification schemes were tested: ecoregional (geographic) and stream type. Nine subecoregions in two ecoregions were in the area sampled in this program, and several stream types were identified that classify the influence of limestone, silica, and organic matter in the streamwater. Four stream types included in this investigation were sand-bottom streams, calcareous-influenced sand streams (with limestone springs or substrates), swamp-influenced streams (draining swamps and bogs), and alluvial streams (large, broad streams with multiple influences). Only the 14 candidate biological metrics (those that showed promise for discriminating reference from impaired conditions) were used to test the alternative classifications.

Metric Category	Rejected Candidate Metrics	Final Core Metrics	Definition Summary	Response to Increasing Biological Condition
Richness Measures	% Ephemeroptera Taxa # Coleoptera Taxa # Orthocladiinae Taxa # Tanytarsini Taxa	% Total Taxa	Measures overall variety of macroinvertebrate assemblage	↑
		EPT Index	Sum of no. taxa in 3 insect orders: Ephemeroptera, Plecoptera, Trichoptera	↑
		# Chironomidae Taxa	Sum of no. larval midge taxa	↑
		# Crustacean/Mollusc Taxa	Sum of no. calcium-dependent tax	↑
Composition Measures	% Oligochaeta, % Odonata, % Ephemeroptera, % Isopoda, % Trichoptera, % Plecoptera, % Coleoptera, % Gastropoda, % Pelecypoda, % Amphipoda, % Orthoclads to Chironomids % Tanytarsini to Chironomids	Shannon-Wiener Index	Measures general diversity using richness and evenness measures	↑
		% Dominant Taxon	Measures dominance of single most abundant taxon	↓
		% Diptera	Relative abundance of dipterans	↓
		% Crustacean/Mollusc	Relative abundance of crustacean/mollusc	↓
Tolerance Measures	# Class 1 and Class 2 Taxa	Florida Index	Uses abundance and pollution tolerance values for some invertebrates, heavily weighted to arthropods	↑
		% Class 1 and Class 2	Total no. Class 1 and Class 2 individuals/total no. individuals	↑
		Hilsenhoff Biotic Index	Uses abundance and pollution tolerance values for all invertebrates	↓
Trophic Measures	% Scraper/Piercer Taxa % Scrapers, % Predators, Density	% Collector-Gatherers	Relative abundance of this functional feeding group	↓
		% Collector-Filterers	Relative abundance of this functional feeding group	↑
		% Shredders	Relative abundance of this functional feeding group	↑

Table 1 Candidate and Selected Core Metrics

The distributions of values of the 14 candidate metrics were plotted as box-and-whisker plots for each of the nine subecoregions investigated. The consistent pattern that emerged from this analysis was that biological metrics of Florida streams tend to aggregate in three groups: the subecoregions of the Florida panhandle (65f, g, h, and 75a), the subecoregions of peninsular Florida (75b, c, and d), and the two subecoregions in the northeast of Florida (75e and f). Metric values of panhandle streams seem to indicate higher stream quality than in the peninsula. The Florida Index, the EPT index and their components were highest in panhandle streams. The Hilsenhoff Biotic Index, an index of tolerant species, was lowest in panhandle streams. Diversity and taxa richness were slightly higher in panhandle streams. Metric values of peninsular streams indicated lower quality than in the panhandle, but slightly higher than the northeast ecoregions. These last two subecoregions, the Okefenokee Swamps and Plains, and the Sea Islands Flatwoods, seemed to have the lowest stream quality of any of the reference sites. However, only four streams were analyzed from this area, and a larger sample would allow comparisons to be made with more confidence.

There were, however, some differences in metric values among the subecoregions within the aggregated groups. In particular, subecoregion 75a, the Gulf Coast Flatwoods, appears intermediate or transitional between region 65, the Southeastern Plains and the other Southern Coastal Plain subecoregions, 75b, c, and d, with several metrics having intermediate values in subecoregion 75a. The Gulf Coast Flatwoods, subecoregion 75a, receives runoff from subecoregions 65f, g, and h, and has lower topographic relief than ecoregion 65.

A similar graphical analysis of metric values plotted by stream type revealed a much weaker influence of stream type, with only four of thirteen metrics having different values in calcareous and alluvial streams than in sand-bottom streams. Two of the metrics are indicators of the variety and abundance of crustaceans and molluscs, which are expected to be more abundant in calcium-rich waters.

Based on the above analysis, the following classification of Florida streams was recommended:

- Streams of the Florida Panhandle, comprising the Southeastern Plains ecoregion (65f, g, h) and the Gulf Coast Flatwoods (75a).
- Streams of peninsular Florida, comprising the Southwestern Florida Flatwoods (75b), the Central Florida Ridges and Uplands (75c), and the Eastern Florida Flatwoods (75d).
- Streams of northeastern Florida, comprising the Okefenokee Swamps and Plains (75e) and the Sea Island Flatwoods (75f).
- Alluvial streams and rivers that receive inflow from several subecoregions. The alluvial rivers are characterized by a predominance of surface run-off, seasonal fluctuations in water quality and flow and a relatively high sediment load.

The above classification must be considered preliminary because of small sample size in several subecoregions and classes. Therefore, the following caveats apply:

- Subecoregion 75a, the Gulf Coast Flatwoods, may be different from the other panhandle subecoregions, but a larger sample (more sites) is needed to verify or refute its affinity to the other panhandle subecoregions.
- Subecoregions 65g, 75c, 75e, and 75f, and the alluvial class, are all under-represented in the data set (N = 2 to 4), and any conclusions regarding these are tentative.

Each of the three major groups is also a contiguous geographic region (panhandle, peninsula, and northeast), with observable physical and chemical differences between the three regions. The observed regional biological differences are partly related to acid-base chemistry of the regions. Peninsula Florida is dominated by limestone bedrock, and surface and ground waters are typically well-buffered. Water in the panhandle and northeastern Florida are more often poorly-buffered or acidic. Relationships between ambient pH and several metric values are seen and can be explained by strong correlations between certain faunal groups and water with a certain pH.

Metric Calibration: The candidate metrics were then calibrated through an evaluation of both reference and impaired sites. The ability of a metric to discriminate between a reference and a known impaired site is essential if the metric is to be useful for monitoring and assessment purposes.

Data from the Florida DEP's Point Source Program were used to evaluate the performance of metrics at impaired sites and to determine their ability to discriminate between "good" and "bad" biological condition. Sites in this point source program were either upstream or downstream of known point source dischargers. Many of the upstream control sites in the point source program were not necessarily good reference sites, because of habitat degradation or some other reason. Two considerations in using the point source data are that although the season of collection was the same as that of the reference sites, some point source data were collected the previous year; and the methods used in the point source program were similar, but not identical in all respects to those employed in the nonpoint source program. However, these considerations did not prevent integration of the data from the two programs to evaluate discriminatory ability.

The evaluation and judgement of the core metrics concluded that five of the metrics, the EPT Index, Number of Total Taxa, Shannon-Wiener Index, Florida Index, and Percent Filterers, were relatively strong in discriminating impairment. Two metrics—the Number of Chironomidae Taxa and Percent Gatherers—were not useful at all in discriminating between reference and impaired sites. It was recommended that these two metrics be removed from the suite of core metrics, pending analysis of additional data.

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A corollary study was performed to compare biological sampling methods to determine whether (1) Hester-Dendy artificial substrate samplers provide data representative of stream biological status, and (2) whether dip nets or Hester-Dendy's are more powerful for detecting biological impairment. Results from statistical analysis of metrics suggest that dip net data are as good or somewhat better than Hester-Dendy data in distinguishing biological impairment in Florida streams. These results, together with the fact that use of a Hester-Dendy is more labor intensive and costly, support the use of dip net collections as the primary macroinvertebrate collecting gear for the NPS monitoring program in Florida.

Florida Index Development: The stream invertebrate index for Florida was developed by aggregating the metrics that proved responsive to independent measures of impacts. Aggregation simplifies management and decision-making so that a single index value is used to determine whether action is needed. The exact nature of the action needed (e.g., restoration, mitigation, enforcement) is not determined by the index value, but by analysis of the component metrics. The approach used to define a Florida index was to develop expectations for the values of each of the metrics from the reference data set, and to score metrics according to whether they are within the range of reference expectations. Metrics within the range receive a high score, those outside receive a low score. The index value is then the sum of the metric scores. The index is further normalized to reference condition, such that the distribution of index values in the reference sites forms the expectations for the region.

In an assessment, streams can be judged for impairment based on the summed index value. If the index value is below a criterion, then the stream is judged impaired. The index value criterion is based on the index value distribution in reference streams; for example, the 25th percentile (lower quartile) of reference expectations is commonly used. Reference sites had been carefully selected to be representative of least impacted conditions in each ecoregion, and investigators involved in site selection and sampling were confident that the reference sites represented best available conditions in Florida streams. Therefore, the lower quartile of each metric distribution in reference sites was selected as the criterion for the minimum value of the metric representative of reference conditions. Thus, any metric value above the lower quartile of the reference distribution received the highest possible score. Using this rationale, scoring criteria were developed which are a modification of the methodology of Karr et al.(1986; Karr 1991). Using the scoring criteria, a stream invertebrate index for Florida was calculated in three different ways as alternatives for optimizing the index.

- All metrics summed.
- As above, but with the Shannon-Wiener Index removed since it is strongly correlated with the Percent of Dominant Taxon as well as with Total Number of Taxa and, therefore, may be redundant with these.
- As above, but with all weak metrics removed. Weak metrics are those with limited ability to discriminate between reference and impaired conditions.

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All three versions of the index were able to discriminate between reference and impaired conditions better than the individual metrics. Removing the Shannon-Wiener Index does not affect discrimination ability, nor does removing the weaker metrics.

The recommended stream invertebrate index for Florida is: (1) to remove the Shannon-Wiener Index because of its redundancy with the Number of Taxa and the Percent of the Dominant Taxon, and its inclusion does not improve the resolution; but (2) to retain the weaker metrics because their correlations with other metrics are not strong (thus they are independent measures), and because they may respond to stressors not represented in the point-source data set. The list of core metrics that compose the stream invertebrate index are: Number of Total Taxa, EPT Index, % Dominant Taxon, % Diptera, Florida Index, % Filterers, and, % Shredders in the Panhandle (Ecoregions 65, 75a) and in the Peninsula (Ecoregions 75b, c, d), with # Crustacean/Mollusc Taxa and % Crustacean/Mollusc added in the Peninsula.

All of these metrics will be re-evaluated with a more complete data set of impaired streams and in different seasons.

DISCUSSION AND CONCLUSIONS

Adding sediment and biological community assessments to traditional water quality monitoring and evaluation approaches greatly enhance the ability of these tools to ascertain the environmental effects of stormwater discharges. The importance of this biological assessment framework in accurately assessing the environmental health of surface waters is seen by comparing Ohio's use attainment conclusions. The Ohio Environmental Protection Agency incorporated biocriteria into its water quality standards regulations in recent years (Yoder, 1989). These biocriteria are based on a system of tiered aquatic life uses representing five classes. These include coldwater habitat, warmwater habitat, exceptional warmwater habitat, modified warmwater habitat and limited resource waters. These designations have been qualitatively defined in ecological terms, and chemical criteria, either quantitative or narrative, have been established for each. Using both the water chemistry and bioassessment data, conclusions about the attainment of beneficial uses in Ohio water bodies include (EPA, 1989a):

- Based on chemical data, 52% of the segments fully attained aquatic life uses;
- Based on biosurvey data, only 23% achieved full attainment;
- The two types of assessment agreed on full attainment in 17% of the cases with overall agreement on 46% of the cases;
- In 35% of the cases, chemical data indicated full attainment but biosurvey data indicated partial or non-attainment. In nearly half of these cases, impairments were due to habitat or flow modifications, or siltation.

Unfortunately, as can be seen from the activities described in this paper, conducting the preliminary technical analyses that are essential to establish the scientific rationale

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for these assessment tools is not easy, quick, nor inexpensive. Ultimately, the goal of these efforts is to develop quantitative biocriteria which can be used to more effectively assess, manage and evaluate stormwater/NPS pollution sources and management efforts. Metrics reflecting community characteristics may be considered appropriate in biocriteria programs if their relevance can be demonstrated, response range is verified and documented, and the potential for application in water resource programs exists. However, before the FDEP can adopt biocriteria, lots more work must be done to further refine, calibrate and evaluate the biometrics. Frequent evaluation of metrics and indices is an essential feature of the use of biocriteria. However, once established, the multimetric approach for assessing biological condition offers the following attributes: (1) relies on information about several populations or species assemblages, rather than just target species; (2) relates to a community-level potential or expectation based on a reference condition; (3) uses multiple metrics to function as surrogate measures of more complicated elements and processes; and (4) incorporates ecological principles that enable an interpretation of exposure/response relations.

Sediment assessment, together with watershed characterization and mapping of pollution sources, can be used to screen watersheds and sub-basins to determine potential "hot spots". Bioassessment and water chemistry sampling can then be done to assess the actual health of the aquatic system in these locations. The initial focus of a bioassessment should be on habitat quality. Based on a regional reference, the habitat at an impacted site may be equal to or less than the desired quality for that particular system. If the habitat at the impact site and reference are equal, then a direct comparison of biological condition can be made. If the habitat at the impact site is lower in quality than the reference, the habitat potential should be evaluated as a first step. A site-specific control may be more appropriate than a regional reference for an assessment of an impact site. If so, then care must be taken in selecting an appropriate site-specific reference site to assure that its habitat and sediment characteristics are representative for the area. Once a determination of the appropriate reference site type is made, possible outcomes of the bioassessment are: (1) no biological effects; (2) effects due to habitat degradation; (3) effects due to sediment or water quality; or (4) effects due to a combination of sediment, water quality and habitat degradation.

The projects described in this paper greatly contributed to the development, refinement, calibration, and testing of several essential sediment and biological community assessment tools in Florida. The Department is anxious to begin using these tools to better assess the effects of intermittent pollutant sources, evaluate the effectiveness of BMPs and management programs, prioritize watersheds and subbasins for management activities, and, in conjunction with the water management districts, to develop and implement the stormwater pollutant load reduction goals (PLRGs) required by State Water Policy and being established through the state's Surface Water Improvement and Management Program. The sediment and biological community assessment methods, in conjunction with the recently started effort by the

Department to receive delegation of EPA's NPDES permitting program and a future initiative for basin wide monitoring, permitting, and compliance, provide the technical and institutional tools needed to cost-effectively reduce stormwater/NPS pollutant loadings on a watershed basis.

However, before these initiatives can be fully implemented, even more analysis and evaluation needs to be done to refine the assessment methods. For the NPS bioassessment program, issues still to be resolved include (FDEP, 1994b):

1. Test the level of subsampling to improve the integrity of the data. The level of subsampling is presently set at 100 organisms. However, only a small portion of the entire sample is processed to obtain 100 organisms. The subsampling levels of 100-, 200-, and 300-organisms need to be tested for appropriateness with a cost/analysis benefit performed following the power-cost efficiency (PCE) procedure of Ferraro et al. (1989). The PCE should provide the best compromise between the least costly subsampling effort (100-organism) and the most rigorous (300-organism).
2. Evaluate the winter index period to validate both the site classification and suite of metrics for assessment and monitoring during that season. The present analyses are relevant only to the first collection of the summer index period. It is probable that the present site classification and core metrics would not be altered significantly for the winter data set, but this supposition needs to be tested. In addition, subsequent summer and winter datasets collected in 1993 and 1994 should be incorporated into the analysis. The FDEP recently obtained a Section 104(b)(3) grant from EPA that will allow these analyses to be performed by Tetra Tech.
3. Validate the classification of 65g, 75a, 75e, and 75f. These subecoregions are under-represented by reference sites. An evaluation of their classification could be improved with the sampling of additional sites. A collaboration with the neighboring states of Georgia and Alabama may be instrumental in increasing the sample size of the sites. A greater portion of the subecoregions of 65g, 75e, and 75f are in those neighboring states.
4. Evaluate the Hilsenhoff Biotic Index (HBI) as a sensitivity measure. The HBI was evaluated as part of the present data analyses. However, too many assumptions had to be made regarding the tolerance assignment to the various taxa. Logically, the HBI should be more meaningful than similar measures in assessing biological condition, because the index incorporates information from the whole assemblage. The proper assignment of tolerance scores should be addressed and the efficacy of the HBI metric re-evaluated. Similarly, tolerance assignments should address a broader range of pollutants.
5. Conduct habitat evaluations at reference and habitat-limited sites to determine the resolving power of the habitat parameters along a gradient of impact. This kind of analysis has been done for the biometrics using macroinvertebrate data from point source impact studies. Sites with nonpoint source habitat limitations e.g., erosion, deforestation. etc. should be included and the evaluation will require site-

specific chemical analyses to separate chemical and physical limitations to the biota.

6. Develop a software program to handle the storage, sorting, and analysis of the biological and habitat data. For the department to successfully implement the bioassessment program, a "user-friendly" program should be developed. A contractor has been hired to review the current Florida DEP computer programs for handling specific biological data sets and to modify them to include the present suite of metrics and assessment approach.

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Water Quality Trends from Stormwater Controls

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__Abstract__

The detection of changes in pollutant levels over time is an important objective of many environmental monitoring programs. This is especially true in stormwater pollution control. In some areas, a great deal of money has been spent to reduce stormwater discharges of pollutants (both urban and rural), and there is much pressure to demonstrate improvements in water quality. Trend analyses can be an important and powerful tool in demonstrating the benefits of stormwater pollution control. Unfortunately, lack of data, or poorly designed data gathering efforts, greatly hinder the use of this technique. This paper will describe several trend analysis tools and the types of data needed for their implementation. It will also present a case study showing water quality benefits in a lake associated with the implementation of an innovative stormwater control program.

__Introduction__

A full-scale plant, using the Karl Dunkers system for treatment of separate stormwater and lake water, has been operating since 1981. The treatment facility is located in the northern part of Lake Rönningesjön, near Stockholm, Sweden. Excess flows are temporarily stored before treatment. Stormwater is pumped to the treatment facility during rains, with excess flows stored inside in-lake flow balancing tanks (the Flow Balancing Method, or FBM). The treatment system consists of a chemical treatment system designed for the removal of phosphorus and uses ferric chloride precipitation and crossflow lamella clarifiers. The stormwater is pumped from the flow balancing storage tanks to the treatment facility. Lake water is also pumped to the treatment facility during dry periods, after any excess stormwater is treated.

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The FBM and the associated treatment system significantly improved lake water quality through direct treatment of stormwater and by pumping lake water through the treatment system during dry weather. The annual average removals of phosphorus from stormwater and lake water by the ferric chloride precipitation and clarification treatment system were 66 percent, while the annual average total lake phosphorus concentration reductions averaged about 36 percent.

Statistically Based Trend Analyses

Several publications have excellent descriptions of statistical trend analyses for water quality data. In addition to containing detailed descriptions and examples of experimental design methods to determine required sampling effort, Gilbert (1987) devotes a large portion of his book to detecting trends in water quality data and includes the code for a comprehensive computer program for trend analysis.

Reckhow and Stow (1990) present a comprehensive assessment of the effectiveness of different water quality monitoring programs in detecting water quality trends using EPA STORET data for several rivers and lakes in North Carolina. They found that most of the data (monthly phosphorus, nitrogen, and specific conductance values were examined) exhibited seasonal trends and inverse relations with flow. Some of the data also exhibited autocorrelation. The remaining random variation (considering the correlations) was then used to determine the number of monthly samples needed for a given power (β) and significance (α). In many cases, large numbers of samples would be needed to detect changes of 25 percent or less (typical for stormwater retro-fitting activities).

Uri (1991) used the Box and Jenkins model to examine trends in sediment loadings to a portion of the Iowa River. The sediment loadings more than doubled in the years from 1948 to 1985. They also presented a method to examine factors causing this trend. They found a strong cause-and-effect relationship between acreage planted in soy beans and corn. For each 1 percent increase in planted area for either of these two crops, a sediment load increase of about 0.4 percent was likely.

Reckhow, *et al.* (1992) prepared a detailed manual presenting nonparametric analysis methods for examining water quality trends in lake waters. The manual presents a brief summary of basic concepts and approaches in applied statistics, followed by discussions of hypothesis testing and common assumptions for statistical tests. The manual contains detailed examples of lake and watershed wide water quality trend analyses. SAS macros are included to efficiently evaluate water quality trends.

Spooner and Line (1993) present recommendations for monitoring requirements in order to detect trends in receiving water quality associated with nonpoint source pollution control programs, based on many years experience with the Rural Clean Water Program. These recommendations, even though derived from rural experience, should also be very applicable for urban receiving water trend analyses. The following is a general list (modified) of their recommended data needs for associating water quality trends with land use/treatment trends:

- Appropriate and sufficient control practices need to be implemented. A high level of participation/control implementation is needed in the watershed to result in a substantial and more easily observed water quality improvement. Controls need to be used in areas of greatest benefit (critical source areas, or in drainages below major sources) and most of the area must be treated.

- Control practice and land use monitoring is needed to separate and quantify the effects of changes in water quality due to the implemented controls by reducing the statistical confusion from other major factors. Monitor changes in land use and other activity on a frequent basis to observe temporal changes in the watershed. Seasonal variations in runoff quality can be great, along with seasonal variations in pollutant sources (monitor during all flow phases, such as during dry weather, wet weather, cold weather, warm weather, for example). Collect monitoring data and implement controls on a watershed basis.

- Monitor the pollutants affecting the beneficial uses of the receiving waters. Conduct the trend analyses for pollutants of concern, not just for easy, or convenient, parameters.

- Monitor for multiple years (at least 2 to 3 years for both pre- and post-control implementation) to account for year-to-year variability. Utilize a good experimental design, with preferable use of parallel watersheds (one must be a control and the other undergoing treatment).

Other water quality trend analysis references contained in Uri (1991) include Box and Jenkins (1970), Hipel and McLeod (1989), Hipel, *et al.* (1988), Hirsch (1988), Hirsch and Slack (1984), and Taylor and Loftis (1989). Reckhow, *et al.* (1992) also listed the following applicable references: Berryman, *et al.* (1988), Hirsch, et al. (1982), Lettenmaier (1976), and Montgomery and Loftis (1987).

Preliminary evaluations before trend analyses are used

Gilbert (1987) illustrates several sequences of water quality data that can confuse trend analyses. It is obviously easiest to detect a trend when the trend is large and the random variation is very small. Cyclic data (such as seasonal changes) often are confused as trends when no trends exist (type 1 error) or mask trends that do exist (type 2 error) (Reckhow and Stow 1990; Reckhow 1992). Three data characteristics need to be addressed before the data can be analyzed for trends because of confusing factors. These include:

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• Measure data correlations, as most statistical tests require uncorrelated data. If data are taken close together (in time or in location), they are likely partially correlated. As an example, it is likely that a high value is closely surrounded by other relatively high values. Close data can therefore be influenced by each other and do not provide unique information. This is especially important when determining confidence limits of predicted values or when determining the number of data needed for a trend analyses (Reckhow and Stow 1990). Test statistics developed by Sen can use dependent data, but they may require several hundred data observations to be valid (Gilbert 1987).

• Remove any seasonal (or daily) effects, or select a data analysis procedure that is unaffected by data cycles. The nonparametric Sen test can be used when no cycles are present, or if cyclic effects are removed, while the seasonal Kendall test is not affected by cyclic data (Gilbert 1987).

• Identify any other likely predictable effects on concentrations and remove their influence. Normally occurring large variations in water quality data easily mask commonly occurring subtle trends. Typical relations between water quality and flow rate (for flowing water) can be detected by fitting a regression equation to a concentration vs. flow plot. The residuals from subtracting the regression from the data are then tested for trends using the seasonal Kendall test (Gilbert 1987).

Reckhow (1992) presents a chart listing specific steps that need to be taken to address the above problems. These steps are as follows:

(1) Check the data for deterministic patterns of variability (such as concentration versus flow by using graphical and statistical methods). If deterministic patterns exist, subtract the modeled pattern from the original data, leaving the residuals for subsequent seasonality analyses.

(2) Examine the remaining residuals (or data, if no deterministic patterns exist) for seasonal (can be short period, such as daily) variations. Again use graphical and statistical methods. If "seasonality" exists, subtract the modeled seasonality from the data (residuals from #1 above), leaving the remaining residuals for subsequent trend analyses.

(3) Conduct the trend analysis on the residuals from #2 above, using the standard seasonal Kendall test . If a trend exists, subtract the trend, leaving the remaining residuals for subsequent autocorrelation analyses.

(4) Test the remaining residuals from #3 above (or the raw data, if no deterministic or cyclic patterns or trends were found) for autocorrelation. If the autocorrelation is significant, re-evaluate the trends using an autocorrelated-corrected version of the seasonal Kendall (or regular Kendall) test. If no autocorrelation was found, use the standard seasonal Kendall test if seasonality was identified, or the

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standard Kendall test if no seasonality was identified. The final residual variation is then used (after correcting for autocorrelation) in calculating the required number of samples needed to detect trends for similar situations.

Statistical methods available for detecting trends

Graphical methods. Several sophisticated graphical methods are available for trend analyses that use special smoothing routines to reduce short-term variations so the long-term trends can be seen (Gilbert 1987). In all cases, simple plots of concentrations versus time of data collection should be made. This will enable obvious data gaps, potential short-term variations, and distinct long-term trends to be possibly seen.

Regression methods. A time-honored approach in trend analysis is to perform a least-squares linear regression on the quality versus time plot and to conduct a *t* test to determine if the true slope is not different from zero (Gilbert 1987). However, Gilbert (1987) points out that the *t* test can be misleading due to cyclic data, correlated data, and data that are not normally distributed.

Mann-Kendall test. This test is useful when missing data occur (due to gaps in monitoring, such as if frozen waters occur during the winters, equipment failures, or when data are reported as below the limit of detection). Besides missing data, this test can also consider multiple data observations per time period. This test also examines trends at multiple stations (such as surface waters and deep waters, etc.) and enables comparisons of any trends between the stations. This method also is not sensitive to the data distribution type. This test can be considered a nonparametric test for zero slope of water quality versus time of sample collection (Gilbert 1987). Short-term (such as seasonal changes) cycles and other data relationships (such as flow versus concentration) affect this test and must be corrected. If data are highly correlated, then this test can be applied to median values in each discrete time groupings.

Sen's nonparametric estimator of slope. Being a nonparametric test based on ranks, this method is not sensitive to extreme values (or gross data errors) when calculating slope (Gilbert 1987). This test can also be used when missing data occur in the set of observations. It is closely related to the Mann-Kendall test.

Seasonal Kendall test. This method is preferred to most regression methods if the data are skewed, serially correlated, or cyclic (Gilbert 1987). This test can be used for data sets having missing values, tied values, censored values (less than detection limits) or single or multiple data observations in each time period. The testing of homogeneity of trend direction enables one to determine if the slopes at different locations are the same, when seasonality is present. Data correlations (such as flow versus concentration) and dependence also affect this test and must be considered in the analysis.

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The code for the computer program contained in Gilbert (1987) computes Sen's estimator of slope for each station-season combination, along with the seasonal Kendall test, Sen's aligned test for trends, the seasonal Kendall slope estimator for each station, the equivalent slope estimator for each season, and confidence limits on the slope.

Watershed Characteristics and Treatment System

Lake Rönningesjön is located in Täby, Sweden, near Stockholm. Figure 1 shows the lake location, the watershed, and the surrounding urban areas. The watershed area is 650 ha, including Lake Rönningesjön itself (about 60 ha), and the urban area that has its stormwater drainage bypassing the lake (about 175 ha). The effective total drainage area (including the lake surface) is therefore about 475 ha. Table 1 summarizes the land use of the lake watershed area. About one-half of the drainage area (including the lake itself) is treated by the treatment and storage operation.

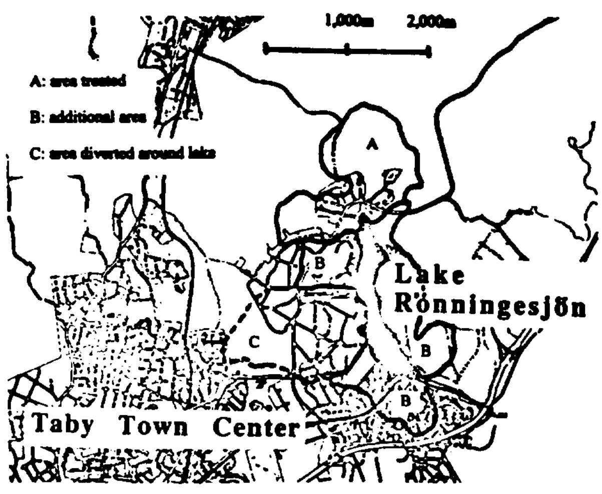

Figure 1. Lake Rönningesjön watershed in Täby, Sweden.

Table 1. Lake Rönningesjön Watershed Characteristics

	Area Treated	Additional Area	Total Area
urban	50 ha	100 ha	150 ha (32%)
forest	75 ha	80 ha	155 ha (32%)
agriculture	65 ha	45 ha	110 ha (23%)
lake surface	60 ha		60 ha (13%)
total drainage	250 ha	225 ha	475 ha (100%)

The lake volume is about 2,000,000 m^3 and has an annual outflow of about 950,000 m^3. The estimated mean lake resident time is therefore slightly more than two years. The average lake depth is 3.3 m. It is estimated that the rain falling directly on the lake surface itself contributes about one-half of the total lake outflow.

The treatment process consists of an in-lake flow balancing storage tank system (the Flow Balancing Method, or FBM) to contain excess stormwater flows which are pumped to a treatment facility during dry weather. The treatment facility uses ferric chloride and polymer precipitation and crossflow lamella clarifiers. Figure 2 illustrates the layout of the FBM, the treatment facility, and the lake discharge in the northern end of Lake Rönningesjön. Figure 3 shows the cross-section of the FBM in the lake. It is make of plastic curtains forming the cell walls, supported by floating pontoons and anchored to the lake bottom with weights.

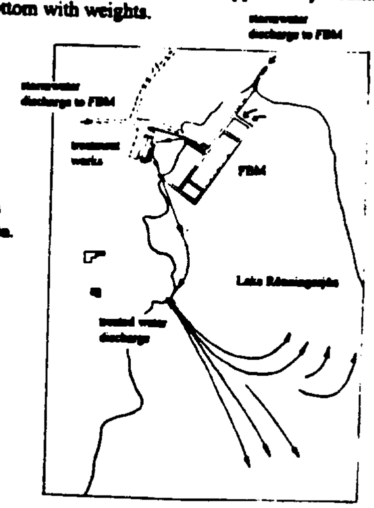

Figure 2. Treatment system layout in Lake Rönningesjön.

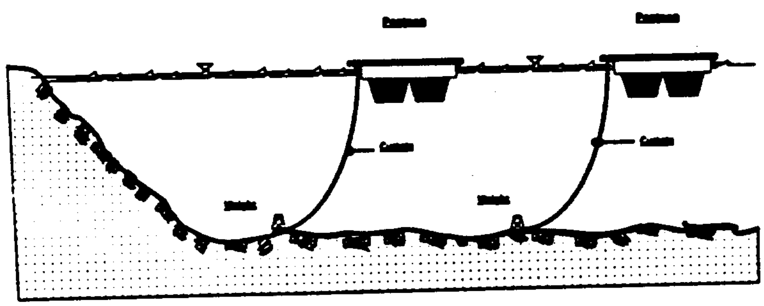

Figure 3. Cross-section of FBM in-lake tanks.

Figure 4 shows that the FBM provides storage of contaminated water by displacing clean lake water that enters the storage facility during dry weather as the FBM water is pumped to the treatment system. All stormwater enters the FBM directly (into cell A). The pump continuously pumps water from cell A to the chemical treatment area. If the stormwater enters cell A faster than the pump can remove it, the stormwater flows through curtain openings (as a slug flow) into cells B, C, D, and finally E, displacing lake water (hence the term flow balancing). As the pump continues to operate, stormwater is drawn back into cell A and then to the treatment facility. The FBM is designed to capture the entire runoff volume of most storms. The Lake Rönningesjön treatment system is designed to treat water at a higher rate than normal to enable lake water to be pumped through the treatment system after all the runoff is treated.

The FBM is mainly intended to be a storage device, but it also operates as a wet detention pond, resulting in sedimentation of particulate pollutants within the storage device. The first two cells of the FBM facility at Lake Rönningesjön were dredged in 1991, after 10 years of operation, to remove about one meter of polluted sediment.

The treatment flow rate is 60 m^3/hr (about 0.4 MGD). The ferric chloride feed rate is about 20 to 35 grams per cubic meter of water. About 30 m^3 of thickened sludge is produced per day for co-disposal with sludge produced at the regional sanitary wastewater treatment facility. The annual operating costs are about $28,000 per year (or about $0.03 per 100 gallons of water treated), divided as shown in Table 2.

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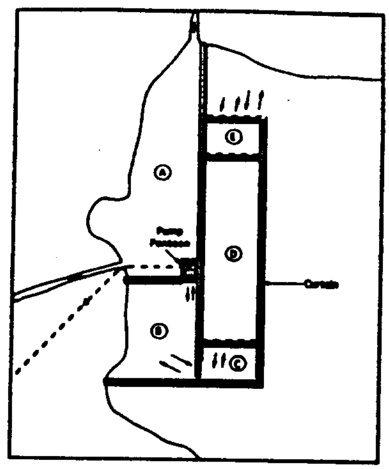

Figure 4. Flow pattern in FBM.

Table 2. Stormwater Treatment System Operating Cost Breakdown

chemicals	26%
electricity	8
sludge transport	3
labor	41
sampling and analyses	22

From 1981 through 1987, the FBM operated an average of about 5500 hours per year (about 7.6 months per year), treating an average of about 0.33 million m^3 per year. The treatment period ranged from 28 to 36 weeks (generally from April through November). The FBM treatment system treated stormwater about 40% of its operating time and lake water about 60% of its operating time. The FBM treatment system directly treated about one-half of the in-flowing waters to the lake (at a level of about 70% phosphorus removal).

Lake Rönningesjön and Treatment System Phosphorus Budgets

Two tributaries flow directly to the treatment facility. Excess flows (exceeding the treatment plant flow capacity) are directed to the FBM in the lake. As the flows in the tributaries fall below the treatment plant capacity, pumps in the FBM deliver stored stormwater runoff for treatment. When all of the stormwater is pumped from the FBM, the pumps deliver lake water for treatment. Tables 3 and 4 summarize the runoff and lake volumes treated and phosphorus removals during the period of treatment.

Table 3. Water Balance for Treatment System (m^3)

	From Trib. A	From Trib. B	Total Stormwater	From Lake	Total treated and discharged	Stormwater, % of total treated
1981	185,100	101,100	286,200	121,600	407,700	70
1982	112,700	41,000	153,700	238,700	391,900	39
1983	14,400	6,400	20,800	250,000	271,000	8
1984	122,000	53,000	175,000	95,000	270,000	65
1985	96,600	46,500	143,100	149,000	292,400	49
1986	216,000	86,000	302,000	48,000	350,000	86
1987	243,000	97,000	340,000	13,000	353,000	96
1988	26,200	19,300	45,500	186,300	231,800	20
1989	24,900	19,900	44,800	267,700	312,500	14
1990	12,160	8,336	20,490	201,270	221,760	9
1991	11,610	7,780	19,390	121,730	141,120	14

Table 4. Phosphorus Treatment Mass Balance (kg)

	From Trib. A	From Trib. B	From Lake	Total to treatment	P discharged to Lake	P removal	% removal
1981	20.3	16.8	10.2	47.3	13.6	33.7	71.2
1982	8.0	8.0	18.0	34.0	12.8	21.2	62.4
1983	1.5	2.5	20.0	24.0	11.0	13.0	54.2
1984	10.0	9.5	3.0	22.5	10.0	12.5	55.6
1985	7.1	5.9	2.1	15.1	4.3	10.8	71.5
1986	15.2	21.4	3.7	40.3	5.1	35.2	87.3
1987	18.6	7.5	1.7	27.8	4.3	23.5	84.5
1988	1.7	2.3	9.2	13.2	6.1	7.1	53.8
1989	1.7	1.4	14.1	17.2	7.6	9.6	55.8
1990	1.3	0.3	10.5	12.1	3.7	8.4	69.4
1991	7.7	9.8	5.6	23.1	8.9	14.2	61.5

There have been highly variable levels of phosphorus treatment from stormwater during the period of operation. 1988 through 1990 had low phosphorus removals. These years had relatively mild winters with substantial stormwater runoff occurring during the winter months when the treatment system was not operating. Normally, substantial phosphorus removal occurred with spring snowmelt during the early weeks of the treatment plant operation each year. The greatest phosphorus improvements in the lake occurred during the years when the largest amounts of stormwater were treated.

The overall phosphorus removal rate for the 11 years from 1981 through 1991 was about 17 kg/year. About 40% of the phosphorus removal occurred in the FBM from sedimentation processes, while the remaining occurred in the chemical treatment facility. This phosphorus removal would theoretically cause a reduction in phosphorus concentrations of about 10 µg/L per year in the lake, or a total phosphorus reduction of about 100 µg/L during the data period since the treatment system began operation. About 70% of this phosphorus removal was associated with the treatment of stormwater, while about 30% was associated with the treatment of lake water.

Observed Long-Term Lake Rönningesjön Water Quality Trends

Lake Rönningesjön water quality has been monitored since 1967 by the Institute for Water and Air Pollution Research (IVL); the University of Technology, Stockholm; the Limnological Institute at the University of Uppsala; and by Hydroconsult Corp. Surface and subsurface samples were obtained at one or two lake locations about five times per year. In addition, the tributaries being treated, incoming lake water, and discharged water, were all monitored on all weekdays of treatment plant operation. The creek tributary flow rates were also monitored using overflow weirs.

The FBM started operation in 1981. Based on the hydraulic detention time of the lake, several years would be required before a new water quality equilibrium condition would be established. A new water quality equilibrium will eventually be reached after existing pollutants are reduced from the lake water and sediments. The new water quality conditions would be dependent on the lake flushing rate (or detention time, estimated to be about 2.1 years), and the new (reduced) pollutant discharge levels to the lake. Without lake water treatment, the equilibrium water quality would be worse and would take longer to obtain.

Figure 5 is a plot of all chlorophyll *a* data collected at both the south and north sampling stations. Very little trend is obvious, but the wide swings in chlorophyll *a* values appeared to have been reduced after the start of stormwater treatment. Figure 6 is a three-dimensional plot of smoothed chlorophyll *a* data, indicating significant trends by season. The values started out relatively low each early spring and dramatically increased as the summer progressed. This was expected and was a function of algal growth. Homogeneity, seasonal Kendall and Mann-Kendall statistical tests (Gilbert 1987) were conducted using the chlorophyll *a* data. The homogeneity test was used to determine if any trends found at the north and south sampling stations were different. The probabilities that the trends at these two stations were the same were calculated as follows:

	χ^2	Probability
season	14.19	0.223
station	0.00001	1.000
station-season	0.458	1.000
Trend	21.64	0.000

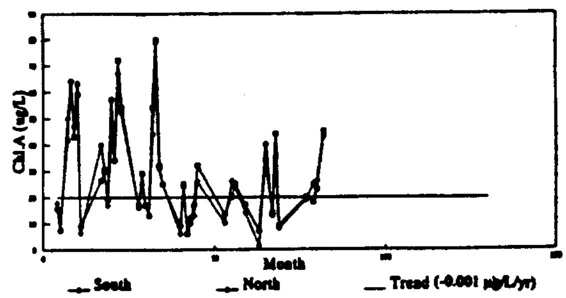

Figure 5. Chlorophyll *a* observations with time (μg/L)

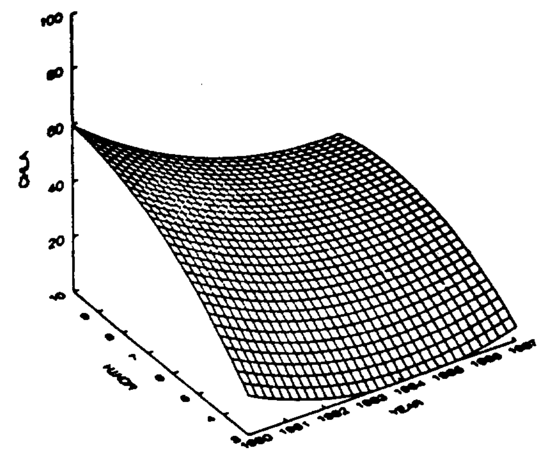

Figure 6. Chlorophyll *a* trends by season and year (μg/L).

This test shows that the trend was very significant (P<0.001) and was the same at both sampling stations (P=1.000). The seasonal trend tests only compared data obtained for each season, such as comparing trends for June observations alone. The station-season interaction term shows that the chlorophyll *a* concentration trends at the two stations were also very similar for all months (P=1.000). Therefore, the sampling data from both stations were combined for further analyses.

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The seasonal Kendall test calculated the chlorophyll *a* concentration trends and determined the probabilities that they were not zero, for all months separately. This test and the Mann-Kendall tests found that both the north and south sampling locations had slight decreasing (but very significant) overall trends in concentrations with increasing years ($P \leq 0.001$). However, individual monthly trends were not very significant ($P \geq 0.05$). The trends do show an important decrease in the peak concentrations of chlorophyll *a* that occurred during the fall months during the years of the FBM operation. The 1980 peak values were about 60 µg/L, while the 1987 peak values were lower, at about 40 µg/L.

Swedish engineers (Söderlund 1981; and Lundkvist and Söderlund 1988) summarized major changes in the algal species present and in the algal biomass in Lake Rönningesjön, corroborating the chlorophyll *a* and phosphorus limiting nutrient observations. From 1977 through 1983, the lake was dominated by a stable population of thread-shaped blue-green algaes (especially *Oscillatoria sp. and Aphanizomenon flos aquae f. gracile*). Since 1985, the algae population was unstable, with only a small amount of varying blue green (*Gomphosphaeria*), silicon (*Melosira, Asterionella* and *Synedra*) and gold (*Chrysochromulina*) algae species. They also found a substantial decrease in the algal biomass in the lake. From 1978 through 1981, the biomass concentration was commonly greater than 10 mg/L. The observed maximum was about 20 mg/L, with common annual maximums of 15 mg/L in July and August of each year. From 1982 through 1986, the algal biomass was usually less than 10 mg/L. The observed maximum was 14 mg/L and the typical annual maximum was about 6 mg/L each late summer. The lake showed an improvement in its eutrophication level since the start of the stormwater treatment, going from hypotrophic to eutrophic.

Figure 7 is a plot of all Secchi disk transparency data obtained during the project period. A very large improvement in transparency is apparent from this plot, but large variations were observed in most years. Figure 8 shows these annual variations in grouped box plots. A large improvement may have occurred in the first five years of stormwater treatment and then the trend may have decreased. The smoothed plot in Figure 9 shows significant improvement in Secchi disk transparency since 1980. This three-dimensional plot shows that the early years started off with clearer water (as high as 1 m transparency) in the spring and then degraded as the seasons progressed, with transparency levels falling to less than 0.5 m in the fall months. The later years indicated a significant improvement, especially in the later months of the year.

Homogeneity, seasonal Kendall and Mann-Kendall statistical tests (Gilbert 1987) were conducted using the Secchi disk transparency data. The homogeneity test was used to determine if any trends found at the north and south sampling stations were different. The probabilities that the trends at these two stations were the same were calculated as follows:

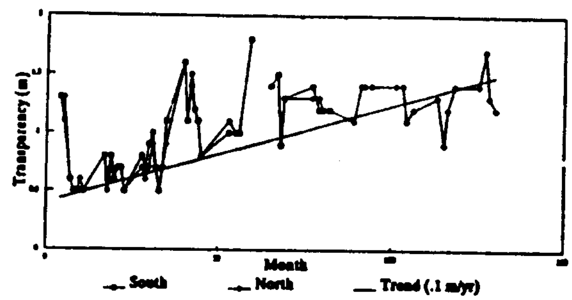

Figure 7. Secchi disk transparency observations with time (m).

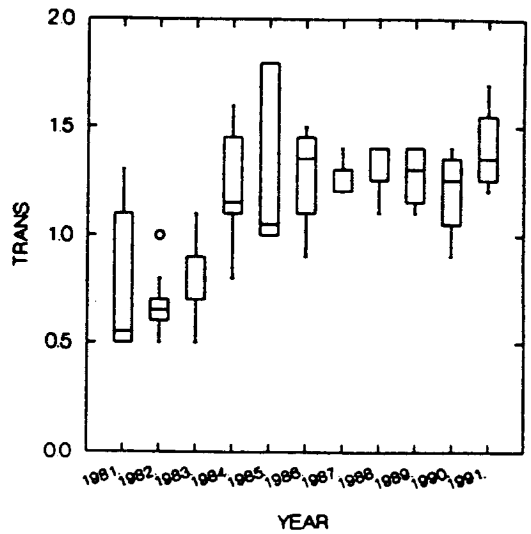

Figure 8. Secchi disk transparencies grouped by year (m).

	χ^2	Probability
season	17.15	0.103
station	0.012	0.913
station-season	3.03	0.990
Trend	29.44	0.000

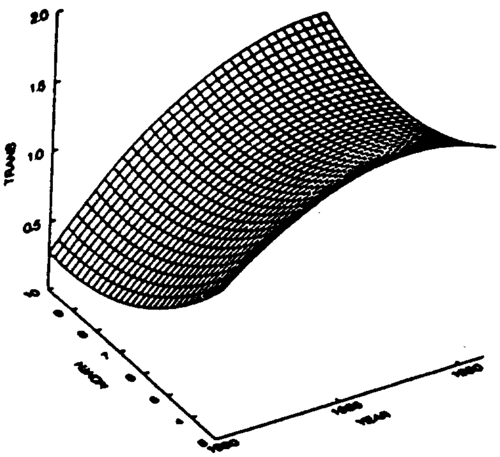

Figure 9. Secchi disk trends by season and year (m).

These statistics show that the observed trend was very significant (P<0.001) and was the same at both stations. The Seasonal Kendall and Mann-Kendall tests found that both the north and south sampling locations had increasing transparency values (the average trend was about 0.11 meter per year) with increasing years (P<0.001). The trend in later years was found to be less than in the early years. The transparency has remained relatively stable since about 1987 (ranging from about 1 to 1.5 m), with less seasonal variations.

Figure 10 plots observed phosphorus concentrations with time, while Figure 11 is a smoothed plot showing seasonal and annual variations together. The initial steep phosphorus concentration decreases in the early years of the FBM operation were followed by a sharp increase during later years. The increase was likely associated with the decreased levels of stormwater treatment during the mild winters of 1988 through 1990 when the treatment system was not operating; large amounts of untreated stormwater were discharged into the lake instead of being tied up as snow to be treated in the spring as snowmelt runoff.

Individual year phosphorus concentrations leveled off in the summer (about July). These seasonal phosphorus trends were found to be very significant ($P \leq 0.002$), but were very small, using the seasonal Kendall test (Gilbert 1987). Homogeneity

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tests found no significant differences between lake sample phosphorus concentrations obtained at the different sampling locations, or depths, irrespective of season:

	χ^2	Probability
season	15.38	0.166
station	0.0033	0.954
station-season	1.64	0.999
Trend	12.43	0.000

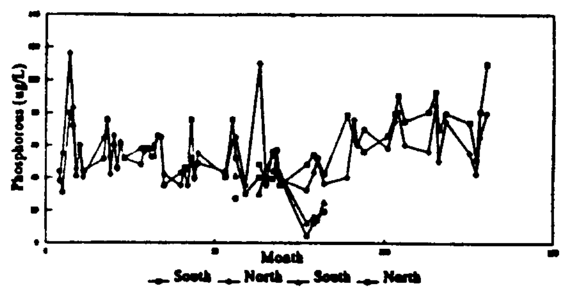

Figure 10. Total phosphorus observations with time (µg/L).

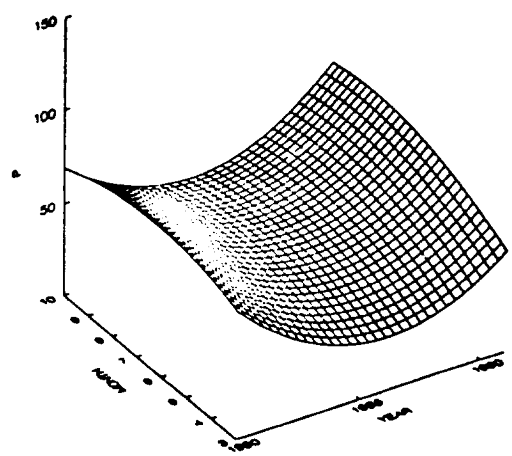

Figure 11. Total phosphorus trends by season and year (µg/L).

The overall lake phosphorus concentrations ranged from about 15 to 130 µg/L, with an average of about 65 µg/L. The monitored stormwater, before treatment, had phosphorus concentrations ranging from 40 to >1,000 µg/L, with an average of about 200 µg/L.

Figure 12 shows all Kjeldahl nitrogen values plotted with time and Figure 13 is a smoothed plot showing seasonal versus annual trends. An increase in nitrogen concentrations is also seen to have occurred from the beginning of each year to the fall months. However, the overall annual trend decreased during the first few years of the FBM operation, but it then subsequently increased. These total nitrogen concentration variations were similar to the total phosphorus concentration variations. However, homogeneity, seasonal Kendall and Mann-Kendall statistical tests (Gilbert 1987) conducted using the nitrogen data found that neither the north or south sampling locations had significant concentration trends with increasing years (P>0.2). However, lake Kjeldahl nitrogen concentration reductions were found to occur during years when the FBM system was treating the largest amounts of stormwater.

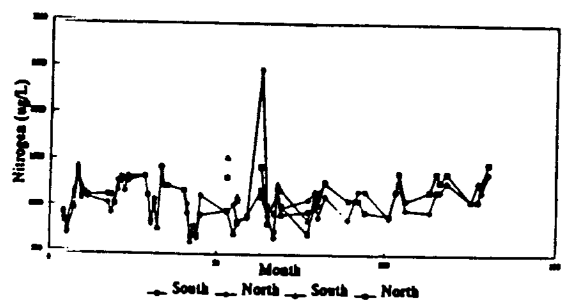

Figure 12. Total Kjeldahl nitrogen observations with time (µg/L).

Lake Water Quality Model

A simple water quality model was used with the Lake Rönningesjön data to determine the total annual net phosphorus discharges into the lake and to estimate the relative magnitude of various in-lake phosphorus controlling processes (associated with algal growth and sediment interactions, for example). These estimated total phosphorus discharges were compared to the phosphorus removed by the treatment system. The benefits of the treatment system on the lake water quality were then estimated by comparing the expected lake phosphorus concentrations as if the treatment system was not operating, to the observed lake phosphorus concentrations.

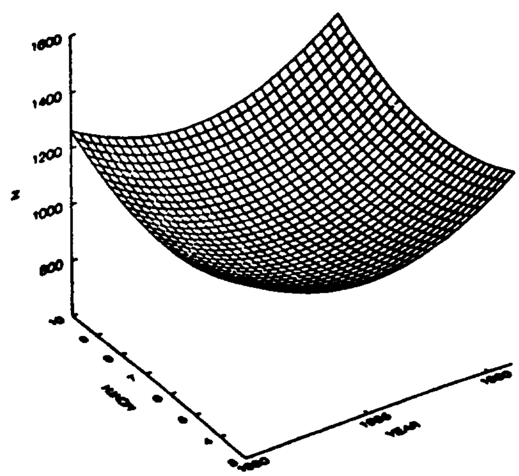

Figure 13. Total Kjeldahl nitrogen trends by season and year (μg/L).

Thomann and Mueller (1987) presented the following equation to estimate the resulting water pollutant concentrations associated with varying input loadings for a well-mixed lake:

$$S_t = (M/V) \exp(-T/Td) \qquad \text{eq. 1}$$

where S_t = concentration associated with a step input at time t,
M = mass discharge per time-step interval (kg),
V = volume of lake (2,000,000 m^3),
T = time since input (years), and
Td = hydraulic residence time, or lake volume/lake outflow (2.1 years).

This equation was used to calculate the yearly total mass discharges of phosphorus to Lake Rönningesjön, based on observed lake concentrations and lake hydraulic flushing rates. It was assumed that the varying concentrations observed were mostly caused by varying mass discharges and much less by variations in the hydraulic flushing rate. The flushing rate was likely to vary, but by relatively small amounts. The lake volume was quite constant and the outflow rate was expected to vary by less than 20 percent because of the relatively constant rainfall that occurred during the years of observation (average rainfall of about 600 mm, with a coefficient of variation of about 0.15).

The total mass of phosphorus discharged into the lake each year from 1972 to 1991 was calculated using the following equation (an expansion of equation 1), solving for the M_{n-x} terms:

$$S_n = M_n\,[\exp(-T_n/Td)/V] + M_{n-1}\,[\exp(-T_{n-1}/Td)/V] + M_{n-2}\,[\exp(-T_{n-2}/Td)/V] + M_{n-3}\,[\exp(-T_{n-3}/Td)/V] + \ldots \quad \text{eq. 2}$$

where S_n is the annual average phosphorus concentration during the current year, M_n is the net phosphorus mass discharged into the lake during the current year, M_{n-1} is the phosphorus mass discharged during the previous year, M_{n-2} is the phosphorus mass that was discharged two years previous, etc.

The effects of discharges into the lake many years previous to a concentration observation have little effect on that year's observations. Similarly, more recent discharges have greater effects on the lake's concentrations. The magnitude of effect that each year's step discharge has on a more recent concentration observation is dependent on the $\exp(-T_n/Td)$ factors shown in equation 2. A current year's discharge affects that year's concentration observations by about 40 percent of the steady-state theoretical value (M/V), and a discharge from five years previous would only affect the current year's concentration observations by less than ten percent of the theoretical value for Lake Rönningesjön. Similarly, a new steady-state discharge would require about 4 years before 90 percent of its equilibrium concentration would be obtained. It would therefore require several years before the effects of a decrease in pollutant discharges would have a major effect on the lake pollutant concentrations.

The annual control of phosphorus ranged from about 10 to 50 percent, with an average lake-wide level of control of about 36 percent, during the years of treatment plant operation. It is estimated that there would have been about a 1.6 times increase in phosphorus discharges into Lake Rönningesjön if the treatment system was not operating. There was a substantial variation in the year to year phosphorus discharges, but several trends were evident. If there was no treatment, the phosphorus discharges would have increased over the 20 year period from about 50 to 75 kg per year. With treatment, the discharges were held relatively constant at about 50 kg per year (as evidenced by the lack of any observed phosphorus concentration trend in the lake). During 1984 through 1987, the phosphorus discharges were quite low compared to other years, but increased substantially in 1988 and 1989 because of the lack of stormwater treatment during the unusually mild winters.

Figure 14 is a plot of the annual average lake phosphorus concentrations with time. If there had been no treatment, the phosphorus concentrations in the lake would

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have shown a relatively steady increase from about 50 to about 100 μg/L over the 20 year period. With treatment, the lake phosphorus concentrations were held within a relatively narrower range (from about 50 to 75 μg/L). The lake phosphorus concentration improvements averaged about 50 μg/L over this period of time, compared to an expected theoretical improvement of about 100 μg/L. Therefore, only about one-half of the theoretical improvement occurred, probably because of sediment-water interchange of phosphorus, or other unmeasured phosphorus sources.

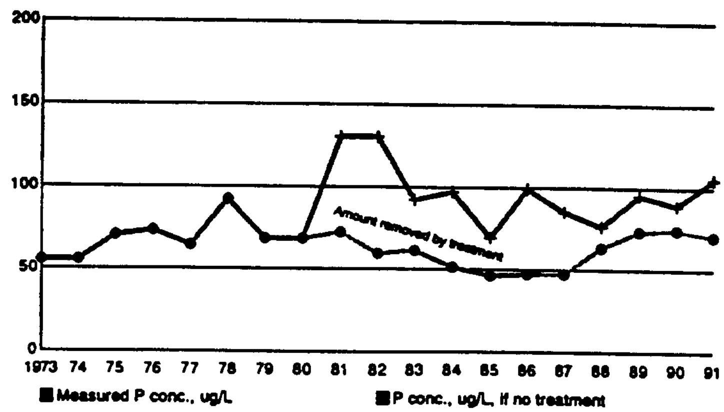

Figure 14. Effects of treatment on Lake Rönningesjön total phosphorus concentrations (μg/L).

Conclusions

The in-lake flow balancing method (FBM) for storage of excess stormwater during periods of high flows allowed for lower treatment flow rates, while still enabling a large fraction of the stormwater to be treated for phosphorus removal. The treatment system also enabled lake water to be treated during periods of low (or no) stormwater flow. The treatment of the stormwater before lake discharge accounted for about 70 percent of the total observed phosphorus discharge reductions, while the lake water treatment was responsible for the remaining 30 percent of the discharge reductions. The lake water was treated during 60 percent of the operating time, but resulted in less phosphorus removal, compared to stormwater treatment. The increased efficiency of phosphorus removal from stormwater compared to lake water was likely due to the more abundant particulate forms of phosphorus that were removed in the FBM by sedimentation and by the stormwater's higher dissolved

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phosphorus concentrations that were more efficiently removed during the chemical treatment process.

Lake transparency improved with treatment. Secchi disk transparencies were about 0.5 m before treatment began and improved to about 1 to 1.5 m after treatment. The total phosphorus concentrations ranged from about 65 to 90 μg/L during periods of low levels of stormwater treatment, to about 40 to 60 μg/L during periods of high levels of stormwater treatment.

The annual average removals of phosphorus by the ferric chloride precipitation and clarification treatment system was 66 percent, with a maximum of 87 percent. The observed phosphorus concentration improvements in the lake were strongly dependent on the fraction of the annual stormwater flow that was treated. The annual average total lake phosphorus discharge and concentration reductions averaged about 36 percent, or about one half of the maximum expected benefit.

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Watershed Protection Using an Integrated Approach

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Abstract

The implementation of stormwater management has historically been accomplished on a piecemeal basis with regulatory requirements being established for new development activities using a standardized approach. Regardless of location, watershed specific problem pollutants, and growth potential, standardized stormwater management requirements tend to be required.

There is general recognition that a watershed approach presents an improved approach for resource protection. This approach considers the cumulative impacts of all sources of stormwater discharges within a watershed including agriculture, urban, and industry. A watershed approach allows for criteria to be developed and implemented which considers an integrated approach to accomplish the various objectives.

The State of Delaware, has embarked on a watershed protection program on a watershed, Silver Lake and its tributaries, which will serve as a prototype for other similar watershed approaches in the State. This watershed, relatively undeveloped, is targeted for high growth over the next 10 years, and a framework must be established if stormwater and resource protection issues are to be addressed.

Hydrologic analyses are provided by the EPA Storm Water Management Model (SWMM). The user friendly characteristics of the geographic information system, ARC/INFO, are utilized to facilitate hydrologic and water quality modeling. Simulations of existing and proposed watershed conditions and inputting industrial discharge moni-

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toring information assist in establishing the pollutants of concern in the watershed, and in making land use and permit decisions.

In addition to the traditional water chemistry analysis, information will be developed regarding the biological impacts that urbanization may have on the watershed. More frequent and more severe stormwater flows degrade habitat by scouring banks and smothering habitats with sediment. A survey of the nontidal streams throughout the State was recently completed where various biological and habitat measures were made. The results of the survey will be used to interpret habitat and biological data collected as part of the Silver Lake Watershed project and to make predictions on stream health in various growth scenarios.

Finally, a major impact of the project relates to the resources necessary to accomplish such an effort. A watershed approach is seen as the ideal way to address land use and permit needs, but the allocation of resources and costs can be significant, and other agencies need to be aware of their obligations.

Background

The State of Delaware has had a National Pollutant Discharge Elimination System Program (NPDES) in effect since 1974, when that program was delegated by the Environmental Protection Agency (EPA). That program has provided an effective mechanism of control over industrial discharges since then. In 1991, a statewide sediment control and stormwater management program was also implemented within the Department of Natural Resources and Environmental Control (Department) whose primary purpose was to reduce the water quantity and water quality impacts that new development activities might have on receiving waters.

These two programs have had little coordination over the past several years as permit applications submitted to both programs have been considered on an individual basis with no linkage of these two programs to target efforts on a watershed-wide basis. The implementation of the statewide stormwater management program has functioned as a baseline program for new development activities while local governments, designers, and land developers acquire an understanding of the types of obligations and practices that are necessary for urban land developments.

When legislation for the statewide stormwater management program was being approved, the need for a coordinated watershed approach was recognized. There are many situations where adverse impacts have already occurred from a water quantity or water quality perspective. In those situations, implementation of controls on new development activities is important but there has to be a process where existing problems can be addressed so that an existing situation can be approved. The Sediment and Stormwater Law has a section devoted to those situations where a comprehensive approach to resource protection can be pursued. That section is defined as Criteria for Designated Watersheds.

The Designated Watershed process represents a consensus approach to address existing water quantity or quality problems within a watershed and prevent those problems from becoming worse. An important component of the Designated Watershed process is the necessity of the local government, where the problem exists, to request that the Department formally designate a specific watershed for initiation of study and recommendations for system maintenance and improvement (DNREC, 1993).

Components of the Designated Watershed study effort include:

1. Stormwater quantity or quality problem identification,
2. Impacts of additional development,
3. Alternative approaches to address existing and future problems,
4. A selected approach that includes the overall costs and benefits,
5. Schedule for implementation,
6. Funding sources for implementation of the selected approach, and
7. A public hearing process prior to plan acceptance.

The initiation of a watershed specific study depends on the availability of funding, but once a watershed is designated, the Department must make every effort to secure funding through federal, State, or local means.

When a watershed is designated, the Department is the lead agency for the study effort, but must coordinate the effort with an appointed advisory committee. The advisory committee is composed of individuals from State, Conservation District, and local agencies in addition to representatives of the regulated community and others who may be impacted by the results of the study. Recommendations, based on the results of the study, can only be made with the overall consent of the advisory group. This approach ensures a cooperative effort to incorporate concerns of committee members.

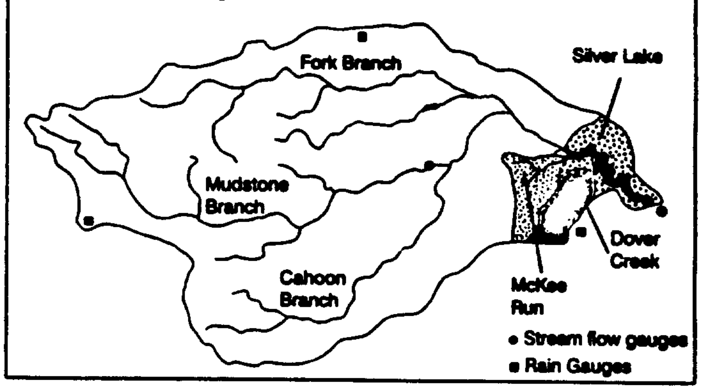
The formal recommendations of the study effort must be approved by the local Conservation District Board of Supervisors, and the local governing body, either county or municipality. Implementation of the study results will also necessitate the development and implementation of a dedicated funding source such as a stormwater utility to ensure design, construction, and maintenance of needed stormwater management structures.

Silver Lake Watershed

The Silver Lake Watershed is approximately 7,695 hectares in contributing drainage area as shown in Figure 1. The predominant land use is agriculture, encompassing 50% of the watershed land use, with forest being approximately 32% and urban development being 18% of the watershed (F. X. Brown Associates, Inc., 1989). The watershed has been experiencing high urban growth with the urban growth increasing by 90% over the last 15 years. The rate of growth is expected to increase in the future.

Soils, for the most part, are deep well-drained soils formed in very old, predominantly sandy sediments, typical of coastal plain soils. Other soils tend to be poorly drained sandy loams. The watershed slopes tend to be gentle with major portions having slopes less than 2%, with only a small portion of the watershed containing slopes greater than 5%. Average rainfall is approximately 1,143 mm/year with rainfall occurring throughout the year.

Figure 1 - Silver Lake Watershed



Silver Lake itself is within the City of Dover while 80% of the watershed is outside of the City in Kent County. The City of Dover has requested the Designated Watershed status for Silver Lake and all of it's tributaries as most of the watershed is out of it's political boundaries. Existing use of the Lake includes swimming, water skiing, recreational boating and fishing. A study of the watershed had previously been done under the EPA Clean Lakes Program so there was good documentation of existing problems in the watershed to justify the Designated Watershed status. The Lake is already highly eutrophic and increasing development in the watershed will increase problems unless an aggressive approach to resource protection is implemented.

There are only two industries in the watershed having industrial discharge permits. Monitoring records from those two industries are available and will be incorporated in the study and implementation phase of the project.

Consensus Approach

It was important that all impacted entities be involved in the planning process as a number of issues are beyond the traditional State role of resource protection. This is a watershed in transition, and land use is a major factor in the ultimate health of the system. In addition to establishing an advisory committee, presentations were made to the local governing bodies of the City and County to acquaint them with the project, as their approval of land use alteration will necessitate their being partners in the project. One means of gaining their assistance was the lure of a Geographic Information System (GIS), that the Department would establish and maintain in the short term. There is general recognition by local jurisdictions that a GIS is an ideal approach to land use planning and the "carrot" provided by the Department to the local jurisdictions was the information contained in the GIS that was to be used for watershed planning.

In addition to involving the local governing bodies, storm drain stenciling is a component to assist in educating the land owners and the general public of the impacts of dumping fluids or chemicals into the storm drain system. Newsletters are delivered on a periodic basis to everyone in the watershed that contain simple facts about the watershed and which strive for feedback on the importance of Silver Lake to the average City or County resident.

Modelling Approach

Computer technology advancement has lead to improved methods for managing and processing (storing, manipulating, displaying and utilizing) data. GIS's are based on a modelling shift to graphical processing made possible by advances in computer hardware capabilities, relational database techniques, and display graphics. GIS functionality makes possible the creation of an environment within a computer in which engineers and planners can readily analyze problems. Such an environment utilizes GIS advances to manipulate data, expert system methods to help the user determine appropriate analyses to be performed, and modern networking to provide access to a number of users to maximize the productive use of data.

ARC/INFO is the GIS that provides data management and user interaction functions. An expert system, which is being created as a component of this project and written in the ARC Macro Language, is referred to as SwmmDuet. Data can be stored, modified and retrieved in a GIS, but, with modern relational database methodologies, they can be related in new ways. Inferences can be drawn and examined visually.

Urban stormwater runoff must be addressed by many jurisdictions throughout the world. Modern concerns about water quality and the severe potential impacts of urban nonpoint source pollution lead to the development of the EPA Storm Water Management Model (SWMM) in 1969-1971. As one of the first computer models to analyze runoff, it suffers from vintage computer technology and would greatly benefit from modern GIS features and data handling methods.

The SWMM model was selected for it's ability to model a wide range of water related parameters, including water quality (Huber, et. al., 1988). That need alone eliminates many existing hydrologic models from consideration. In addition, SWMM has a proven track record of use on many different watersheds, and is in the public domain. One concern with the model is the difficulty and expense of data collection. The approach of linking SWMM to a GIS was to maximize data use for other related purposes.

The flexibility and capabilities of SWMM make it both powerful and difficult to run. SWMM determines the temporal and spatial distribution of runoff generated in a watershed for a given rainfall pattern by deterministic methods. It accounts for the influences of antecedent rainfall, snowmelt, evaporation, stream flow and groundwater seepage. Both the quantity and quality of flow can be evaluated. The myriad influences that characterize hydrologic flows make hydrologic modeling complex. The SWMM user can specify a variety of mechanisms to be modelled and vary the basic model of analysis by choosing different blocks of code and options within each block for processing.

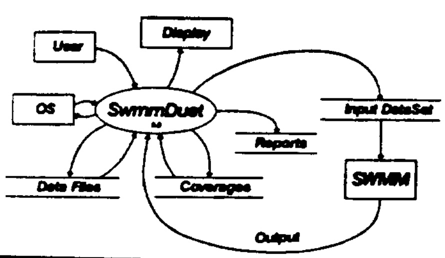
An engineering shell is being created to facilitate the solution of hydrologic modeling problems with SWMM. It is a computing environment created with the GIS, ARC/INFO. With it, hydrologic data can be entered, edited, manipulated, and displayed with ease by the graphical user interface inherent in ARC/INFO. SwmmDuet, written in the associated ARC Macro Language provides:

1. ARC/INFO functionality from a graphical menu-driven user interface;
2. Expert system guidance to lead the SWMM modeler through the block selection and appropriate data entry menus required of selected options;
3. Automatic assembly of the input dataset (transparent to the user); and
4. Post-processing of SWMM output supporting queries for graphical displays of SWMM modeling output (future implementation).

Utilization of data is facilitated in the engineering shell. This makes it more productive and cheaper with reuse. A GIS facilitates use by reducing retrieval time and speeding display in meaningful ways. Expert systems minimize the time needed to reach decisions concerning how data will be used.

SwmmDuet integrates GIS functionality with concepts of expert systems to facilitate stormwater modeling. The program helps the user manage hydrologic data, prepare the input dataset for the SWMM program, and review the results. It enhances the capabilities of the GIS, ARC/INFO, upon which it is built. The enhancement is based on the recognition that a GIS can act as a repository for instructions as well as state variable values. ARC/INFO provides the flexibility and capabilities to integrate the data and enhance task management. SwmmDuet stores hydrologic data as well as the data and instructions for stormwater management. Figure 2 is a context diagram which provides a schematic view of the SwmmDuet interactions with the user, data storage, display, and the SWMM program.

Figure 2 - Context Diagram



Apparently unrelated benefits result from the melding of deterministic analyses and the GIS tools for spatial analysis. There are many obvious applications which should improve accuracies and reduce required computational time. For example, given access to a road coverage within a watershed, the computation of street curb distance can be easily made and used in the specification of street surface buildup.

The coverages needed for the Runoff Block of SWMM are listed in Table 1. A description of the various thematic data stored in datafiles is thereby related.

Table 1
Data Storage
Coverages \& Datafiles

Coverages	Description	Files for thematic data
base_map	map registration data	
basin	subcatchment delineation	basin.data
	erosion data	erosion.data
	groundwater data	seepage.data
	infiltration parameterization	infiltration.data
	subbasin landuse aggregation	landuse.data
	snow data	snow.data
	ground surface	surface.data
	subbasin soil characterization	soil.data
	surface quality data	surface_quality.data
conduits	sewers and natural channels	conduits.data
controls	control structures characteristics	structures.data
gages	rain gages	gages.data
landuse	areal characterization by landuse	
pollutant	point sources & plumes	pollutant.data
process	map of chosen SWMM analysis	process.data
soil	hydrologic soils groups distribution	
topo	physical relief	

Non-spatially referenced data can also be stored, such as characteristics of pollutants and landuse. Time series for hyetographs and hydrographs record values at consistently increasing times in subsequent records. To facilitate access, multiple storm hyetographs are related to the raingage in which they were recorded; the raingages are spatially referenced. The listing of referenced data files are shown in Table 2.

Table 2
Non Spatially Referenced Data

DataFile	Descriptions
air_temp.data	air temperature time series
areal_depletion.data	snow distribution
evaporation.data	monthly average evaporation rate
hyetograph\%i\%.data	precipitation time series
landuses.data	treatment by landuse
pollutants.data	characteristics of treatment
wind_speed.data	monthly average wind speed data

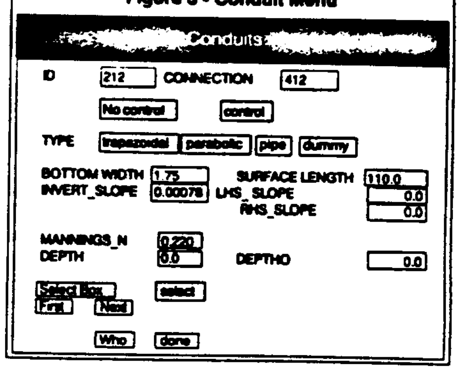
The data for the model are stored in ARC/INFO coverages and files. Accessible to a variety of users, a graphical user interface of ARC/INFO has been modified by customized menus to facilitate access and minimization of data editing and data entry errors. SwmmDuet creates the data set for SWMM from interactive responses entered by the user through this set of menus. Parameter values are requested as needed based on options specified. Unnecessary data need not be entered because only those data required are requested by the software. The graphical paradigm is utilized wherever possible to clarify user understanding. Users can concentrate on the hydrologic aspects of stormwater management.

Form menus enable the user to edit project coverages such as CONDUITS without necessarily having detailed ARC/INFO knowledge. As seen in Figure 3, one need only select the feature, in this case a pipe, and enter the appropriate hydraulic parameters.

The overall SwmmDuet menuing system consists of four main menus. Shown in Figure 4, they help the user:

1. Access help for SWMM modeling and use of SwmmDuet,
2. Enter or edit data which are associated with features, or spatially independent,
3. Choose processing options, and
4. Initiate automatic generation of data or processing.

Figure 3 - Conduit Menu



Calibration and verification of the SWMM model will be accomplished in fall, 1994. SWMM is a source generation model and the goal of the overall effort is protection of Silver Lake. Over the next year, the outputs from SWMM will be linked to the Water Quality Analysis Simulation Program (WASP)(Ambrose, et. al., 1988) to simulate the impact that the loadings will have on the Lake. This is necessary since reductions in pollutant loadings from surface waters after implementing stormwater quality control practices may occur, but there needs to be an assessment of response in the Lake due to lake dynamics such as resuspension of pollutants from sediments. By linking SWMM with WASP, the expected benefits of various watershed development scenarios can be modelled to further justify the implementation of necessary water quality and land use controls.

Stormwater Monitoring

The implementation of the model depends on the quality and amount of data that is inputed. The SWMM model is a data intensive model and the acquisition of data is imperative to overall project success. The general information that is being inputed into the model is contained in Table 1 and Table 2, but the stream flow, chemical sampling, and analysis of sampling results are treated separately in this paper.

There are two permanent stream flow gauges in the watershed, one upstream on Maidstone Branch and the other just below the spillway of the Silver Lake Dam. Both have been established and are read monthly by the United States Geological Survey (USGS). In addition to the two permanent stations, seven temporary stations have been established throughout the watershed where instantaneous flow readings are taken twice a year to give a representation of flow contribution in the major tributaries.

Related to the flow gauges, three rainfall gauges have been placed in the watershed by the USGS. The locations of the rain gauges and the permanent stream flow gauges are shown in Figure 1. It is recognized that additional rain gauges would improve the modelling results, but economics dictated the use of three. Information from the rain and stream flow gauges are digitized by USGS for input into the watershed model.

The chemical analysis includes testing for those parameters listed in Table 3. The intent is to have a broad initial analysis to determine what pollutants are present in the watershed. Based on the results of the initial sampling, parameters which are not detected, or where their level is not considered to be a problem, subsequent sampling may not include testing for that parameter.

Initial monitoring is targeting an urban subcatchment so that data inputs for urban land uses can be fairly well refined. Monitoring of catchments containing other predominant land uses such as agriculture or forest will also be monitored in conjunction with this project. It is intended that monitoring will be accomplished even after a watershed plan has been approved. This would continually refine the model and provide for a barometer of performance in terms of watershed health.

Figure 4 - Menus

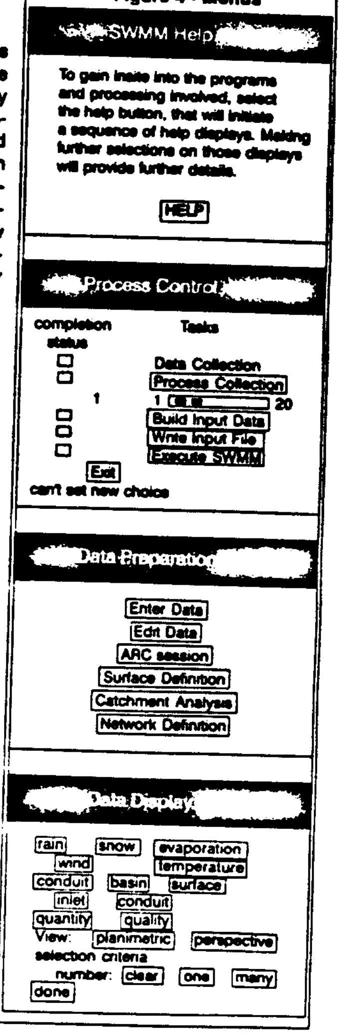


Table 3
Test Parameters

Organics Test		
	TPH	
Metals	Aluminum (100ppb)	Arsenic (5ppb)
	Copper (5ppb)	Iron (100ppb)
	Lead (3ppb)	Zinc (10ppb)
General Tests	Filtration for Dissolved Samples	Alkalinity
	BOD (Read Daily)	CBOD (Read Daily)
	Chemical Oxygen Demand (COD)	Dissolved Org. Carbon (DOC)
	Chlorophyll a and Phosphate a	Dissolved Oxygen
	Chloride	Total Organic Carbon
	Hardness	Nitrate/Nitrite (Soluble)
	Nitrate/Nitrite	TKN (Soluble)
	Ammonium (Soluble)	Organic Nitrogen (includes TKN, NH_3)
	Residue, Nonfilterable, Total TSS	Specific Conductivity
	Sulfate	Phosphorus, Total (Soluble)
	Phosphorus, Total	o-Phosphorus, Total (Soluble)
	o-Phosphorus, Total	Turbidity
	pH	Temperature

The NPDES permited activities in watershed are subject to permit reissuance every five years. The watershed analysis will allow for a consideration of changes that would be necessary or appropriate for those industries to meet objectives in terms of watershed protection. The use of the SWMM model will give the Department the flexibility to consider the specific pollutants of concern with regard to future permit conditions.

The watershed study in conjunction with a recommended plan of action will have a significant impact on future requirements for new development activities. Existing State regulations have a baseline requirement relating to 80% reduction in suspended solids from a new land use after completion of the construction activity. The study results may determine that nutrients are the critical pollutants of concern. In that situation, criteria for permanent stormwater management practices on new development activities may be required to provide for nutrient reduction in addition to the statewide suspended solids reduction requirement.

Habitat and Biological Monitoring

Habitat quality and biological measures can be cost-effective tools for measuring the effectiveness of stormwater controls. Measures of the condition of the resource are needed to evaluate the effectiveness of controls. In this regard first and second order nontidal streams in the watershed need to be considered for three reasons. First, these resources are directly affected by urban stormwater and are often impacted by few other major pollution sources. Thus, it is relatively easy to relate land use and stormwater to the response of the resource. Secondly; physical habitat and biological measures for streams are well established in the literature. This includes both the

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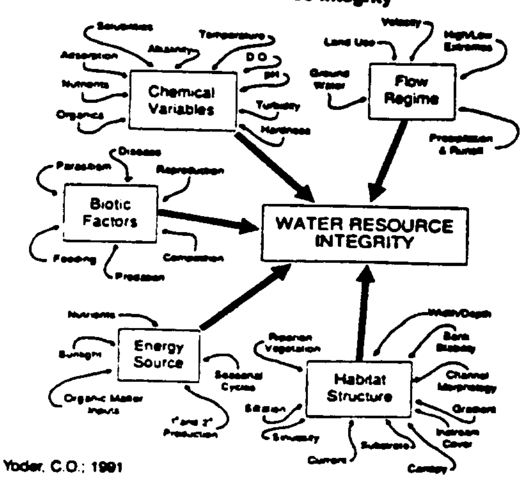
methods of data collection and analysis as well as the establishment of the threshold needed to define conditions; e.g. "good", "fair", and "poor" or "slight", "moderate" or "severe" degradation. While wetlands are often the first aquatic resource to receive stormwater, measurements and threshold are much less developed. And thirdly; the vast majority of nontidal stream resources are first and second order. Delaware has an estimated 3150 miles of nontidal streams; identified as blue lines on USGS 1:24,000 scale maps. Approximately 85 percent are first or second order. It is important that any watershed protection plan protect these headwater streams, and their protection is necessary to protect larger resources downstream.

The focus here is on nontidal perennial streams. It should be recognized that intermittent streams and headwater wetlands also directly receive stormwater and are at even greater risk to the associated impacts. Intermittent streams and wetlands are protected by Delaware Surface Water Quality Standards (DNREC, 1993). Their protection from the impacts of urbanization is necessary to sustain their structure and function and that of larger waters downstream such as streams, ponds, and estuaries.

There are many attributes of water resource integrity, as shown in Figure 5 (Yoder, 1991). We tend to focus on water chemistry and flow because they have been the cornerstone of water pollution control over the years. It is recognized that urban stormwater may require a different approach than the traditional approach used to assess and control point sources. The intermittent nature of stormwater runoff makes the assumption of steady-state used for point sources (e.g., 7Q10) inappropriate. Biologi-

Figure 5
Water Resource Integrity



Yoder, C.O.; 1991

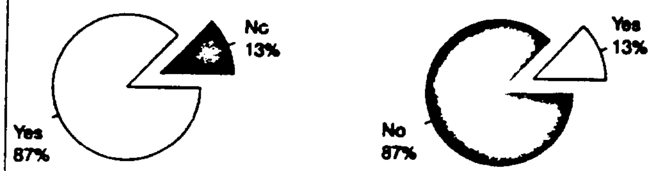
cal and habitat measures may provide a cost-effective way to assess both the direct impacts of urbanization (e.g., channelization, construction in wetlands and in floodplains, etc.) and the indirect impacts caused by changes in hydrology. Both chemical/flow and biological/habitat measures are important and needed. Together, they can provide a strong technical basis for stormwater controls.

Continuous sampling devices make it feasible to take flow and water quality measurements continuously over long time periods. However, even with this more detailed data, we are missing one very important piece of information. There are no criteria for many of the most common stormwater pollutants; e.g., nutrients and suspended solids. We are often still left with the question; Is this level too high? In reality, what we are often forced to conclude is that there is no impact if the existing criteria are not exceeded. And this does not address the impacts to other aspects of stream ecosystem health such as physical habitat and biological quality.

In 1991, DNREC began a project to assess the habitat quality and biological integrity of the State's nontidal stream resources. Streams were randomly sampled in the Fall of 1991 and 1993 for the purpose of producing a Statewide assessment of the condition of nontidal streams for the State's Section 305(b) report. Section 305(b) of the CWA requires the State to report to EPA on the condition of its waters every two years. Figure 6 compares the results of the 1994 assessment using traditional chemical measures, primarily dissolved oxygen, and the approach using habitat and biological measures (Maxted et. al., 1994). As shown, traditional chemical measures vastly underestimated the proportion of the State's stream resources not attaining aquatic life uses.

Figure 6
DNREC Aquatic Life Use Attainment

State of Delaware 1994 305(b) Report
Aquatic Life Use Attainment - All Nontidal Streams



Fixed Stations - Dissolved Oxygen
(no statistical confidence)
(not resource based)

Probabalistic - Habitat/Biology
(95% confidence interval +/- 5-6%)
(resource based)

A similar response was documented by the Ohio EPA when biological monitoring data were added to their 305(b) assessment. Approximately 50% of the stream segments that were determined to be impaired in 1991 were impaired based upon biological measurements alone (Rankin, 1991). In other words, the State would have identified

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only half of the impairments if only chemical measures had been used. In both of these cases, nonpoint sources were identified as the cause of the much of the impairment reported solely on the basis of biological measures.

Habitat quality and biological measures reflect conditions over long time periods. Such temporal integration is important for intermittent pollution sources such as urban stormwater. Macroinvertebrates have life stages ranging from months to several years, and habitat quality reflects conditions over months and years as well. The lack of vegetation along an eroded stream bank or the accumulation of sediment in the stream channel indicate unstable conditions over periods of several years.

The habitat and biological measures used by DNREC are taken from guidance developed by U.S. EPA (Plafkin, et. al., 1989). The methods developed by EPA have provided a consistent basis for reported data, and have been adopted for use by all of Delaware's neighboring States. The measures vary by physiographic region defined as ecoregions (Omernik, 1987). Almost 95 percent of the State is in the Mid-Atlantic Coastal Plain ecoregion. This region is characterized by flat terrain. Streams have velocities less than 1.0 fps, lack shallow riffles, and are naturally depositional. The Northern 5 percent of the State is in the Northern Piedmont ecoregion. This region is characterized by gently rolling terrain. Streams have velocities greater than 1.0 fps and commonly have riffles. Riffles are shallow areas with fast well aerated water. They contain the greatest diversity of macroinvertebrates in piedmont streams. Under natural conditions they show little evidence of deposition.

The basic measures of the quality of the invertebrate community are taken from a taxonomic list of the organisms found in samples collected using standardized collection methods. Sampling is done in the most stable habitats found in the stream. In the coastal plain ecoregion, collections are made in snags, banks, and aquatic macrophytes using a standard D-frame dip net. In the piedmont ecoregion, collections are made in riffles using a kick-net.

Three types of measurements or biological metrics are taken from a taxonomic list to quantify the condition of the community. The first type of metric are richness or diversity measures. The quality of the community is indicated by the total number of unique taxa. Strength and stability of the community is achieved through redundancy. The second type of metric are tolerance measures. Certain groups of organisms are indicators of pollution while others are indicators of high quality and stable conditions. The third type of metric are composition measures. These reflect the structural make-up of the community and often include the proportion or percentage of the total animals of various groups. A summary of the metrics used by DNREC are listed in Table 4.

The strength of any assessment measure is its ability to distinguish between healthy and degraded conditions. Table 5 is a summary of the mean metric values (genus level taxonomy) calculated from selected macroinvertebrate data collected in the coastal plain and piedmont ecoregions. As shown, sites rated as biologically "poor" had re-

Table 4
DNREC Biological Metrics

Metric Name	Description	Type
taxa richness	total number of unique taxa	richness
EPT* richness	total number of EPT taxa	rich/tolerance
% EPT abundance	% of sample that are EPTs	tolerance/comp
% dominant taxon	largest % of a single taxon	composition
% chironomidae**	% of sample from this group	tolerance
biotic index	composite tolerance by taxon	tolerance

* EPT - the orders ephemeroptera (mayflies), plecoptera (stoneflies), and trichoptera (caddisflies); large diversity or abundance indicates high quality.
** chironomidae - family of midges; large abundance indicates stress.

duced total diversity (TR), reduced diversity and abundance of sensitive organisms (EPT, %EPT), an increase in pollution tolerent organisms (%Midge), and a reduction in community composition (%DT). Similar results are shown for the coastal plain and piedmont ecoregions.

Table 5
Sensitivity of Biological Metrics
by Condition and Ecoregion
(Mean Values at Genus Level)

Ecoregion/ Condition	N	TR	EPT	%EPT	%Midge	%DT
Coastal Plain						
"good"	22	29	8	36.5	24.6	21.9
"fair"	17	25	4	16.1	29.1	25.1
"poor"	3	20	2	3.0	79.9	30.4
Piedmont						
"good"	13	23	10	67.8	9.1	32.2
"fair"	19	21	5	32.2	20.5	24.6
"poor"	6	17	3	15.1	32.8	35.9

taxonomic richness (TR), EPT richness (EPT), percent EPT abundance (%EPT), percent chironomidae (%Midge), and percent dominant taxon (%DT).

Measures of habitat quality used by DNREC are shown below in Table 6. They include four types of measures: general characteristics (degree of channelization), instream measures (variety and abundance of stable habitats submerged in the water such as snags and riffles, evidence of deposition, and the quality of pools), stream bank measures (evidence of erosion and the type of vegetation along banks), and riparian zone measures (shade and width of buffer zone). The measures are shown for the coastal plain and piedmont ecoregions.

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Table 6
Measures of Habitat Quality

Northern Piedmont Region	Coastal Plain Region
channel modification (g)	channel modification (g)
instream habitat (is)	instream habitat (is)
bank stability (b)	bank stability (b)
bank vegetative type (b)	bank vegetative type (b)
shading (r)	shading (r)
riparian zone width (r)	riparian zone width (r)
velocity/depth ratio (g)	pools (is)
sediment deposition (is)	
embeddedness (is)	
riffle quality (is)	
riffle quantity (is)	

(g) general, (is) instream, (b) stream bank, (r) riparian

The scoring of physical habitat is designed around the premise that, just as with biological quality, ecological functions increase with stability. Thus, "poor" sites in the urbanized piedmont region lack stable submerged habitats (e.g., riffles and woody snags buried by sediment or completely absent), have eroded and unvegetated banks, and show human activities (e.g., mowed yards, parks, structures) within the floodplain or riparian zone.

One of the strengths of the Rapid Bioassessment Approach developed by EPA is its ability to report scientific results in a form understandable to non-scientists. This is done by comparing the values of each individual metric with reference values. Reference values are derived from sites that are least altered by man. The scores of the individual metrics are added together to produce a single score for each site. A simple scaling system is used to produce a single habitat quality score and biological quality score for each site. The scores are reported as "percent of reference".

Another strength of this approach is its ability to determine if impairment to the biological community is caused by habitat or water quality stressors. The habitat and biological data are plotted with biology on the y-axis (dependent variable) and habitat on the x-axis (independent variable). Figure 7 illustrates this presentation of data (Maxted et. al., 1992). As shown, the majority of sites (69%) in the coastal plain region of the State had impaired biology, and the majority of the impacts were caused by "poor" physical habitat. 80% of the sites with "poor" biology had "poor" physical habitat.

In the fall of 1993, macroinvertebrate and habitat data were collected at 57 sites in the Northern Piedmont ecoregion. The region is heavily urbanized and provides the basis for evaluating the sensitivity of these measures to urbanization and stormwater. The following are preliminary results. Figure 8 shows a strong relationship between habitat and biological quality. In addition, 100% of the sites with "poor" biology had "fair" or "poor" physical habitat, while 92% of the sites with "good" biology had "good" or "fair"

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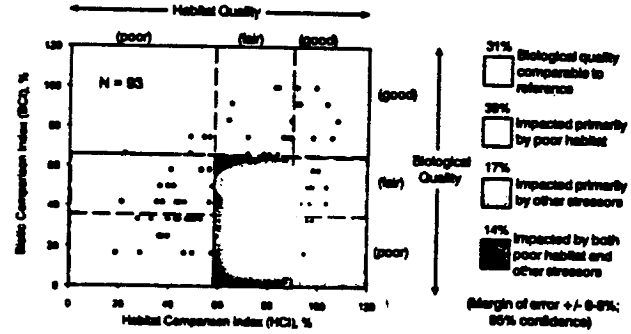
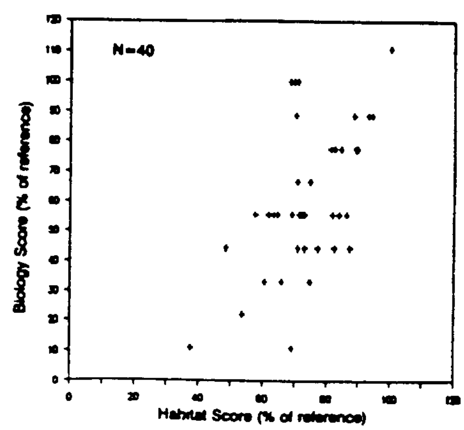
Figure 7
Assessment Summary
Kent and Sussex Counties, Delaware



habitat quality. Overall, the data indicate that (1) the majority of perennial nontidal streams in the piedmont region are degraded biologically, (2) and this condition is the result of urbanization and its effect on physical habitat.

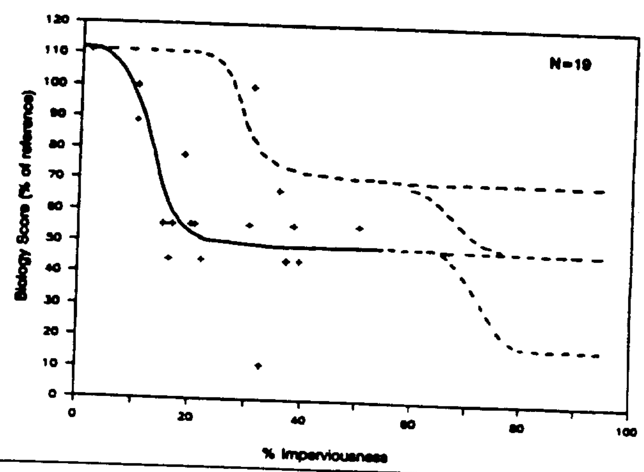
Several investigators have shown, using a variety of biological measures, that the

Figure 8
Relationship Between Habitat and Biological Quality
Piedmont Ecoregion - New Castle County, Delaware



biological community deteriorates dramatically when the percent imperviousness of the watershed exceeds 10-25 percent (Jones and Clark 1987, Klein 1979, Limburg and Schmidt 1990, Pedersen and Perking 1988, and Booth and Jackson 1994). A preliminary analysis of 19 sites sampled in 1993 has been completed. Figure 9 shows that the biological quality drops dramatically when the percent imperviousness in the watershed increased above 8-15 percent. These results are similar to the results reported in the literature. There appears to be a threshold of urbanization beyond which irreversible impacts occur in nontidal streams. Biological and habitat measures provide the basis for evaluating environmental threshholds, such as percent watershed imperviousness, that would not be practical using chemical measures.

Figure 9
Affect of Watershed Imperviousness on Biologic Integrity within the Northern Piedmont Ecoregion of Delaware, 1993
(macroinvertebrates in Riffle Habitats, Genus Level Taxonomy)



The next research question to be answered using these data is whether sites with stormwater controls achieve the physical, chemical, and biological conditions that are comparable to reference sites with healthy aquatic resources. It is assumed that the controls are working to protect aquatic resources. If conditions are comparable, the program is on the right track. If the conditions with controls are no different than conditions without controls, adjustments are needed to achieve the resource-based goals of the stormwater program. This process can only be carried out with resource-based monitoring. Biological and physical habitat measures can be cost-effective measures that will build upon traditional chemical and hydrological measures

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Cost Analysis

The initial concept for this project appeared to be straight forward, but the costs have escalated, primarily due to areas where they were not expected. The linkage of ARC/INFO and SWMM requires an enormous amount of computer storage. The data storage alone is in the six to eight gigabyte range. The end result was that the Departmental computer was not adequate to provide for data storage and retrieval. The decision was made to purchase an individual work station for this project rather than to attempt to update the Departmental system. The cost of the work station, which would also act as a server for approximately 18 individuals, was $35,000.

The modelling effort also had numerous areas where existing data turned out to be inadequate or in error. Existing subcatchment boundaries were inaccurate. Existing storm drain systems were not contained in files that were easily extracted. The County didn't have a good listing of existing land uses. Every situation where assumptions were made, turned out to require additional effort to verify or correct. Overall costs for the three year effort are included in the following tables. Table 7 represents costs that were incurred during year 1 (DNREC, 1992).

Table 7
Project Costs for Year 1

Purpose	Cost
Program Manager (includes Other Employee Costs)	$51,923
GIS Contracting	$15,000
Mailings (bulk rate)	$ 6,000
Rain Gauges and flow measurements	$23,000
Printing Newsletter	$ 1,000
SWMM Training	$ 3,000
Other Contracting	$71,000
Total Direct Costs for Year 1	$170,923

These budgeted costs were in addition to the use of existing staff, which significantly exceeded the funded Program Manager Position. Funding sources included State general funds through staff participation, NOAA Section 309 funding, and NOAA Section 306 funds.

The project is in Year 2 at this time and the funding levels are indicated in Table 8. It must be recognized that this project is falling significantly behind the timetable originally outlined prior to project initiation so much of the cost in Year 2 is to provide information that was expected in Year 1.

These costs are in addition to the use of existing staff resources. There are also other unknown costs to Kent County and the City of Dover for their involvement. Federal funding sources include NOAA section 309 funding, NOAA Section 306 funding, and from EPA under Section 319.

Table 8
Project Costs for Year 2

Purpose	Cost
Program Manager Salary (includes other employee costs)	$ 51,923
Travel	$ 3,000
Rain Gauges and Flow Measurements	$ 16,460
Water Quality Sampling	$ 79,846
Public Education	$ 26,000
GIS System Services	$ 10,000
Storm Drain Labeling Program	$ 22,000
Wetland Identification and Orthodigitizing	$ 50,000
Other Contracting	$ 69,912
Direct Costs for Year 2	$329,141

In addition to funding of the watershed project itself, additional funding was obtained from EPA, under Section 319, for the water quality retrofit of an existing urban shopping center by construction of a constructed wetland. In addition to being a water quality retrofit the project is also a demonstration of the types of activities that will be components of a watershed restoration and protection plan. The location of the wetland is highly visible to any individual visiting the shopping center and signs will be strategically placed to detail the retrofit and its benefit to the Silver Lake watershed. The site is approximately 12.1 hectares in size The retrofit cost $40,000 for actual construction with an additional $10,000 for planting with wetland and transition plants.

Funding for Year 3 has only tentatively been assigned. The only clear fact is that the original three year project will result in either a four or five year effort. Funding is only assured through year 3 and as much of the project as possible must be completed in that time frame. The intended funding levels for year 3 are shown in Table 9.

Table 9
Project Costs for Year 3

Purpose	Cost
Program Manager (includes other employee costs)	$ 55,753
Environmental Programs in Schools	$ 12,000
Water Quality Sampling	$ 25,000
Contractual Services	$107,625
GIS needs and Digitizing	$ 15,000
Newsletters	$ 20,000
Public workshops and hearing	$ 1,500
Direct Costs for Year 3	$236,878

The total estimated direct project costs for this watershed project are $736,942, which computes to $95 per hectare ($39/acre) to accomplish the necessary effort. This cost does not include the State or local government costs for State or locally funded staff participation. Also these costs do not include other interests that may exist on another project such as fisheries or wildlife investigations. Additional products or areas of concern would increase the cost per acreage figure.

To look at the overall effort, it would provide a benefit to understand the costs associated with sampling and data analysis. In terms of instrumentation, the Department purchased three ISCO automatic samplers and bubbler flow units at a total cost of $19,500. In addition to the automatic samplers, two YSI data loggers were purchased at a total cost of $12,990 which are programmable to measure temperature, DO, pH, and specific conductivity. These costs are in addition to the laboratory costs related to data analysis. Table 10 presents representative costs for data analysis. The number of samples was arbitrary in order to get representative costs for sample analysis, but the unit costs are accurate if the following constituents are to be sampled. The laboratory costs do not include costs associated with actual collection of samples. Sample collection is being done by available staff having some experience with sample collection.

Biological monitoring to conduct the habitat assessment , flow measurement, basic water quality analyses, and a macroinvertibrate collection costs approximately $1,200 per site. At least 25 sites are necessary in the watershed to project an accurate representation of stream health. Long term trends, in relation to watershed health, would require analysis once every two years. The index period should be accomplished in the fall when vegetation and algae die off makes analysis easier and shows what has happened over the summer, which is considered the critical period in terms of temperature and DO. Ideally, approximately 1/2 of the sites should be checked each year with a total evaluation of all 25 of the sites occurring every two years. The annual cost for this work would be $14,400 compared to the much greater cost associated with chemical monitoring.

<u>Evolution</u>

There are a number of aspects of this project that are expected to provide stepping stones for stormwater management program evolution and for an approach to resource protection on a more comprehensive basis. From a stormwater management program perspective, one product of this effort will be the consideration of SWMM from an individual site design standpoint. Historically, stormwater management design has been based on hydrologic models that have no water quality design components. SWMM, especially from a suspended solids standpoint, can provide information relating to the performance of a stormwater management basin for water quality in addition to water quantity. The intent will be to provide training for local design consultants and regulatory agencies over the next two years so that a change to the regulations specifying stormwater design using the SWMM model could be accomplished.

Table 10. Water Quality Parameters and Laboratory Costs for Initial Model Calibration

Test Category	# of Samples	Unit Cost	Total Cost
Organics Test			
TPH	40	56.00	480.00
Metals			
Filtration (2x)	40	12.00	960.00
Preparation (flame)	80	12.00	960.00
Flame/ICAP			
Aluminum (100ppb)	80	11.20	896.00
Iron (100ppb)	80	11.20	896.00
Zinc (10ppb)	80	11.20	896.00
Preparation (furnace)			
Arsenic (5ppb)	80	24.00	1920.00
Copper (5ppb)	80	24.00	1920.00
Lead (3ppb)	80	24.00	1920.00
General Tests			
Filtration for Dissolved Samples	40	12.00	480.00
Alkalinity	40	13.60	544.00
BOD (Read Daily)	40	71.00	2840.00
CBOD (Read Daily)	40	77.00	3080.00
Chemical Oxygen Demand (COD)	40	23.20	928.00
Dissolved Organic Carbon (DOC)	40	23.20	928.00
Chlorophyll a and Phosphate a	40	25.00	1000.00
Dissolved Oxygen	40	8.00	320.00
Chloride	40	12.75	510.00
Total Organic Carbon	40	20.00	800.00
Hardness	40	10.40	416.00
Nitrate/Nitrite (Soluble)	40	12.00	480.00
Nitrate/Nitrite	40	12.00	480.00
TKN (Soluble)	40	32.00	1280.00
Ammonium (Soluble)	40	22.40	896.00
Organic Nitrogen (includes TKN, NH_3)	40	56.80	2272.00
Residue, Nonfilterable, Total TSS	40	11.90	476.00
Specific Conductivity	40	8.00	320.00
Sulfate	40	17.75	710.00
Phosphorus, Total (Soluble)	40	18.70	748.00
Phosphorus, Total	40	18.70	748.00
o-Phosphorus, Total (Soluble)	40	12.15	486.00
o-Phosphorus, Total	40	12.15	486.00
Turbidity	40	12.80	512.00
pH	40	0	0
Temperature	40	0	0
Total Cost for staff and resources			$35,372.00

The cost of the project, for the watershed planning and education effort alone, is $95/hectare. Recognizing that some of the expenses are related to development of the SWMM Duet and linking of SWMM to ARC/INFO, future watershed planning efforts are expected to be less than the cost per hectare for this project. In fact, if the one time only expenses are deducted from the total project cost, the cost of the watershed planning is reduced to $63.47 per hectare ($25.70/acre). This is considered a fairly accurate picture of what a similar cost would be for other watershed specific planning efforts. The cost per hectare may be an intimidating factor depending on the size of the watershed and the level of effort needed to justify a watershed specific approach.

This project, and it's associated costs, was deemed necessary as the final product will be the development and implementation of a watershed protection plan linking NPDES permitted activities and traditional nonpoint sources, and the implementation of a funding mechanism such as a stormwater utility. In addition to the project itself, it was considered necessary to attempt such an effort to provide staff with the expertise to conduct watershed studies, especially in light of watershed approaches being considered in the revised Clean Water Act.

The expected results of the study effort will be seen in two areas: political and scientific. From a political perspective, the results of the effort will form the basis where land use and permit decisions are made at the local level. It is critical that the local governments accept the conclusions of the study effort and establish criteria for land use issues in the watershed. In addition, the final product will necessitate a funding mechanism for implementation of study recommendations, and the City and County must have and accept the necessity for a dedicated funding source.

From a scientific basis, there are a number of products from this effort which will facilitate resource protection throughout the State. The development of an engineering shell for the SWMM model will facilitate the use of that model on other watersheds. Experiences learned through this initial effort related to data collection and analysis, modelling, and consideration of alternative approaches to resource protection will be valuable elsewhere. The linkage of chemical and biologic monitoring results will also provide a valuable tool for consideration of overall stream health transferable to other watersheds. The consideration of watershed imperviousness and expectations for maintenance or restoration of stream health also is valuable to recognize.

Conclusions

Watershed analysis, especially from a water quality standpoint, is data intensive and costly to implement in terms of funding, time, and expertise. For these reasons the most accurate models are generally not used on a widespread basis. On this project it was felt that the detail needed must be adequate to "sell" the City and County on the need to take aggressive action if Silver Lake is to be protected. A similar approach in other watersheds will have to be considered very carefully before a similar commitment is made. It is hoped that the conclusions of this study will sell resource protection programs elsewhere in the State.

From a water quantity perspective, the cost of watershed analysis tends to be within reasonable bounds, but the cost of a comprehensive analysis from a water quality standpoint is much more expensive. An alternative approach, when water quality is the primary issue, would be to define existing or proposed land uses in a watershed and conduct a simplified analysis using available loading information from the Silver Lake effort or other projects. The real world impact of the various land use scenarios would be discussed in terms of pollutant loadings and impacts to stream health in terms of biology and habitat.

SWMM is ideally suited for watersheds having a mix of industries in conjunction with traditional nonpoint source loadings. Modelling, in conjunction with data collection, would give a relative view of the impacts that the industrial discharges have with respect to overall watershed loadings. Then a watershed specific strategy can be developed to assess future NPDES permit conditions versus nonpoint source strategies.

It is essential that a dedicated staff and funding mechanism be in place if watershed approaches, including chemical and biologic monitoring, are to be pursued. The rationale that existing staff can assume a greater work load in conjunction with existing responsibilities just won't work. The incorporation of biologic indicators into the traditional chemical sampling process is also critical. Results to date have indicated that, regardless of our best intentions, stream health cannot be maintained or restored if water quality alone is considered. The actual use of the land is so important if resource protection is a program goal, and those decisions are usually made by local government. Education and consensus building at all levels of government and society are necessary if stated goals are to be achieved.

Can stormwater controls protect and maintain the physical, chemical, and biological integrity of our waters? Can we increase the % imperviousness threshold, thus allowing a greater intensity of urban development, with stormwater controls? The answers to these two important questions can only be achieved through resource-based monitoring, and biological and physical habitat measures are well suited to assess urban stormwater impacts. We should not wait 20 years to find out that a multi-billion dollar investment in control has resulted in little improvement in stream condition, or worse that mid-course corrections could have averted widespread and irreversible impacts. Let's not assume that someone else will do this monitoring for our program. The data generated will provide the basis for improving the program and will provide for sound public policy decisions.

These goals can be achieved through the use of existing resources within Federal and State stormwater programs. Funding can also be provided through the support of projects funded through other Federal research programs such as EPA's Environmental Monitoring and Assessment Program (EMAP), USGS's National Water Quality Assessment (NAWQA) program, EPA and State monitoring programs, the Section 319 program, biodiversity programs, and EPA's biocriteria program. And, new funding mechanisms can be established as part of the CWA reauthorization. Most importantly, we need to remember that the goal of the CWA is also the goal of the stormwater control program. To meet this goal, we need to the take ownership of resource-based monitoring by retaining monitoring expertise within the stormwater program. With this expertise, we can keep the lines of communication open between the stormwater program and the variety of resource-based monitoring programs.

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SESSION VII: Monitoring Receiving Water Trends

DISCUSSION

Time-Scale Toxic Effects in Aquatic Ecosystems
Edwin E. Herricks

The critical issue

- A single storm event seldom produces severe environmental change
- Stormwater effects are cumulative - produced over a long time span after wide scale changes in the watershed.

Dose-response curve is the proper tool to evaluate time-related toxicity to the ecosystem.

The Microtox test - bacteria have a 5 minute response time; shows good response to storm events; problem is it doesn't give you a clear picture of what happens. Rotifer test kit from Belgium is a better test. It is available on the market.

Herricks notes that WEF will publish a report reviewing test system procedures - should be available in September.

Questions/Comments

Comment: Temperature, pH, conductivity, and dissolved oxygen are good variables to measure since long records, sometimes with continuous recording, often exist.

Question: For TMDL why can't we incorporate test systems and enlarge to bioassimilation capacity?
Answer: Good idea, but a very rigorous protocol must be developed to do this. ASTM is likely to provide one soon.

Question: When the rotifer test was done, wasn't the organism exposed to a discrete concentration for a long time, rather than an actual storm condition?
Answer: That is true and it is why long-term exposure may produce something different. We need to handle these situations according to pollutant loadings, especially with conservative pollutants.

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Question: Don't most urban streams fit your class 3, where we do not see fish kills and other Phase 1 and 2 impacts. What about these other effects?

Answer: What you say is true for streams in highly urbanized areas, but streams in areas going through urbanization will go through these other phases. Using caged organisms will integrate and reflect the effects of these phases.

Question: How do you account for avoidance behavior in a toxicity test?

Answer: Must take this into account, but critters that can't move do exhibit a similar response. A test procedure based on sessile organisms could assist in this regard.

Question: Will biomonitor organisms adapt, like insects have to pesticides, to stormwater conditions, and not show effects?

Answer: No, the time period for adaptation is very long, and the exposures we are talking about are too short to change the genome, which is required for this kind of adaptation.

Question: What role has the loss of canopy and greater diurnal temperature variation played in this work?

Answer: This is an agricultural stream with little canopy that has evolved to a new "natural" condition that is stable and has a high fish biotic index.

Use of Sediment and Biological Monitoring
Eric Livingston

Thrust of presentation is on the institutional side of determining the cost- effective sampling of sediment that give useable results.

Simply do not have a handle on the quality of their waters - only have data on 10% of 8000 lakes, for instance. Nor do they have enough data to develop sediment guidelines.

Current environmental standards are not relevant to the actual quality of the environment.

They propose normalizing metals data to aluminum.

Bioassessments have become more practical to do. EPA rapid bioassessment protocols are available, but they must be applied in a way that is comparable to the natural habitats in a region. Even regional specificity may not be enough, may have to adjust to local conditions.

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They intend to develop and test biocriteria - expect to take 5 years.

In Ohio, they have found that 52% of their waters meet chemical criteria, but only 25% meet biological criteria.

Conclude that it is possible to meet biomanagement criteria, but it will take a long time, and only happen if continued funding support is available.

<u>Questions/Comments</u>

Question: At what level can we now make an assessment of bioeffects?
Answer: Certainly not at the BMP level.

Question: How do we standardize (depersonalize) bioassessment, i.e. standardize protocols?
Answer: The problem is that, statutorily, we have no targets and there is fragmentation. We need a clear focus. However, there is a lot going on, and we can learn from each other.

Question: How is standardization addressed in your sediment monitoring?
Answer: We have protocols for depth and do cores also.

Comment: Most of the work is being done by a few really dedicated individuals, and not by a range of scientists who are receiving adequate funding.

Question: Is it fair to say that if we identify sediment contamination problems as you have described it is a macroscale phenomenon (e. g., point versus nonpoint sources), rather than at the level of whether or not a BMP works?
Answer: Yes, the focus of this method is at the watershed scale.

Question: Is Ohio classifying discharges that cause problems?
Answer: Ohio is way ahead in applying these methods. There are requirements for states to develop programs but no money. Therefore, people who want to do something just do what they think is best, and sometimes a good program like Ohio's develops. Section 319 is the program that could provide the money, but it is not because of a policy interpretation.

Question: How did you arrive at the metrics you are using in biomonitoring?
Answer: Metrics allow us to quantify using a single number. We listed all the possibilities, sorted them and chose the ones that responded most clearly to conditions, and then aggregated those into an index. They need five years of validation before we finally accept them.

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Question: Don't metrics have to be changed regionally?
Answer: Yes.

Comment: I have not seen a single study that states that they were able to use standard metrics - had to make some adjustments.

Question: Have you used fish in your biotic index?
Answer: We have used invertebrates. Fish present special problems, like mobility.

Water Quality Trends from Stormwater Controls
Robert Pitt

Questions/Comments

Question: During this time was watershed stable?
Answer: Yes, but there was some transition of farmland to housing (this may have contributed to poor performance). Stormwater treatment system kept pollutant loading to lake constant, rather than increasing.

Question: How does the Corps of Engineers view putting these in-lake treatment systems in natural waters?
Answer: I would have to look into this.

Question: What about maintenance?
Answer: The facility rides the weather out pretty well, maintenance is minor.

Question: How was internal recycling of phosphorus factored into your trend analysis?
Answer: We got only about half of the potential benefit from treatment, and internal recycling factors into the uncertainty associated with the other half.

Comment: This approach offers an alternative to retrofit of treatment basins into existing areas. Treatment system acts just like a wet pond. (Editor's note - Why not then create a wet pond or wetland treatment system on the shoreline that looks more natural?).

Question: What software do you use for your trend analysis?
Answer: Gilbert's code, with in-house modifications. Reckow also has good SAS macros that can be used. Unfortunately, no standard statistical package can do the job.

Question: What was the cost of treatment?
Answer: The cost was 4 cents/1000 gallons, 20% of which was the cost of monitoring. The overall cost was $40,000 per year, including disposal of residuals.

Question: How do costs compare with other types of BMPs?
Answer: Cheaper, but there can be problems with water quality impacts, or with Corps of Engineers' rules.

Question: What is the cost effectiveness of this treatment relative to alternatives?
Answer: End-of-pipe treatment is sometimes necessary, but there is often a lack of land, making this option less expensive than alternatives that use land.

Question: Can chemical addition be useful on a larger scale?
Answer: This is generally site-specific.

Question: What permitting requirements did you have in your New York City application?
Answer: It was an EPA demonstration project, and I did not get involved in the permitting (ask Rich Field). This method is a good option when you have not land.

Question: What was the effect of ice on the storage tank in Sweden?
Answer: It got 2-3 feet thick and caused some damage to the structure. It was easy to patch the curtain in the spring and reattach any loose wood. We have 10 years of experience in Sweden and 6 in New York, and maintenance is minimal.

Question: Is chemical addition feasible on a large scale?
Answer: Whether or not it is feasible is site-specific. This is really a big wet pond, and chemical addition may not be necessary to achieve what you are trying to do.

Question: What was the rate of sediment accumulation?
Answer: The rate is about 1 inch per year. It needed to be dredged after 10 years.

Comment: You incorporated both monitoring and modeling. We should do more of that.

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Watershed Protection Using an Integrated Approach
Earl Shaver, John Maxted, Gray Curtis and Eavid Carter

"Water is not supposed to be brown" is a perception that our people have become accustomed to.

Delaware has adopted a Designated Watershed approach into its law for WQM; Dove/Silver Lake/St. Jones is the first designated watershed. This watershed is in transition from agriculture to urban land use. They are using a systematic approach for the identification of all sources of inflow and quantifying their loads.

Using SWMM to do forecasting - will interface ArcInfo GIS with SWMM.

Biological Assessment - Focusing on 1st and 2nd order streams using established technologies in the literature. Using macroinvertebrate community as a primary indicator of the condition of the aquatic resource.

Habitat Quality - Use four general categories. Assessment is summarized by plotting Habitat Comparison Index (HCI) with Biotic Comparison Index (BCI).

Questions/Comments

Comment: If we don't look at the whole system we can destroy our aquatic ecosystem without ever violating WQ criteria. Also, if we are to have a healthy ecosystem, it must be diverse.

Answer: This approach is expensive. Must build up a public support base for the program. Education of the public and engineers, as well as contractors, is essential for a successful program.

Question: People tend to measure success of public education by the number of talks given and brochures handed out. Brochures, etc. don't change behavior. Voluntary training and mandatory testing work better. What do you think?

Answer: Keep training at the level of the audience. For example, most contractors hunt and fish and can relate to the environment through that. Education programs should have a feedback loop from the audience. In our case contractors said they want more. I want to add that we would not have a program if it were not for NPDES; it can't be voluntary.

Question: About your contractor training program. Is there follow-up? How does Delaware do inspection and enforcement?

Answer: Yes, we have enforcement using law enforcement officers. Local governments refer cases to the state if necessary. State enforcement people go out (with guns) and assess fines. Developers will comply

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with regulations if there is a level playing field, and you can't have a level playing field if the program is voluntary.

Question: But state programs do not give a nationwide level playing field, do they?

Answer: That's true. We had a large department store building in Delaware for the first time, and they had never filed a notice of intent before.

Comment: Education must include the practitioner as well as the general public.

Comment: The Environmental Education Network involving 128 nations has water quality test sets that can give a framework for public involvement, including children.

Comment: EPA has an NPS bulletin board which is a good source of information, and a good place to share your information with others.

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Monitoring BMP Effectiveness at Industrial Sites

Aicardo Roa-Espinosa[1], Ph.D. and Roger T. Bannerman[2]

ABSTRACT

Storm water runoff sample were collected from five industrial sites. These samples were collected by five monitoring methods. These five methods were: Flow weighted composite, time discrete, time composite, source area and first 30 minutes. Heavy metal, total solids and suspended solids were determined for all the sampling methods for seven storms. Individual samples were collected to illustrate the change of contaminant concentration in runoff versus change in storm water discharge (a pollutograph).

One of the most difficult aspects of the flow based automatic sampling is site selection, due to the difficulty in finding the proper outfall for installation of the flow measuring device and the related cost of installation. The sampling methods that do not utilize flow measuring devices are easier and less costly to install and operate. The consideration of proximity to the source or representativeness of the sample is higher for the source sampler method when compared to the other sampling techniques tested here.

If it is assumed that sampling at the outfall gives the most representative sample, then the time composite is the best method due to low cost and the need for less technical expertise. However, although it was not directly compared to the other methods in the field, it is surmised that the new design of a source sampler discussed in this text will be superior to the other methods for accuracy and reproducibility of results. In addition, if closeness to the source gives the most representative sample, then the new source sampler should be the best method.

INTRODUCTION

In many states industries are currently collecting or preparing to collect and analyze samples of their storm water runoff to fulfill chemical monitoring obligations of their

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National Pollutant Discharge Elimination System (NPDES) permit, which regulates the discharge of storm water related to industrial activity. Because pollution prevention is the primary focus of this regulatory program, most state environmental agencies believe that the chemical monitoring of runoff will produce important information to help to focus planning efforts and identify current contaminant movements. As it has in the past, chemical monitoring that relies on the collection of a flow proportional sample will likely be required because it is considered to most accurately represent the actual discharge of contaminants (USEPA, 1992). Unfortunately, this type of runoff sampling technique is often expensive, technically difficult, and very time consuming.

This study was designed as an evaluation of the various storm water runoff sampling techniques available for collecting industrial site runoff. The importance of such a comparison becomes clear as one considers that industries will rely on the results of these analyses to make decisions regarding changes to their storm water pollution prevention plans, an obligation of the industrial storm water permit.

The first step of this study was to establish criteria for comparing the different techniques. The criteria selected were:

How difficult it is to select a site (Site selection)
Sampling costs
How concentrations compare to flow composite (Accuracy)
How concentrations compare among several storms (Reproducibility)
How well concentrations represent the source of pollution (Representativeness)
Technical expertise required to use the method (Technical Difficulty)

Three industrial sites were selected for study based upon site definition, all the runoff being directed to a single outfall, and a desire to cooperate with the project. In addition, the runoff at the outfall had to be related only to the activities of that particular industry.

Initially, no single sampling method was considered as superior based on the previously listed criteria. All of the sampling methods were compared at all three industrial sites. The following sampling techniques were compared: full storm flow composite, full storm time composite, first 30 minute time composite, time discrete, and source area samplers, and the concept of the new source sampler.

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METHODS

Description of the Sampling Methods

Flow Composite: A composite sample consisting of a mixture of aliquots of constant volume collected proportional to the flow rate;

Source Area: A sample consisting of a mixture of variable volumes collected, and which is proportional to sheet flow runoff volume over time;

Time Composite: A sample prepared by collecting fixed volume aliquots at specified time intervals and combining into a single sample;

Time Discrete: Individual samples of fixed volume aliquots collected at specified time intervals and selected according to the hydrograph for individual analysis;

First 30 Minutes: Individual samples taken during the first 30 minutes of a storm event and combined into a single sample.

Roof Samplers

Roof samplers were installed to divert a small portion of the flow in a roof drain to a gallon bottle. A quarter inch (inside diameter) stainless steel tubing was attached to the inside of the drain, and a vinyl tube directed the water from the stainless steel tubing to the bottle. One of the tubes was positioned where the majority of the water was flowing, and the other allowed air to escape from the bottle or to return the excess water when the bottle was full.

Lawn Samplers

The lawn sampler, first used by Bannerman et al. (1993), consisted of two four foot long PVC pipes (1/2 inch in diameter) placed in a depression on the surface of the soil, with the pipes forming an angle of approximately 150 degrees. The water entered the pipes through three inch slits cut along the entire length of each pipe. Each pipe was wrapped with a fiberglass screen to prevent entry of debris. The pipes were held in place by clothespin anchors. A source sampler was placed between the pipes, flush with the ground to collect water. Silicon tubing delivered the water from the pipes to the source sampler, which was fitted with a special cap to accommodate the two pieces of tubing.

Source Area Samplers

An area sample device, modified in size from the street sampler discussed in Bannerman et al. (1993), was used to sample sheet flow runoff from each type of source area recognized at each of the participating industries. A sampler consisted of a 10 inch inside diameter PVC pipe cut to a length of about 12 inches. A 10 inch inside diameter coupling was cut in half and glued to the top of the pipe. This sleeve

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was placed in a hole drilled in the pavement and cemented in place. A cap of one inch thick gray PVC (for the sleeve) with a 5/8" hole at the center was placed at the top of the cemented sleeve. Attached with four aluminum screws to the gray PVC was a bottle cap with a 2.5 liter glass bottle for collecting the storm water sheet flow sample. The final sample collected by the source samplers was a flow composite of discrete samples over time. A clean bottle was installed shortly before each storm event to prevent contamination of the storm water sample by a new storm, traffic or the normal operations of the site. The following number of source area samplers were installed to cover the different source areas at each facility: Warman International, 7 source samplers; AC Rochester and Delco Electronics, 14 source samplers and 13 roof samplers; PPG Industries, 9 source samplers and 7 roof samplers.

New Source Area Samplers

A prototype of a new source sampler has been built. A prototype circuit board would be used to raise and lower a piston in the lid of the sheet flow sampler. At the beginning of the runoff event the sampler would be triggered by a moisture sensor. The piston would go down for a set period of time (approx. 5, 10, 15, 20, 30 seconds). The piston would stay closed for a preset time (approximately 1 minute). The computer board would stop sampling after a preset time or when the level of the sampled sheet flow closed the piston.

LABORATORY PROCEDURES

Cleaning Procedures

The glass bottles used to collect the flow composite samples, roof samples, lawn samples, and source samples were cleaned by washing with double distilled water and phosphorus free soap, rinsed, washed with 20% hydrochloric acid , rinsed again with double distilled water, washed again with acetone and finally rinsed with double distilled water. Sampler caps were cleaned with double distilled water and phosphorus free soap, and rinsed with double distilled water.

Sample Collection

Sample collection and documentation occurred as soon as possible after the end of the runoff event, but in no case more than six hours after the rain event ended. All collected samples were refrigerated until they were combined into a composite sample and split for analysis. Preservation procedures were done immediately upon arrival at the USGS laboratory in Madison. The preserved samples were delivered to the Wisconsin State Laboratory of Hygiene (SLOH) for water quality analysis or to a commercial laboratory for analysis of the organics.

The time composite, time discrete, and source samples were analyzed for the following constituents: Calcium (Ca), Chemical Oxygen Demand (COD), Copper (Cu), Hardness (as $CaCo_3$), Lead (Pb), Magnesium (Mg), Nickel (Ni), Total Solids

(TS), Suspended Solids (SS) and Zinc (Zn). The flow composite samples were analyzed for Antimony (Sb), Arsenic (As), Beryllium (Be), Cadmium (Cd), Calcium (Ca), Chromium (Cr), COD, Cu, Hardness, Pb, Mg, Ammonia-N, Nitrate plus Nitrate-N, Total Kjeldahl Nitrogen, Ni, Total Phosphorus, TS, SS and Zn.

Sample Splitting
Sample mixing and splitting was performed at the USGS Water Resources Laboratory, located on Seybold Road in Madison. The samples coming from the same areas were combined into a composite sample and split, using a Teflon coated churn splitter. After splitting each composite sample, the churn splitter was rinsed three times with double distilled water. Separate sample control forms were used to document which samples were combined, their volumes, and additional comments on the storm water event.

Sample Preservation
The samples collected for metal analysis were preserved with 2.5 ml of 35% nitric acid (HNO_3), and nutrient analysis were preserved with 2.5 ml of 2% sulfuric acid (H_2SO_4). The samples for total and suspended solids and COD had no preservatives added. The samples for the toxicity test were refrigerated at 4^0C.

Water Quality Analysis Data
Water quality data were transferred from the State Laboratory of Hygiene (SLOH) to the USGS's QWDATA data base. ASCII files were created by QWDATA and exported to a PC DOS computer for load computations using EXCEL 5.0 software.

RESULTS AND DISCUSSION

From the standpoint of the number of samples taken during the storm event, the time composite method took more samples than the other methods during the entire storm event, followed by the flow composite, time discrete and the first 30 minutes.

Table 1 details the number of subsamples collected in four different methods for storm water analysis. All but the first 30 minutes had samples representing all of the hydrograph.

Site selection

The first step in the industrial storm water runoff project was to summarize the information from the industrial sites. The information from industry group applications was selected to determine the possible industries to be monitored. Twenty-six SIC codes were selected based on the EPA toxicity code (1 low and 10 high). The descriptions of the raw materials and finished products that possibly were in contact with the storm water was updated from the storm water runoff applications.

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The industries in the storm water application have a description of the materials handled and exposed to storm water.

TABLE 1. Number of samples collected by four different methods for storm water analysis

DATE	FLOW COMPOSITE	TIME DISCRETE	TIME COMPOSITE	FIRST 30 MINUTES
AC-06-30-93	23	6	41	2
AC-08-05-93	8	6	72	3
AC-08-19-93	7	8	40	3
TOTAL	38	20	153	8
PPG-08-05-93	11	6	24	3
PPG-08-09-93	11	6	22	3
PPG-09-13-93	26	8	24	3
TOTAL	48	20	70	9
WR-06-13-93	13	6	15	3
WR-06-17-93	13	6	24	5
WR-06-29-93	20	8	26	3
WR-07-17-93	8	7	11	3
WR-07-25-93	30	7	30	4
TOTAL	84	34	106	18

The comparison of the sampling methods called for the selection of sites that fulfill the criteria described in the introduction. The study encountered a significant amount of difficulty in accommodating all the sampling methods at a single outfall. The fact that from 474 industries only 94 presented isolated drainage areas made the site selection difficult. The fact that of the 94 sites, only 14 had a single pipe outfall suitable for accurate flow measurement coupled with a minimal amount of gravel at the site, only compounded site selection difficulty. The sampling methods that take samples at the end of a pipe have a high degree of difficulty in selecting the site.

Cost

Table 2 presents the cost of the equipment for different sampling methods. Table 2 shows that sampling methods that take samples proportional to flow rate discharge are the most expensive due to the equipment utilized to run the samplers, the communication accessories, the data loggers to store the information and the shelters to protect the equipment. The sampling methods that do not utilize flow measurement devices and instrumentation are far less expensive.

For the cost of the laboratory analysis for one storm for full inorganics, full organics, full metals and invertebrate bioassay, once the sample is collected the cost of the analysis of the samples was the same except for the time discrete sample. A minimum of six selected samples according to the hydrograph were analyzed to describe the pollutant concentration during the storm event (pollutograph).

TABLE 2. Summary of the sampling cost including: equipment, installation and lab analysis (1)

Method	Cost Ranking	Total
Flow composite	High	$16,052
Time discrete (2)	High	$22,682
Time composite	Medium	$5,920
Source area fixed	Low	$2,189
Source area variable	Low	$2,889
First 30 minutes	Low	$1,800

(1) Cost of lab analysis for 1 storm event
(2) Approximately six discrete samples

Accuracy

The study used the assumption that the automatic flow weighted sample was the method that most accurately represents the true runoff. Because of these assumptions the composite sample was used as the base to compare the results of the other sampling methods. The advantage of the flow weighted sample is obvious when measurements of the flow are needed to be recorded to evaluate the instantaneous flow load calculations or to associate the concentration of samples taken over time with the flow rate discharge. Figures 1 and 2 give a graphic illustration of the number of the subsamples for a single storm event by the four sampling methods.

The highest number of subsamples corresponded to the time composite. The time composite method reflects the accuracy by the number of subsamples taken. Initially when concentrations are high a large enough number of samples are taken that the over sampling during the last part of the storm is compensated by the initial high concentrations to give fairly accurate results that are the closest to the flow composite method.

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Figure 1. Discharge, flowcomposite, time composite and time discrete samples selected at AC Rochester stormsewer, August 05, 1993.

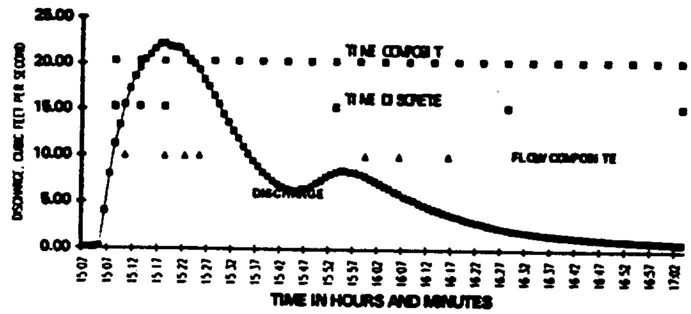
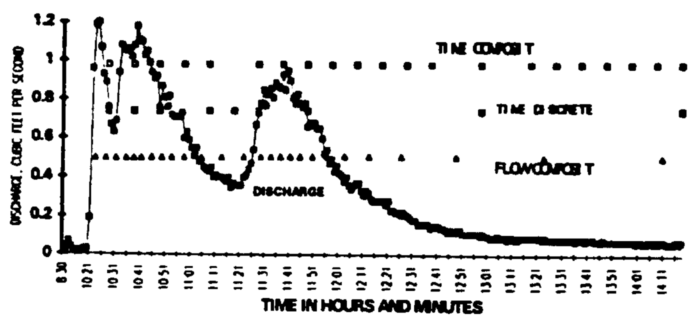


Figure 2. Discharge, flowcomposite, time composite and time discrete samples selected at PPG Industries, September 13, 1993.



Sampling storm water will generate flow data and chemical characterization of the storm water runoff. Figures 1 and 2 show how the flow data was represented for a storm event runoff and how the monitoring of the storm was done by the different sampling methods. To evaluate accuracy of the characterization of the storm water data it is important that the composite sample be based on a large number of subsamples during the storm event. The composite samples with smaller coefficients of variability are the samples taken with the larger number of samples. The coefficient of variability increases with the decreasing number of samples (Table 3).

Figures 3 and 4 illustrate that three samples during the first 30 minutes are a composite of the highest concentrations during the storm event runoff. The same results were found to be true for all the events at all sites monitored.

Figure 3. Discharge, concentrations at discrete times selected for copper at Warman International, July 17, 1993.

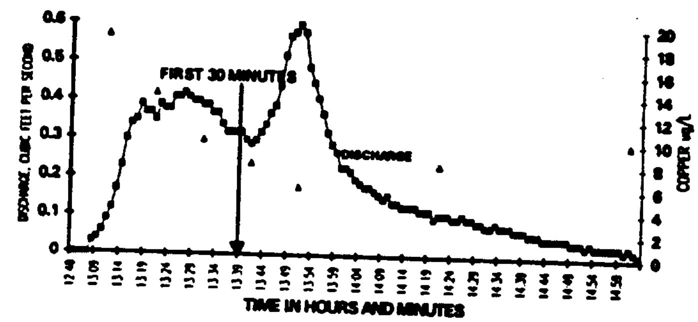
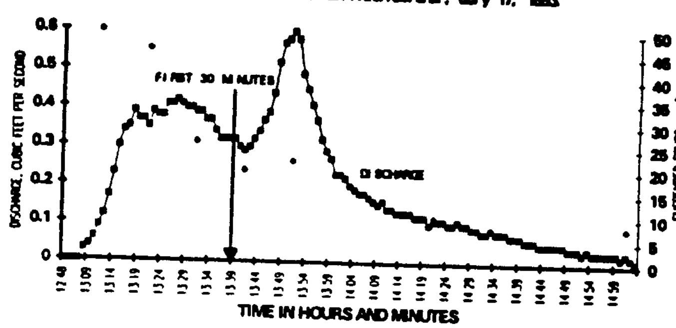


Figure 4. Discharge, concentrations at discrete times selected for suspended solids at Warman International, July 17, 1993.



The number of storms are very important in determining the accuracy of the flow composite geometric means at each site. Table 3 presents what could happen when storm water runoff is characterized by infrequent extreme observations. The probability of sampling extreme characterization values is always present. The differences range from minus 78% for suspended solids to 4% for total solids at AC Rochester. For the highest concentration from a single storm event the least

TABLE 3. Effect of number of storms on the accuracy of the flow composite geometric means at each site.

NUMBER OF EVENTS	GEOMETRIC MEANS Copper, ug/L total recov.	Zinc, ug/L total recov.	Total Solids, mg/L	Suspended Solids, mg/L
		AC ROCHESTER		
1 (lowest conc.)	12	57	172	8
1 (highest conc.)	30	150	204	84
3 (storm events)	14	76	148	24
5 (storm events)	16	91	165	36
% DIFFERENCE 5 vs LOWEST	-25%	-37%	4%	-78%
% DIFFERENCE 5 vs HIGHEST	88%	65%	24%	133%
% DIFFERENCE 5 vs 3	-13%	-16%	-10%	-33%
		PPG INDUSTRIES		
1 (lowest conc.)	16	140	136	49
1 (highest conc.)	52	330	452	32
3 (storm events)	18	153	133	57
6 (storm events)	26	186	188	53
% DIFFERENCE 6 vs LOWEST	-38%	-25%	-28%	-8%
% DIFFERENCE 6 vs HIGHEST	100%	77%	140%	-40%
% DIFFERENCE 6 VS 3	-31%	-18%	-29%	8%
		WARMAN INTERNATIONAL		
1 (lowest conc.)	5	68	36	17
1 (highest conc.)	12	140	112	56
3 (storm events)	7	67	71	15
5 (storm events)	8	81	70	26
7 (storm events)	7	74	70	19
% DIFFERENCE 7 vs. LOWEST	-29%	-8%	-49%	-11%
% DIFFERENCE 7 vs HIGHEST	71%	89%	60%	195%
% DIFFERENCE 7 vs. 3	0%	-9%	1%	-21%
% DIFFERENCE 7 VS 5	14%	9%	0%	37%

(1) % DIFFERENCE = (LOWER # OF EVENTS GEOMEAN - HIGHER # OF EVENTS)/HIGHER # EVENTS di

difference for total solids was 24% at AC Rochester and the largest difference was 195% for suspended solids at Warman International (Table 3). The lowest percentage difference of the four constituents compared occurred when 5, 6 and 7 events were compared with a single storm event characterization. Table 3 illustrated that the number of events certainly has an effect on the accuracy of the geometric means. For all the sites when a single storm was characterized, extreme values of the four constituents analyzed were found. These values happened for all the sites monitored. Based on the previous discussion the accuracy of the storm water characterization is

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affected by the number of subsamples, the part of the storm sampled, and the sampling method used.

Results from the industrial storm water runoff monitoring done in 1993 suggest that the time settings for the sheet flow sampler must be included in the new design. The new design will have to collect discrete samples from the sheet flow. The first generation of source samplers indicated that it is very important to define the period and the segment of the storm from where the samples have been composited over time. The new source area sampler improves the accuracy because it provides a sample composite over time. Table 4 compares the accuracy of the methods.

Table 4. Ranking of the accuracy for different sampling methods

Method	Accuracy
Flow composite	Good
Time discrete	Good
Time composite	Good
First 30 minutes	Poor
Source area (old) passive	Poor
Source area (new) electronic	Good

Reproducibility

Table 5 compares the flow composite geometric means monitored with the time discrete for the first 30 minutes of individual storms for each site. The characterization of individual storms can give results that can be categorized as extreme infrequent observations, but are nonetheless probable. Table 5 shows that the storm water is more reproducible when larger number of subsamples are taken during the entire storm event. The appropriate reproducible method of sampling storm water to be used to compare with the same site or between individual sites or groups of sites is a method such that the subsamples cover the entire storm event. The reproducibility of a composite sample of many subsamples during the entire storm event is less influenced by the high concentrations at the beginning of the hydrograph and the small concentrations at the receding part of the hydrograph.

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Table 5 compares the flow composite geometric means with the time discrete for the 30 minutes for the sites monitored. The geometric means coefficient of variability for the four constituents analyzed was larger for the time discrete first 30 minutes when compared with the flow composite data for the same four constituents. The variability at AC Rochester for copper was slightly higher for the first 30 minutes, and much larger for zinc, total solids, suspended solids. At PPG industries the variability for all the constituents was higher for all the constituents for the first 30 minutes sampling method. At Warman International the variability for all the constituents was similar for both sampling methods.

Figures 5 and 6 represent the monitoring data during storms at different sites. The concentration for copper and suspended solids concentrations are much higher at the beginning of the storm compared with the middle and end of the storm. The flow composite samples represent the entire storm event or a composite of subsamples. Although the flow composite is accurate and reproducible the problem of the flow composite sample is that the flexibility of analyzing multiple samples during the entire storm is no longer possible. To explore the behavior of pollutant concentrations during the individual storm events is no longer a possibility with the flow composite sampling method. The time based sampler has allowed us to analyze the behavior of the pollutants during a storm event. The analysis of the first 30 minutes shows that the concentrations tended to be much higher at the beginning and declining at the receding part of the hydrograph (Figures 5 and 6). The problem of sampling always the first 30 minutes of the storm event is that the variability of the concentration during this part is much higher than the rest of the methods that sample the entire storm event.

To understand storm water runoff contamination we have to look into the contribution of the pollution process from different types of sources. The pollutants present in storm water depend on the industrial yard activity. The pollutants present in the runoff are carried out by a physical process which is the washing off of such contaminants. Many times it is going to be difficult to determine the source unless the industrial yard has source area samplers to determine the areas of concern producing the contamination. Other times it will be very difficult to determine the source at all. The choice of specialized pollution prevention could be very uncertain without the development of better ways to determine the approximate location of the source and the effectiveness of the source area controls or Best Management Practices (BMP's).

The storm water project tested an inexpensive and easy method for industry to monitor industrial runoff. Installation and operation of the sampler had to be simple. The sampler was flexible enough to collect a representative sample of the storm water event.

Figure 5. Discharge and concentrations at discrete times selected for copper at AC Rochester stormsewer, August 05, 1993.

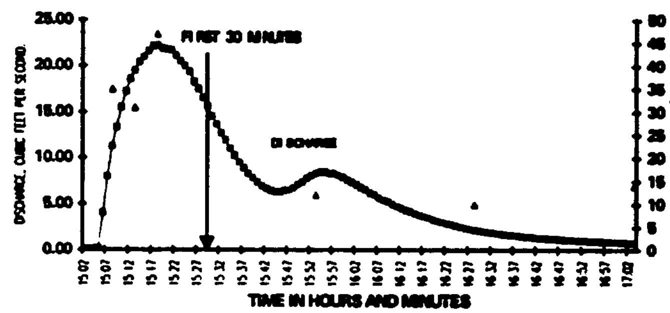

Figure 6. Discharge and concentrations at discrete times selected for suspended solids at AC Rochester stormsewer, August 05, 1993.

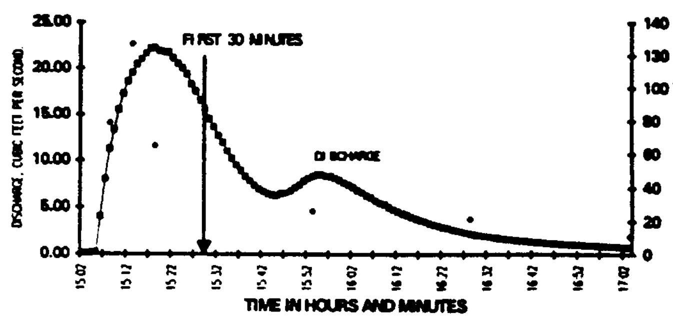

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TABLE 5. Reproducibility in flow composite concentrations and time discrete for first 30 minutes of the storm

	GEOMETRIC MEANS AND COEFFICIENT OF VARIATION FOR EACH CONSTITUENT							
	Copper, ug/L total recov.		Zinc, ug/L total recov.		Total Solids, mg/L		Suspended Solids mg/L	
DATE CV%	Flow composite	First 30 minutes	Flow composite	First 30 minutes	Flow composite	First 30 minutes	Flow composite	First 30 minutes
			AC ROCHESTER					
6/30/93	12	22	57	70	172	612	24	14
8/5/93	18	33	97	205	132	325	32	103
8/19/93	14	39	78	160	144	644	73	241
CV%	21%	27%	26%	47%	14%	33%	73%	96%
			PPG INDUSTRIES					
8/5/93	17	26	160	250	138	236	77	122
8/9/93	16	47	140	273	136	568	49	314
9/13/93	21	17	160	173	126	140	45	74
CV%	15%	51%	8%	23%	5%	71%	31%	75%
			WARMAN INTERNATIONAL					
6/13/93	8	14	82	185	75	155	39	95
6/17/93	12	12	140	159	112	138	56	39
6/29/93	5	19	53	143	68	187	14	18
7/17/93	11	14	84	120	82	128	22	39
7/25/93			68	167	36	133	17	106
CV%	38%	20%	39%	32%	37%	15%	60%	64%

TABLE 6. Ranking of the reproducibility for different sampling methods

Method	Reproducibility
Flow composite	Good
Time discrete	Good
Time composite (high frequency)	Good
Time composite (low frequency)	Poor
First 30 minutes	Poor

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Self-monitoring will be required as part of the storm water industrial permits for Wisconsin industries. Monitoring would target sources of pollution not adequately controlled by a pollution prevention plan. Source sampling is a method for isolating the level of pollutants washed-off from these sources of pollution. The location and size of these sources varies from industry to industry.

The experience gained in monitoring storm water runoff from industrial sites where samples from a thin layer of water were running across a paved surface during a runoff event allowed us to collect a sample as close as possible to the source of concern and then compare the source area sample with the more technically difficult methods. This demonstrated that the end of the pipe characterizations do not represent the true source of the pollutants present in the storm water runoff.

The source sampling approach for self-monitoring is the easiest to use and always collected a sample with a low degree of difficulty. Not only was the source sampler able to collect samples close to the source, but it was able to collect samples of the part of the storm desired. The source sampler balances the need to have a feasible monitoring method with a method flexible enough to collect a sample for all the industrial sites of the storm water project.

__Technical Difficulties__

The flow proportional methods have a high relative difficulty due to the installation of the flume and the instrumentation at the site to record the rainfall data, flow discharge and the times and flow where the samples were taken. This part of the sampling technique requires knowledge of hydrology, fluid mechanics and the operation of the data logger. The source samplers are less difficult when compared to the automatic sampling techniques because the source sampler does not use a flume and instrumentation, and does not need the command of hydrology and fluid mechanics principles. The ranking of medium difficulty for the first 30 minutes is due to the difficulty of selecting the right outfall to take the grab samples called for by the permit.

The sampling methods that utilize proportional flow rate discharge have the highest degree of technical difficulty which is reflected in the cost (flume, installation, instrumentation and technical skills). The lower cost is reflected in a low technical difficulty for the source samplers because they do not utilize a flume, installation is low technology, and the skills are basic.

Table 7 illustrates the range of skills to take a good sample for the sampling methods. The flow composite samples are initially taken at predetermined flow volume without knowing the characteristics of the rainfall event. This demands continuous attention to change the preset parameters according to the event. The difficulties collecting the

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TABLE 7. Ranking of the technical difficulties for different sampling methods

	SAMPLING EFFORT			
METHOD	EQUIPMENT INSTALLATION	FLUID MECHANICS	SAMPLER OPERATION	SAMPLE PROCESSING
FLOW COMPOSITE	High	High	High	Low
TIME DISCRETE	High	High	Medium	High
TIME COMPOSITE	Medium	Low	Medium	High
SOURCE SAMPLER	Low	Low	Low	Medium
NEW SOURCE SAMPLER	Low	Low	Low	Medium
ROOF SAMPLER	Low	Low	Low	Low
FIRST 30 MINUTES	Low	Low	Low	Low

flow volume based samples make the relationship between the rainfall physical characteristics and the contaminant concentrations and loads even harder. To compare the sampling methods, excellent communication and knowledge was necessary not only of the sampling equipment but also of the software and communication package with the sampling station.

Table 8 ranks the technical difficulties of the different sampling methods. The flow composite samples demand a range of skills even before the equipment can be operated. Once the samples are taken, understanding the hydrological data, hydraulic data and rainfall data is very important to determine the loads and understand the behavior of the contaminants with the hydrograph. The methods that do not demand the command of such skills make the sampling process simpler (source area samplers).

TABLE 8. Technical difficulties summary of the different sampling methods.

Method	Ranking
Flow composite	High
Time discrete	High
Time composite	Medium
Source sampler	Low
New source sampler	Low
Roof sampler	Low
First 30 minutes	Low

The source sampling approach for self-monitoring is the easiest to use and always collected a sample with a low degree of difficulty. The source area sampler balanced the need to have a feasible monitoring method flexible enough to collect a sample for all the industrial sites of the storm water project.

Representativeness (Proximity to the source)

The main goal of storm water regulation is to prevent the movement of pollutants through storm water to rivers and lakes, affecting the water quality of such receiving waters. The most effective monitoring should be based on the identification of the sources of pollution instead of the end of the pipe monitoring. Storm water monitoring should be implemented to reduce the non point pollution leaving the industries into the receiving waters. The most representative sample, usually related to proximity to the source, is important because this will provide the permit reviewers with information regarding the true sources of pollution and the individual performance of the Best Management Practices (BMP's) and programs to reduce non point pollution. The characterization of samples close to the source are the most fair to the Department of Natural Resources (DNR) as a regulator and to the industry as permittees because this can identify the source of the problem and propose real reduction plans of contaminants. The end of the pipe is the least representative because the outfalls are located far from the potential sources and represent a dilution of the true contamination. Table 9 ranks the best representativeness of the various sampling methods.

TABLE 9. Representativeness of the sampling methods

Method	Ranking
Flow composite	Low
Time discrete	Low
Time composite	Low
Source area	High
First 30 minutes	Low

The current storm water regulations rely on the end of the pipe monitoring discharge characterization data from a given industry to assess the degree of non point pollution to the receiving waters. This approach does not provide the permit reviewers with information on the true sources of contamination. In industrial sites, pollutants from other source areas such as high traffic, storage, auto parking, truck parking, roofs and lawn are significant and should be characterized to support a comprehensive plan to reduce non point pollution loading to the receiving water.

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The data from the samples collected by source area samplers in their present design showed that the concentration for the analytes tested was higher than the concentration obtained by the time weighted sampling equipment for that particular time.

The comparison of measured volume with volume estimated by Pitt and Voorhees' 1989 Source Loading and Management Model (SLAMM) at each site is shown in table 10. The runoff values of the volume measured and estimated for AC Rochester varied from minus 3% to 23% for three events compared. The comparison for Warman International varied from minus 14% to 14%. The comparison of the two flow measurements methods is a way to relate the concentrations measured by the four sampling methods. The attempt is to relate the results of the concentration to the hydrological and meteorological data. This is an attempt to answer with a degree of confidence what are the influences that the different source areas play in the concentration at the outfall. When determining if a facility is discharging high levels of contaminants it is more important to know the concentration at the source than the concentration at the outfall and it is more important to know the runoff volume of each source area than the total volume at the out fall. The systematic monitoring of the structural BMP's must be developed and field tested because without a clear hydrological relationship between the sources and the concentration at the outfall it is impossible to determine the effectiveness of such BMP's. The transferability of the results can be used to compare the effectiveness of the BMP's on reducing the contaminants. The model SLAMM to estimate volume runoff (Table 10) is sufficient to permit systematic analysis of the data at a variety of industrial sites. To measure the effectiveness of the BMP's two key parameters must be obtained and reported in all the BMP's installed. These are the concentrations at the source and the volume of runoff. These two parameters need to be reported in every pollution prevention plan to test its effectiveness. The reporting of the concentrations and runoff volume (Table 10) appears to give respectable data to draw conclusions now on how the data is related to the source, and in the future to determine the BMP's at different industrial sites.

Conclusions

Industries and municipalities have already started to monitor and collect storm water data in a variety of ways, using different sampling methods (manual or automatic, flow or time based). Much of the data will be associated with the efficiency of future storm water management practices. It is very important that if a variety of sampling methods are to be used as management assessment tools, they be carefully evaluated to understand if they can adequately fulfill the task.

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TABLE 10. Comparison of measured volume with volume estimated by SLAMM at each site.

DATE OF EVENT	MEASURED VOLUME, CUBIC FEET	ESTIMATED VOLUME, CUBIC FEET	PERCENT DIFFERENCE
	AC ROCHESTER		
6/30/93	105,360	122,500	16%
8/5/93	52,500	64,500	23%
8/19/93	149,000	144,300	-3%
	WARMAN INTERNATIONAL		
6/13/93	6,200	6,200	0%
6/17/93	3,000	3,100	3%
6/29/93	4,300	3,700	-14%
7/17/93	1,400	1,600	14%
7/25/93	12,300	12,800	4%

In order to better understand how these methods may fulfill a particular task, Table 11 presents a way to visualize their effectiveness through a ranking of storm water sampling methods according to an evaluation of the various aspects involved in selecting a monitoring method. These aspects of monitoring are: site selection, cost, technical difficulty, most representative, accuracy and reproducibility. In order to select the best sampling method, each method has been ranked numerically according to each aspect.

As was shown in Table 3, one of the most problematic aspects of automatic flow based sampling is site selection, due to the difficulty in finding the proper outfall for installation of the flow measuring device. In Table 11, the sampling equipment and methods that do not utilize flow measuring devices are indicated as easier to install at an outfall, having lower costs associated with their use, and less technical difficulty.

If the consideration of proximity to the source or most representative sample is a higher concern, Table 11 indicates that the source sampler method will be much more useful, when compared to the flow based and time based automatic sampling methods. In addition, it is hoped that the accuracy and reproducibility of the new design of source sampler will be superior to the past designs. If we instead consider that sampling at the outfall gives the most representative sample, then the time composite is the best method.

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TABLE 11. Ranking by methods of sampling and by site selection, technical difficulty, accuracy and reproducibility and representativeness

CRITERIA min	Flow comp.	Time discrete.	Time comp.	Old source sampler	New source sampler	First 30
Site selection	1	1	1	5	5	3
Cost	1	1	3	5	5	5
Technical difficulty	1	1	3	5	5	5
Accuracy	5	5	4	1	5	1
Reproducibility	5	5	5	1	5	1
Representativeness	1	1	3	5	5	1
TOTAL POINTS	14	14	19	22	30	16

The ranking of 1 represents the worst, a ranking of 3 represents median conditions and a ranking of 5 the best conditions.

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NOTE: Detailed data on each industry site is available from the authors

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MONITORING OF WETLANDS, WET PONDS, AND GRASSED SWALES

by

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Abstract

The use of best management practices (BMPs) to minimize the impact of storm water flow often involves engineered features such as wet and dry ponds, created and natural wetlands, and grass swales. The main purposes of each of these types of BMP are essentially the same: to reduce peak flows; to remove suspended solids; to provide opportunity for natural systems to reduce concentrations of dissolved organic and inorganic pollutants; and to control erosion. Integral to the use of such systems is the need for a monitoring program to assess the effectiveness of these BMPs in reducing pollutant loads in discharged storm water. Federal and State regulations include specific requirements for industrial and municipal storm water monitoring programs that can be, and often are, labor and resource intensive practices. While the storm water regulations have specific requirements for monitoring of discharges for permitting purposes, there remains a need to continue the development of representative and cost-effective monitoring systems that provide data on the efficiency of a variety of structural best management practice (BMP) systems. Data must be usable both for the purpose of demonstrating pollutant removal efficiency, and for the more general purpose of providing process information to facilitate development of design criteria. This paper examines current monitoring requirements, key elements in the design of a monitoring program, and current methods for assessing the effectiveness of runoff controls.

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Background

The 1987 amendments to the Clean Water Act (CWA) added section 402(p), which included provisions for the regulation of storm water discharges. Under CWA §402(p), the U.S. Environmental Protection Agency (EPA) was directed to promulgate regulations incorporating discharges of storm water into the National Pollutant Discharge Elimination System (NPDES) permit program.

In November 1990, EPA published regulations governing NPDES permit applications for storm water discharges (43). These regulations included requirements for monitoring both dry weather (i.e., base flow) and storm-related flows to determine the concentration of various contaminants (specified in the regulations) in that discharge. EPA has published several guidance documents on developing and implementing such a monitoring program which provide greater detail on the specific elements required.

Under the Federal program, storm water sampling must begin (a) at a predetermined 0.1 inch of rainfall, and (b) no sooner than 72 hours after the last storm event. Two sampling protocols must be followed for storm water discharges. First, a grab sample of at least 100 mL must be collected during the first 30 minutes of discharge. Second, a flow-weighted composite sample must be taken. The flow-weighted composite sample must either be taken with a continuous sampler that proportions that amount of sample collected with the flow rate or be the combination of at least three sample aliquots, with each aliquot being volumetrically proportional to discharge flow. The collection of samples in this manner is problematic at best, requiring either automated equipment or the ability to have a sampling team in the field on very short notice.

Analysis of organic and inorganic compounds, microbiological species, and water quality parameters is required under the regulations. The specific constituents include the organics listed in 40 CFR Part 124 Appendix D, Table II; the toxic metals, cyanide, and total phenols listed in 40 CFR Part 124 Appendix D, Table III; and additional parameters specified in 40 CFR §122.26(a)-(c). The EPA guidance document *Guidance Manual for the Preparation of Part 1 of the NPDES Permit Applications for Discharges from Municipal Separate Storm Sewer Systems* (40) provides detail as to the parameters that should be addressed in a storm water monitoring program. Table 1 provides a summary of these recommended parameters.

The regulations also require the use of the analytical methods specified in 40 CFR Part 136. If there is no method specified for a particular compound, alternative methods meeting specified criteria can be utilized for the analysis. For the most part, standard laboratory methods exist for the contaminants listed; however, standardized field methods using remote sampling and analytical

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Table 1

Recommended Monitoring Parameters

Conventional Water Quality Parameters	**Metals**
pH	Antimony
Total suspended solids	Arsenic
BOD_5	Beryllium
COD	Cadmium
Settleable solids	Chromium (total)
Temperature	Hexavalent chromium
Conductivity	Copper
	Lead
Nutrients	Mercury
Dissolved phosphorus	Nickel
Total phosphorus	Selenium
Soluble phosphorus	Silver
Total Kjeldahl nitrogen	Thallium
Nitrate/nitrite nitrogen	Zinc
Cyanide	
	Biological parameters
Organic Compounds	Fecal coliform
Oil and grease	Fecal streptococcus
Volatile organic compounds (VOCs)	Microtox®
Base/neutral organics/acids (BNAs)	*Daphnia* bioassay
Polychlorinated biphenyls/pesticides	Fish bioassay
Total phenols	

Adapted from *Automatic Stormwater Sampling Made Easy* by Thrush and DeLeon (38)

systems are not available. Thus, most monitoring programs using field sampling and analysis systems probably will require a method validation element.

The monitoring requirements of regulatory programs should always be considered in the design of a monitoring program for storm water BMPs. Incorporating

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these requirements into a study provides data adequate for two purposes: demonstration of compliance plus the data needed to determine how the design and operation of such systems can be improved.

Design of a Monitoring Program

Any program to monitor the effectiveness of storm water BMPs must have clearly defined goals and carefully designed strategies to achieve those goals. In the case of a monitoring program for the types of BMPs discussed in this paper, the goals of the monitoring program should include:

- Estimating storm event flow and loading rates.
- Determining actual flow rates and identification and quantification of the influent and effluent pollutants of concern.
- Assigning the reduction (or increase) in a pollutant of concern to the appropriate physical, chemical, or biological system in a mass balance.
- Assessing possible impacts to other resources, especially groundwater.
- Assessing possible improvements in the design and operation of both the BMP and the monitoring program.

Integral to the design of a monitoring program is the need for a quality assurance (QA) program. Because environmental monitoring data are collected under often less than ideal conditions and a specific sampling event may not be repeated, researchers need to demonstrate that data collection and analysis procedures are based on accepted scientific practices. Typically, QA efforts focus on the laboratory analysis only; however, this is but one small part of the entire investigative process, and it is uncommon to see papers in the literature make specific reference to the entire QA protocol followed. One recommendation for all researchers conducting studies on the effectiveness of storm water BMPs is the use of an accepted protocol for incorporating QA into the monitoring program and to reference the QA program in their discussion. One model for integrating quality assurance into environmental monitoring programs was proposed by Clark and Whitfield (9). Briefly, this model proposes a system with fourteen elements:

(1) A careful study design to delineate the goals of the study and the methods to achieve those goals.
(2) A study plan documenting for all study participants the roles, responsibilities, and authorities of each participant.
(3) Written protocols or standard operating procedures to be followed during the course of the study.
(4) Careful preparation for all field activities before departing on a sample collection expedition.

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(5) Field team-headquarters liaison to ensure communication of study activities, problems, and corrective actions taken between "headquarters" and field teams.
(6) Written procedures for sample collection including sampling location selection, sample collection, on-site analysis, and recording of data and observations.
(7) Written procedures for sample handling between the time of collection and receipt at the laboratory where the analysis will be conducted.
(8) Oversight of analytical laboratories in addition to incorporation of the "in-house" QA program of the analytical laboratory into the project QA plan.
(9) Ensuring data are supplied by the analytical laboratory in a usable manner that minimizes the need to reenter data.
(10) Data validation and statistical analysis of the data received to determine the accuracy and precision of the reported results.
(11) Procedures for data approval and the release of the validated data.
(12) Plans for providing the data to the public, regulatory agencies, or others in an established format useful to the recipient.
(13) Procedures for statistical analysis of the data to determine trends or specific relationships between data points or data sets.
(14) Procedures for reporting and interpretation of the data to determine if the goals of the study are fulfilled.

While this appears a cumbersome process and a burden on the investigator, use of a QA program such as is outlined by this model helps ensure that the data collected are of maximum utility, accuracy, and precision. Further, providing a reference in published works to the QA protocols followed may enhance the utility of research efforts that follow.

Estimation of Storm Event Flow Rate and Pollutant Loadings

There are two components to determining storm event flow rates and pollutant loading. First, one must estimate these characteristics in order to plan and implement a monitoring program. This is especially important for monitoring programs that will utilize automatic sampling or analysis devices. Second is the verification of those estimates, and refining of the sampling procedures through analysis of the results of the implemented program.

There are several critical elements to estimating storm event flow rates. First, there is a regulatory definition of a representative storm event, critical to estimating runoff volume for the purpose of determining compliance:

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...[A] storm event that is greater than 0.1 inch and at least 72 hours from the previous measurable (greater than 0.1 inch rainfall) storm event. Where feasible, the variance in the duration of the event and total rainfall of the event should not exceed 50 percent from the average or median rainfall event in that area. [40 CFR §122.21(g)(7)].

EPA provided only limited discussion of analytical techniques to use on precipitation data to determine what constituted a representative storm event in the document *Guidance Manual for the Preparation of Part 1 of the NPDES Permit Applications for Discharges from Municipal Separate Storm Sewer Systems* (40). A paper by Hamilton (15) discussed the approach used in conducting an evaluation to determine the criteria for a representative storm event in the Winston-Salem and Greensboro, North Carolina area. For the Winston-Salem area, the National Oceanic and Atmospheric Administration (NOAA) used the following parameters:

1. A storm was defined by a total rainfall accumulation of at least 0.1 inch, with rates averaging at least 0.01 inch per hour.
2. Data were recorded on at least an hourly basis.
3. The start of a rainfall event begins in an hour when at least 0.01 inch of rainfall is recorded.
4. The minimum dry period to signal the end of a rainfall event was 10 hours.
5. At least 10 years of data were required for analysis (data from 1948 to 1986 were actually used).

The City of Greensboro, North Carolina used the same data set, but used two different parameters:

1. The minimum dry period to signal the end of an event was 3 hours.
2. The minimum dry period prior to the start of an event was 72 hours (per the regulatory definition).

Even though the same data set was used for these studies, there was a significant difference in the values for representative storm events, with the NOAA approach yielding consistently higher values for duration, frequency, total precipitation, and average precipitation. This difference led the North Carolina Department of Environmental Management (NCDEM) to define a storm event as a storm having a precipitation depth of 0.2 to 0.8 inch and a duration of 3 to 13 hours. Guidance letters from NCDEM specifically recommended against the use of high-intensity, short-duration storms as a representative storm event.

Other studies used different methods for determining what constituted a representative storm. Thrush and DeLeon (38) recommended using data from

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the National Weather Service to determine an average storm by calculating the numeric average of all the storms during the period examined, or by using the frequency of return of a storm of a given intensity which met the regulatory definition. Brown (6) used average data for three years in a study conducted in Minnesota. Chang and Crowley (8) defined a storm event as "any rainfall event with no breaks for more than six consecutive hours in duration." Neither the Brown nor the Chang and Crowley paper explicitly stated that the regulatory definition was reflected in their determination of a storm event. Woftiw (51) developed a computer program to use weather radar by deriving storm intensity-duration curves. This technique is limited to use in areas where there are long-term precipitation data and a weather radar service, but offers promise as system to assess storm events.

Another point to consider is the potential for bias in precipitation data. This will be especially important if a researcher is collecting precipitation data as part of the monitoring program. A study by Legates and DeLiberty (23) suggests the typical gaging system used in the U.S. (i.e., a 324 cm^2 gage, 79 cm above ground level, without a wind shield) introduces a systematic bias into the data record. This bias results from a variety of factors including wind effects (especially on snow), wetting losses to the inner walls of the gage, evaporation, splashing, and other factors dependent of the specific gage being used. According to this study, this bias typically ranges from 10 to 40 percent below actual values, with the worst bias being introduced in the winter months. In the U.S., no correction factors are applied to account for such bias, so, researchers may wish to attempt to correct precipitation data using the methods discussed by Legates and DeLiberty. Poissant and Béron (34) encountered similar problems with the design and operation of an automatic sequential rainfall sampler they designed and tested. The areal distribution of the weather stations is also a potential source of bias. The U.S. Department of Agriculture (UDSA) technique for determining rain gage placement density (39) suggests 4 gages are required for a drainage area of 1 mi^2, 15 for a drainage area of 10 mi^2, and 50 for a drainage area of 100 mi^2. The high costs of such an extensive gaging system would need to be carefully weighed against the benefit derived from the additional accuracy of the data collected.

For characterization purposes, occasions may arise where it is not practical to obtain detailed information on stormwater flows, and discharges must be estimated. This situation may be expected to limit the utility of resulting event mean concentration (EMC) data for pollutants of interest. In addition, the confidence in loading data derived from the product of such EMC's and estimated discharges may be similarly limited. In the absence of flow measurement data, an estimate of the total runoff from a representative storm may be made using the depth of precipitation. The formula for this determination has been adapted from EPA's guidance document *Guidance*

Manual for the Preparation of Part 2 of the NPDES Permit Application for Discharges for Municipal Separate Storm Sewer Systems (41):

$$V_r = P \cdot A \cdot 0.009 \cdot IMP + 0.05$$

Where:
V_r = runoff volume (l^3)
P = rainfall depth (l)
A = drainage basin area (l^2)
IMP = percentage of impervious area in drainage basin

Care must be taken when determining the value for the percentage of impervious area. Even small differences between the estimated impervious area and the actual impervious area can yield significant differences between estimated and actual storm event flow rates.

Once these parameters have been determined, they should be refined by analysis of actual data from the monitoring program. Typically, storm hydrographs are used to analyze the characteristics of a given storm. This analysis allows the researcher to determine the total and the peak flow as a function of time during the storm event. Should the values for the estimated flow and actual flow vary by more than a factor of 2, the estimating procedure should be revisited.

There are a variety of models for estimating storm water pollutant loading rates. Andrews (3) provides analysis of three such models: the model used in EPA's *Guidance Manual for Part 2 Applications for Dischargers from Large and Medium Separate Stormwater Systems* (41); the U.S. Geological Survey (USGS) Nationwide Regression Equation (NRE); and the "P8" computer model developed by W.W. Walker. Andrews suggests that the selection of a model will depend mostly on the user's short- and long-term needs; however, his analysis suggests that although it is more complex, over the long term, the "P8" model will offer the greatest utility. Akan (1) also provides an analysis of several models to estimate pollutant loadings. Marsalek (25) suggests that planning-level evaluation of pollutant loads in storm water should also consider the impact of the environmental pollutants. It will suffice to say that estimates from these models will need to be refined once sampling results are available. Once actual data are available, a variety of models can be used to extrapolate such data to unmonitored areas.

Determining Efficiency of Storm Water BMPs

In order to assess the efficiency of a pond, wetland, or grass swale, it is necessary to accurately characterize the mass of pollutants entering and leaving the system. Although each of these systems has a different design basis, most of the pollutant removal mechanisms are similar. Pollutants entering the system are removed by washout without treatment, settling (especially in conjunction with suspended solids), biological uptake and/or conversion, volatilization, or infiltration. Water entering the system either flows out, infiltrates, or is lost through evapotranspirative processes. Expressed as a mass balance around an external system boundary this relationship takes the form:

$$M_d + C_r \cdot V_r + C_i \cdot V_i = C_o \cdot V_o + C_p \cdot V_p + M_s + M_b + M_v$$

Where:
M_d = mass from direct dry deposition (m)
C_r = concentration in precipitation falling directly into system (m/l^3)
V_r = precipitation volume falling directly into system (l^3)
C_i = influent concentration (m/l^3)
V_i = inflow volume (l^3)
C_o = effluent concentration (m/l^3)
V_o = effluent volume (l^3)
C_p = concentration infiltrating into ground (m/l^3)
V_p = infiltration volume (l^3)
M_s = mass deposited as sediment (m)
M_b = mass taken up by biota (m)
M_v = mass lost by volatilization (m)

BMP removal efficiency would then be described by the equation:

$$E = \frac{C_i \cdot V_i - C_o \cdot V_o}{C_i \cdot V_i} \cdot 100\%$$

E = efficiency of system at pollutant removal, %
C_i = constituent influent concentration (m/l^3)
V_i = inflow volume (l^3)
C_o = constituent effluent concentration (m/l^3)
V_o = effluent volume (l^3)

Assessing Flow and Constituent Concentrations

Obviously, at least two stations are required to assess the effectiveness of a BMP at treating storm runoff: one immediately prior to, and one immediately following the BMP. However, additional sampling stations within the unit are advisable, and may yield valuable information as to the degree of treatment achieved as the flow passes through the system and may also assist in identifying the processes responsible. Establishing such a system is relatively easy; typically inflow to

BMPs is from engineered collection systems serving a larger area that directly impacts the BMP through overland flow. For designs where overland flow is the main source of runoff entering the BMP, a diversion system is needed to channel the flow so it can be monitored and sampled.

There seems to be no standard practice for monitoring storm water flows or the collection of storm water samples. Researchers use weirs, flumes, and other primary devices to measure storm water flow past a given point in order to generate a hydrograph that either will allow manual combining of grab samples into a flow-weighted composite or will be used to trigger automatic sampling devices to directly collect flow-weighted samples. For example, Lynch and Corbett (24) used modified broad-crested Trenton weirs with a sharp-crested, 90-degree, V-notch in the center; McTernan *et al.* (28) used a type-H flume for primary flow control and a pressure transducer flowmeter; Izuno *et al.* (18) used 0.80-, 1.6-, and 2.4-cm diameter PVC pipes that had been calibrated to yield a known relationship between discharge and hydraulic head over the pipe; the Occoquan Watershed Monitoring Laboratory (OWML) (30) used Palmer-Bowlus and type-H flumes; and Higgins *et al.* (16) used 3-ft H flumes, culverts, broad-crested weirs, and 90-degree notch weirs. One study on an experimental plot of fescue with similar conditions to a grass swale conducted by Gross *et al.* (14) used a 0.76 by 1.0-m metal weir with a covered H-flume to measure runoff volumes and to collect samples for analysis.

Each of the types of primary devices has advantages and disadvantages. The advantages of weirs are that they are generally low cost, easily installed, and quite accurate. The disadvantages are that they can cause significant head loss in the flow stream and create a pool that may affect sediment transfer past the device. The advantages of flumes are that they are typically are self-cleaning due to higher flow velocities, there is no "dam" across the channel that will cause pooling, and operate with smaller head loss than weirs. The disadvantages are that they are more costly, more difficult to install, can be submerged by extremely high flows, and are often less accurate. However, the self-cleaning nature of a flume may be an important consideration in measuring storm water flows which are often high is suspended solids and flotsam. This intrinsic feature of flumes may minimize problems from the buildup of settled solids behind the structure or by flotsam occluding orifices. Ultimately, the selection of what type of flow measurement system to use will involve "professional discretion."

A secondary device such as a pressure transducer, flow meter, or other mechanical stage-height detector and stage-height recorder are required to record the flow as a function of time in order to apportion grab samples; however, this sampling technique has several drawbacks. First, it is labor intensive. Personnel will have to be available at very short notice to respond to storm events. In large scale sampling programs, commitment of personnel resources is also a major

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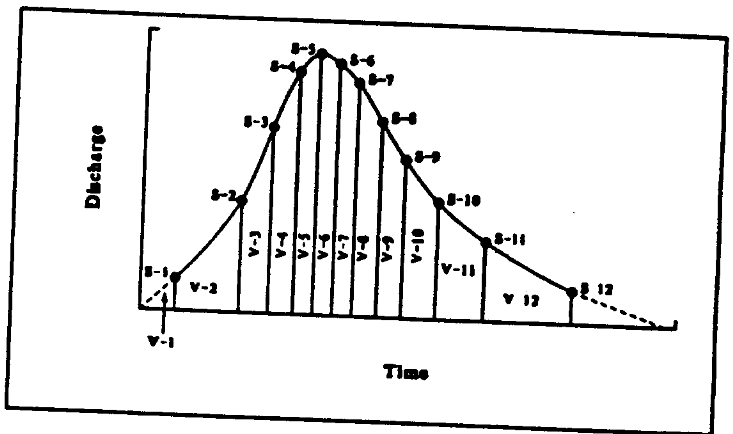

Figure 2. Schematic of Automatically Collected Flow-Weighted Samples.

Notes:
1. With the exception of V_1 (*i.e.*, V-1 above), all V_i (*i.e.*, V-1) are equal.
2. If V_i is very small, the error induced by unequal volume represented by sample 1 and unsampled volume post sample 12, will also be small.
3. If V_i is small, a better representation of flow near peak is also obtained.

contaminant of interest may be found in a higher concentration at the surface or at some other level in the water column. Contamination of groundwater by dense non-aqueous phase liquids (DNAPLs) and the resulting difficulties associated with remediation of this type of contamination is another example. There are a variety of devices that will collect vertically integrated samples. Two passive types of systems are the multi-slot divisor and the Coshocton-type sampler. The disadvantage to using a multi-slot divisor is that a settling tank to remove large sediment particles is usually required to keep the device from becoming clogged. With a Coshocton wheel this typically is not a problem. In a Coshocton wheel water is discharged from a type-H flume onto a rotating water wheel. An elevated sampling slot on the wheel collects an aliquot sample as the wheel traverses the water pouring from the flume. In this way a vertically integrated sample is collected (39). There are also a variety of other more complex devices for collecting vertically integrated samples. Martin *et al.* (26) conducted a study comparing surface grab samples and a cross-sectionally integrated, flow-weighted sampling device. As has been well documented in the literature, there can be considerable cross-sectional variation in suspended sediment concentrations. This becomes important when one considers the pollutants sorbed onto such

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sediments. The study concluded that concentrations of suspended sediments and the associated pollutants were routinely lower in manually composited surface grab samples than in cross-sectionally integrated, flow-weighted samples. Generally, the magnitude of the difference increased with flow rate. One other observation was that grab samples consistently contained more fine-grained sediments than the integrated samples.

One report discussing the use of microcomputers for flow measurement warrants additional discussion. OWML (30) uses an inexpensive microcomputer, an analog-to-digital converter, and a 10 psig contact pressure transducer to monitor storm flows. The computer receives a signal from the transducer (via the A/D converter) and calculates the stage using the following equation:

$$HT = \frac{PT}{1000} \cdot 4.614 \frac{ft}{volt}$$

Where: HT = stage in feet
PT = pressure transducer signal in millivolts
The factor of 4.614 is required to convert ft/psi to ft/volt

The stage is compared to a rating table stored in random-access memory. Each minute, the value for the stage is compared to the value for the previous minute. If the stage has risen at least 0.1 foot over each of the last three successive minutes, a storm event is considered to have begun, and the computer starts continuous monitoring and triggering of an automatic sampling device to collect a flow-weighted composite sample. Base flow data are written to disk every hour and storm flow data every 10 minutes. The data record includes: date, time, stage, flow, discharge, incremental discharge, and whether a sample was collected. The data record is downloaded to an IBM-compatible format for analysis.

Using the value for total volume for a storm event, along with values for the number of samples to be collected and a known sample size for composited samples (both set by the investigator), the volume of storm water flow between collection of each sample may be calculated using the following relationship discussed by Thrush and DeLeon (38):

$$\frac{V_r}{FSI} = N = \frac{V_{sc}}{V_{is}}$$

Where: V_r = runoff volume (l^3)
FSI = volume of flow per sampling interval (l^3)
N = number of samples
V_{is}, V_{sc} = Volumes of incremental and composited samples (l^3)

Typically, the volume of the composited sample should reflect the sum of the volumes required for each of the analyses conducted as part of the monitoring program, plus an appropriate safety factor. However, because it is common that storm event flows will often not yield sufficient volume for all analyses, the researcher should be prepared to prioritize the tests to be performed on incomplete samples.

The sampling routine in the computer program used by OWML is controlled by a flow-totalizing subroutine. This routine is based on the following equation:

$$IV = \frac{Q_i + O_{i-1}}{2} \cdot (t_i - t_{i-1})$$

Where:
IV = volume of flow during interval (l^3)
Q_i = discharge at present stage (l^3/t)
Q_{i-1} = discharge at previous stage (l^3/t)
t_i = time at present stage (t)
t_{i-1} = time at previous stage (t)

The values for IV are summed every minute, and when this value exceeds the value for V_{in}, a sample is collected. By analyzing the times when samples where collected against the hydrograph, the researcher can determine if the sample collected is truly representative of the entire storm event. Ideally, the hydrograph will show that sampling was conducted throughout the entire storm event, with the greatest number of samples being collected during the period of peak flow, and with the desired total sample volume being collected.

One issue that needs to be stressed in using remote and automated sensor and sampling systems is the need for quality assurance for these practices. One journal article by Whitfield and Wade (50) discussed the need to develop new QA procedures when using electronic logging devices and made several specific recommendations regarding QA procedures for electronic monitoring. These procedures fall into three areas: (1) sensor validation in the field, (2) time controls for data loggers, and (3) precision and accuracy of sensors over time.

According to this article, little can be done to verify the accuracy of a sensor using field instrumentation. This is because field instruments rarely are as accurate or precise as a laboratory system, while this is the degree of accuracy and precision required. Since field verification is not practical, Whitfield and Wade recommended operating electronic monitoring systems for a fixed number of day duty cycle, with calibration before the system is taken into the field and recalibration when the duty cycle ends. This allows a correction factor to be applied to the data. Unstated in their paper was the need for careful use of such correction factors. Careful analysis of the data collected is necessary to determine if the "drift" was consistent over time, or whether a catastrophic failure occurred. In the latter case, application of the required correction factor to data collected prior to system failure would clearly be inappropriate.

Regarding time controls, Whitfield and Wade discovered that when more than one instrument is used to monitor a given parameter, strict time control (± 5 seconds), with weekly verification, is necessary to prevent generation of time artifacts. Further, a record of all adjustments must be kept to allow for use of correction factors on data collected. While this may not be necessary for systems where sampling is done over longer periods of time, it is critical during high-frequency, short-interval sampling programs, sampling when conditions are changing rapidly, and sampling where temporal correlation of data sets will be performed. For careful tracking of time, microcomputer-controlled systems with the ability to automatically access outside standard reference clocks (e.g., as is available through Loran-C) can be invaluable.

In the last area, precision and accuracy, Whitfield and Wade identified the need to adjust data to account for drift introduced by deterioration related to the age of the sensor. Their study showed that dissolved oxygen sensors were subject to the greatest degradation in performance. Oxidation-reduction potential and pH sensors demonstrated bias over time rather than degradation in sensor performance. As with the first case, knowing the calibration at the time a sensor is placed into service and the calibration at the end of a given service interval, corrections can be made to account for such fluctuations. Additional studies on how age affects other sensors such as pressure transducers, A/D converters, and other features of electronic monitoring systems would prove useful.

Infiltration Measurement and Collection of Samples of Infiltrated Water

Protection of groundwater resources is of such concern that in 1986 Congress amended the Safe Drinking Water Act (SDWA) to include a new program for wellhead protection. This desire to protect groundwater resources is mirrored in a variety of other Federal and State laws severely restricting or prohibiting the land disposal of hazardous waste. Because infiltration of storm water is the major contributor to groundwater recharge, storm water BMPs need to be designed and operated in a manner that will prevent, or at least minimize, contamination of groundwater. Given the high concentrations of some contaminants in storm water, application of design strategies such as are used for hazardous waste surface impoundments (e.g., use of impermeable clay or synthetic liners) may be advisable. Whipple (48) suggests a programmatic control strategy integrating storm water management and infiltration controls. This proposal suggests classifying areas based on the need to protect surface waters and groundwater;

creating a "harmfulness index" for various runoff sources (e.g., industrial/commercial, residential, and undeveloped areas); and requiring specified BMPs depending on the land use and need for protection. Whipple also proposed some special types of BMPs that might be employed for storm water flows known to be contaminated by various classes of pollutants.

The rate of migration of waterborne or liquid pollutants into the ground depends primarily on the hydraulic conductivity of the underlying soil. Higher hydraulic conductivity allows more rapid movement of water into the ground, and allows pollutants to travel farther into the soil column before other processes, for example, adsorption, begin to retard the migration. Determining the rate at which water infiltrates into the ground (i.e., hydraulic conductivity) is accomplished using a permeameter or piezometric wells. The design and operation of these devices are well described in the literature and will not be discussed in detail. For a detailed discussion of the operation of these devices, the reader should refer to a text on hydrogeology, such as by Fetter (13) or Driscoll (11).

Tensiometers are used to determine the negative head exerted by the tendency of water to infiltrate into the ground. An adaptation of a tensiometer can be used to collect samples of infiltrated water. One study by the OWML (30) used a device constructed by attaching a porous cup (similar to those used on tensiometers) to one end of a five-foot-long PVC pipe, and a rubber plug (to create an airtight seal) to the other end. A sample collection tube was passed through the rubber plug and extended to the bottom of the porous cup and a second tube for applying pressure or vacuum to the system was passed through the rubber plug and extended halfway down the pipe. The device was placed into a bored hole approximately three feet deep, and packed into place with excavated soils to prevent surface water from passing down into the soil alongside the PVC pipe. Twenty-four hours prior to sampling, a vacuum was applied to the shorter tube in the system to reverse the negative pressure head and so draw water from the soil into the porous cup. Samples were collected from the device by applying pressure via the shorter tube, thus forcing the water up the longer tube and into the sample container.

There are many methods for estimating infiltration of storm water. The reader is directed to Driscoll (11) for an excellent discussion of these established methods. One new method to determine volume losses due to infiltration not described by Driscoll was developed by Kalita *et al.* (19). They described a mathematical method to model losses from the side walls and bottom of ponded fields under variable water table conditions. The field aspects of their study used an experimental plot are not readily adaptable to the study of systems such as ponds, wetlands, and swales. However, their results do suggest that vertical and lateral infiltration losses from ponded systems can be predicted with a high degree of accuracy, provided adequate hydrologic data are available. The specific factors that would need to be known include: soil-moisture characteristics, hydraulic conductivity, water table depth, evaporation rate, and pond depth.

Assessment of Deposition in Sediments

There are two reasons to monitor the deposition of sediments in storm water BMPs. First, one of the primary reasons for storm water management systems is to control erosive losses of soil into waterways, hence deposition of sediments in storm water BMPs can severely impact storage capacity. Striegl's study (37) of suspended sediments and metals removal by Lake Ellyn, a small lake outside Chicago, showed that in the course of 10 years, the lake accumulated 8,300 m^3 of sediments, a 13 per cent loss of storage capacity. Second, and equally important, is the cumulative effects of pollutants associated with sediments on the benthic community, rooted vegetation, and the land where spoils from dredging the BMP are ultimately disposed of. This last point is worthy of special comment. Studies by a variety of researchers show that toxic metals from urban runoff accumulate in sediments at relatively high concentrations. For example, Striegl's study found mean concentrations of copper, lead, and zinc were 275, 1,750, and 228 mg/kg dry weight, respectively. Nightingale (29) also found concentrations of lead as high as 1,400 mg/kg. These values for lead concentrations are of particular concern in that they exceed the 1,000 mg/kg concentration used by EPA as a guideline for remedial activities under Superfund. No data are available, but an interesting question arises as to how dredged sediment would fare if subjected to the Toxicity Characteristic Leaching Procedure (TCLP) test to determine if it is a characteristic hazardous waste under the Resource Conservation and Recovery Act (RCRA). Under the Federal RCRA program as described in 40 CFR §261.24, a waste demonstrates the characteristic of toxicity for lead if the TCLP extract concentration is greater than 5.0 ppm (mg/kg).

As was stated previously, the rate of migration of liquid or aqueous pollutants into the ground depends primarily on the hydraulic conductivity of the underlying soil. Higher conductivity allows more rapid movement of water into the ground, and consequently less time for degradative, filtering, or adsorptive processes to occur. Other factors, however, do play a major role in the ability of a pollutant to associate with sediment. Oxidation-reduction potential, pH, temperature, and presence of hydrous gels of iron or aluminum all play a role. Adsorption of pollutants onto sediment, however, is of particular concern. Adsorption is greatest when sediment particles have a high surface area/mass ratio; when sediment particles have negatively charged surfaces, as is the case for silts and clays; when the sediment has a high cation-exchange capacity; and when organic carbon fractions in the sediment are high.

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As described in the EPA handbook *Remediation of Contaminated Sediments* (42), studies of sediments rely on a variety of sampling and analytical techniques to determine the mass of pollutants in sediments or the overall condition of the benthic community. Almost all involve collection of samples using digging tools such as spoons, scoops, and trowels or coring devices such as split-spoon samplers, piston-tube samplers, or augers. *Standard Methods* (2) provides detailed discussion of various sediment sampling devices, protocols, and analytical techniques. Each has its advantages and disadvantages. For example, the very nature of digging tools makes collection of similar samples from a variety of locations problematic and the disturbance of the sample by the collection method suggests that it may not be representative of actual near-bottom conditions. Coring devices are expensive, bulky, and often difficult to handle. Further, core samplers do not work well in sandy soil or in rock-laden areas. Coring devices can also breach the integrity of a engineered structure, opening a migration pathway for contaminants. Last, attributing pollutants concentrations in sediments to specific storm events can be difficult in any system other than a new construction. For these reasons, sediment sampling as part of an effectiveness study poses some serious challenges.

One method described in the literature that may prove a useful tool in the analysis of sediments is to collect the suspended particles that will become sediment before they settle. Walling and Woodward (45) described the design and use of a simple field-based water elutriation system for monitoring particle size and characteristics. Their system uses four glass sedimentation chambers (25-, 50-, 100-, and 200-mm diameter) linked by glass and flexible PVC tubing. A peristaltic pump provides suction to draw water directly from the channel being monitored into the 25-mm sedimentation chamber via a tube that extends nearly to the bottom of the chamber. Water is drawn off this chamber by means of a second tube positioned at the top of the chamber, and is directed to bottom of the 50-mm chamber. This process is repeated until the water has passed through all the chambers. This technique offers several advantages over traditional sampling techniques in that it provides the researcher the opportunity to assess the characteristics of the suspended sediment based on effective particle size. This does, however, require the assumption that the sediment collected in this manner is representative of the sediment accumulating at the bottom of the BMP. One possible modification to the operation of this system for collecting samples from the bottom would be to apply a microfilter to the collection tube, fill the system with filtered water taken near bottom, remove the filter, manually disturb the sediment, and then collect the sample. Another use would be to monitor the effectiveness of the BMP at removal of particles of various sizes as a function of distance from the inlet into the system.

Physical and chemical analysis of samples

The Federal regulations require the use of the standard analytical procedures described in 40 CFR Part 136 or the use of another accepted standard procedure such as those in the American Public Health Association reference *Standard Methods for the Analysis of Water and Wastewater*. There are, however, drawbacks to the use of these analytical methods.

First, the accepted analytical methods for metals yield total metals concentrations (a conservative approach that may not reflect actual impacts to aquatic organisms) rather than the quantity of metals that are readily bioavailable. Typically, the bioavailable forms are free metal ions or those metals weakly bound in inorganic complexes. Papers by Paulson and Amy (32 and 33) discuss the point that the majority of metals in storm water are found sorbed to particulates or in strongly complexed organic forms that are not readily bioavailable. These studies showed that although storm water quality was quite variable, the relationship between bioavailable and total concentrations was consistent. The factors controlling the speciation between dissolved and bioavailable forms include: (1) suspended solids types, (2) pH of the water, (3) total metals concentration, and (4) dissolved organic carbon concentration and character. Paulson and Amy developed a computer model using the EPA's MINTEQA2 to predict the speciation of copper, zinc, and lead into bioavailable and nonbioavailable forms. The results of the modeling effort suggest that in addition to analysis of total metals, an estimate of the bioavailable concentration would be worthwhile in assessing potential impact to aquatic biota.

The second area of concern is that several of the analyses required under the regulations are nonspecific tests. For example, the test for "oil and grease" is non-specific. *Standard Methods* defines "oil and grease" as any compound recovered as a substance soluble in trichlorotrifluroethane or other solvents. This is not specific for hydrocarbons; chlorophyll, organic dyes, and other compounds will be included in the results from this test. If possible, in addition to these nonspecific analyses, it is recommended that during the first few sampling rounds analysis be conducted for a larger suite of specific constituents (for example, chlorophyll) than is required under the regulations. Once the initial rounds of sampling are completed, the suite of constituents can be winnowed down to a manageable and cost-effective suite by eliminating those compounds that are not detected. This is not to say that the nonspecific tests are not valuable tools; Wass (46) used the oil and grease method with moderate success in evaluating the effectiveness of a submerged-flow vegetated treatment system used to treat runoff from a vehicle maintenance yard. The only problem encountered with using this non-specific method occurred when cold-mix asphalt was used to construct berms to redirect runoff at the study site. An unusually heavy rain leached some of the

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constituents from the asphalt, causing a short term increase in the concentrations of oil and grease detected.

Biological Testing

Little definitive work has been published relating efficiency of storm water treatment to the growth of plants or other organisms, nor does there appear to be any definitive standard vegetative analysis for storm water BMPs. Most of the available work discusses either the results of simulated studies or the effects of various agricultural or silvicultural techniques of the quality of storm runoff in streams. For example, Gross *et al.* (14) conducted an interesting study of runoff and sediment losses from tall fescue under simulated rainfall. This study demonstrated that seeding density for turfgrass plays a major role in its ability to act as a sediment trap, and the conclusion was made that well-maintained residential turfgrass stands should contribute to decreasing total runoff volume and sediment loadings. Little other research has been done in recent years on the effectiveness of various grasses as sediment traps or on their ability to assimilate dissolved pollutants. Clearly, this is an area where additional research is needed. The use of reed beds for sludge dewatering was discussed by Kim (20). This study suggests that beds containing the reed *Phragmites* are an effective means of dewatering sludges from 1 to 10 percent solids, suggesting that this species may be a valuable means of promoting evapotranspiration from sediment-laden BMPs operated as dry ponds.

Standard Methods (2) provides an excellent discussion of accepted techniques for sampling macrophyton in method 10400. The reader is directed to this reference for the details of these sampling techniques. It is important to note that these techniques are not specifically developed for storm water BMPs; however, they should certainly be applicable.

Vegetation monitoring was conducted as part of the study by the OWML (30) discussed elsewhere in this paper. The vegetation analysis consisted of identification plant species and a biomass measurement. The biomass measurement was conducted by trimming to ground level the plants in randomly spaced circular plots with an area of 1 m^2. The harvested plants were separated by species, washed with a weak acid solution, and oven dried to constant weight. Below-ground biomass was estimated by excavating a 12 cm by 20 cm soil sample using a piece of PVC pipe. Plant material was manually separated from the soil, washed with a weak acid, and dried. Samples were collected throughout the growing season and the biomass measurement technique repeated to give an indication as to the rate of biomass production. A decomposition study was also conducted by placing a known amount of washed and dried plant litter from known species into 36 porous polyester bags and placing these bags in areas where those plants were dominant. Every month, six bags were removed at

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random and weighed to determine the quantity of plant material that had decomposed. The study did not attempt to correlate biomass production with pollutant removal efficiency, but these procedures allowed an analysis of the rate at which organic matter accumulated in the wetland under study.

Recent regulatory initiatives have seen the inclusion of toxicity testing requirements in NPDES permits, including those for storm water discharges. There are problems with toxicity testing for storm water flows. As pointed out by Isom (17), one "glaring deficiency" with toxicity testing is the lack of a national laboratory certification program. Collins *et al.* (10) pointed out that one of the most difficult problems with conducting toxicity testing on storm waters using fathead minnows or *Daphnia* stems from the 36-hour maximum holding time permitted. Because it can be difficult to determine when there will be a storm event (a fact borne out by local television weather forecasts across the U.S.), the laboratory may not have a ready supply of test organisms of the appropriate age. Further, these tests are expensive. Many researchers have examined the potential for microbial toxicity testing as a means of providing a more cost-effective assay; however, none of these tests have proven to be as effective as the standard test using fathead minnows or *Daphnia*. For example, Arbuckle and Alleman (4) assessed the potential for using the commercially available Microtox® test and a procedure using enriched nitrifier cultures. Their study showed that neither test was as sensitive as the *Daphnia* test. *Standard Methods, 18th Edition*, contains two proposed methods for toxicity testing of aquatic plants. One technique is for Duckweed and the other for a variety of vascular plants. These are laboratory techniques and have not yet been approved, nor have these techniques been adapted to field use.

Conclusion and Recommended Directions for Research

There are many areas still to be explored in conducting research on monitoring of storm water BMPs. One of the most important areas where research could be focused is the development of standard methods for conducting studies of storm water BMPs. Currently, there are few standard practices in the field. This makes relating data from one study to another very difficult at best, and impossible at worst. A short list of proposals for research into standardizing protocols for storm water BMP evaluations follows.

1. Development of standard methods for the calibration and operation of remote sensors.

2. Development of standard methods for metering flow (i.e., use of standard designs of weirs, flumes, or other systems).

3. Development of a standard method for sampling infiltrated waters.

4. Development of standard methods for the collection and analysis of suspended sediments and deposited sediments.

5. Development of methods to relate vegetation assessments to treatment efficiency.

6. Development of a recommended list of analyses for bioavailable metals and development of standard analytical methods for those analyses.

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Monitoring the Effectiveness of Structural BMPs

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Abstract

With the implementation of the NPDES regulations for stormwater discharges there has been a high level of interest in establishing reliable pollution control performance characteristics for structural treatment controls which may be applicable for managing the quality of runoff from urban land uses and industrial facilities.

This paper describes monitoring techniques and data analysis protocols for establishing the pollution control performance of structural treatment controls for stormwater runoff. These techniques are applicable for monitoring oil/grit separators, filtration basins, extended detention basins and wet-detention basins. The following monitoring considerations are addressed:

- General considerations for monitoring instrumentation
- Characterization of contributing drainage area
- Rainfall measurement
- Flow measurement for structure inflow and discharge
- Water quality sampling for analytical characterization of structure inflow and discharge
- Monitoring period of record and storm events rainfall depth distribution
- Structure overflow and bypassing
  - On-line/off-line configurations
  - Storage volume

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- Data analysis
  - Hydrologic mass balance
  - Water quality constituent balance
  - Single event and long-term pollutant control performance

This information is organized to provide guidance for future monitoring activities so that municipalities and industries can implement cost-effective and technically sound BMP performance monitoring programs to support NPDES compliance and BMP specification development for future stormwater management applications.

Introduction

The purpose of this paper is to provide guidance for the development and implementation of effective pollutant control performance monitoring programs for structural stormwater runoff treatment controls.

The monitoring of pollutant reduction performance of structural treatment controls for stormwater runoff presents numerous challenges. Typically, treatment structures such as oil/grit separators, filtration basins, extended dry-detention and wet-detention basins are designed and constructed to meet minimum capture volume/surface area specifications to meet prescribed regulatory requirements and to meet specific site physical constraints such as slope limitations, high ground water elevation, and integration with site plan layout demands. During structure design, little or no consideration is made for siting monitoring stations to characterize inflow and outflow flow rates and water quality improvement performance. Therefore, the usual challenge is to retrofit monitoring equipment to existing structures.

This reality typically dictates that each treatment structure selected for monitoring be evaluated individually to establish feasible methods for reliable flow measurement and water quality sample collection. Also, the basic flow configuration of the structure bears on the extent of monitoring required to characterize structure performance under the range of hydrologic events, both small and large, that occur in the location of the study. On-line structures can be subject to resuspension and washout of accumulated pollutant materials during large storm events and pollutant flux associated with dry weather baseflow can be significant. These occurrences can have a significant effect on long-term pollutant control performance. Properly designed off-line structures are not subject to extreme event

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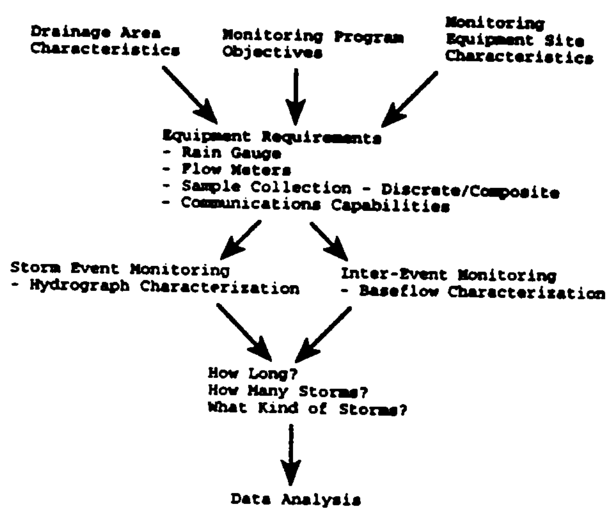
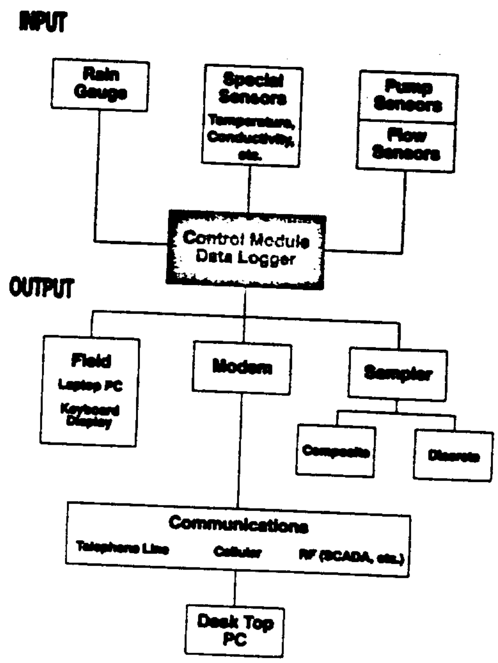
"washout" processes; however, long-term performance monitoring of off-line structures must take into account bypassed volumes that do not receive any treatment. Also, the control performance of wet basins which combine complex physical, chemical and biological pollutant reduction mechanisms is significantly influenced by the variations in hydraulic residence time that occur in response to the normal variation in rainfall/runoff volume and inter-event time periods that are part of the expected "normal" hydrometeorologic cycle. Therefore, accurate characterization of the integrated, long-term pollutant reduction performance of these structures can require intensive sampling programs that address characterization of a wide range of wet weather and dry weather inflows and outflows.

The flow chart below presents the design and implementation steps required for an effective structural treatment control performance monitoring program. The remainder of this paper presents recommendations and guidance on how to address these requirements.



<u>General Considerations for Monitoring Instrumentation</u>

Because of the difficulties associated with timely field personnel mobilization and achieving consistent manual flow measurement and sample collection techniques for extended monitoring program periods, this paper is focused on the application of automated monitoring systems only. Therefore, a limited overview of automated systems is included to highlight the capabilities of these systems. The primary components and configuration relationship of an automated monitoring system are illustrated in the following diagram.



Automated Monitoring Station.

The major component of an automated system is the control module/datalogger microprocessor, which functions to interrogate and record input data from external sensing devices including the flow meter and rain gauge, can perform complex calculations based on these inputs and produce signals to drive ancillary devices, including the automatic sample collection unit and remote communications devices. This flexibility allows for these automated systems to detect storm flow conditions and initiate sampling with no human interaction.

Remote communications capabilities allow for: 1) sample collection rates to be reset to meet variable storm magnitude or baseflow conditions, 2) effective, real-time tracking of storm/hydrograph/sample collection progress, and 3) efficient direction of field crews for sample recovery. Additional equipment considerations for rainfall and flow measurement are included in later sections of this paper.

Characterization of Contributing Drainage Area

It is important to characterize the contributing drainage area tributary to the treatment structure in order to: 1) establish anticipated peak flow rates for the range of storms to be monitored, and 2) identify all significant tributary areas to the structure.

Establishing the anticipated peak flow rate is important for selecting and sizing the inflow primary flow measurement device, such as a weir or flume. Since storms of a depth less than the 2-year return period storm typically account for more than 90% of annual rainfall, designing the flow measurement device to meet the 2-year storm peak flow criteria is a good target. Standard hydrologic methods such as SCS TR-55 can be used to estimate peak flows and total design storm runoff volume based on tributary area, soil type, slope, and land use. It is also recommended that hydrographs be generated for the smaller more frequent storms, such as the 3-month and 6-month events, to establish the nominal flow metering range to allow adequate characterization of these more frequent storms.

A structure may have multiple inflow points, which will require multiple monitoring sites, or may have significant overland sheet flow contributions to the basin between the inlet and outlet. There are additional equipment and operation costs associated with the increase in monitoring sites, and increased pollutant control performance data analysis uncertainty associated

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with characterizing inflows associated with unmonitored direct overland flow contributions.

Assuming that performance monitoring of structural treatment controls will be coordinated with other land use related discharge quality monitoring activities, information on land use distribution, percent impervious cover, and age of development should be compiled so that the inflow characterization data is useful for establishing land use related stormwater quality impacts.

Rainfall Measurement

Although rainfall measurement is not specifically required to measure structural control performance, acquisition of incremental rainfall data in the tributary watershed area is strongly recommended because inflow runoff quality may be influenced by rainfall intensity, depth, and duration and, most importantly, rainfall records are necessary to establish the range of storms for which structural control performance has been monitored. It is recommended that rainfall be recorded with a tipping bucket rain gauge with a minimum sensitivity of 0.01 inch with input to a datalogger.

Flow Measurement - Inflow and Outflow

Flow measurement can be accomplished using any of a number of primary measurement devices such as weirs and flumes. A good reference on these devices is the ISCO Open Channel Flow Measurement Handbook (1992). Flumes are recommended over weirs because of their self-cleaning capability, lower head loss, and reduced influence from approach velocity. Weirs must be periodically cleaned to remove deposits of sediment or other solids upstream of the weir or accuracy will be affected. However, weirs are generally recognized as being more accurate than flumes. Properly installed and maintained, most types of weirs and flumes will produce better than ±10 percent accuracy.

The primary factors which affect the selection of type and sizing of the primary flow device are the minimum and maximum range of flow rates to be measured and any limitations associated with the existing site physical configuration. Sizing of the primary flow device for inflow is based on the hydrologic analysis of the inflow monitoring point tributary drainage area discussed previously. Sizing of the primary flow device for outflow should be based on level pool routing of inflow hydrographs for wet-detention basins and design drawdown flow rates for extended detention and filtration

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basins. Since oil/grease separators generally have a small storage volume, inflow rate is typically assumed equal to outflow rate and only one flow monitor is installed and is used to provide flow information to drive both the inflow and outflow automatic samplers.

For example, Palmer-Bowlus flumes are recommended for round pipes because of ease of installation. H-flumes have been effectively used at pipe/culvert outfall locations. Weirs typically are best suited for measurement of open-channel flow where low approach velocities can be achieved by increasing weir height and removal of accumulated materials from the upstream face is practicable. Also, compound weirs can be configured to provide very broad flow ranges beyond the capacity of a single flume or simple weir. If a weir is employed under non-"ideal" siting conditions (i.e. inadequate crest height, high velocity of approach), or if better than ±10 percent accuracy is desired for normal installations, it is recommended that a specific rating curve be developed based on independent volumetric flow measurements such as timed gravimetric, tracer dilution, or velocity-area techniques.

In addition to weirs and flumes, several manufacturers offer instrument systems which combine an electromagnetic or sonic-doppler velocity sensor with a flow depth sensor to determine flow rate through a velocity-area continuity computation. These types of systems are costly and it is best to conduct independent flow verification calibration to correlate velocity measurements with actual average flow velocity. Properly installed and calibrated, these devices can produce flow measurements within ±2 percent accuracy for flow velocity up to 20 feet/second.

Flow measurement by weir, flume or velocity sensor requires concurrent depth of flow measurement. Recommended instrumentation includes direct contact electronic pressure transducers, bubbler/isolated pressure transducer combinations, and electronic ultrasonic water surface level sensors. The bubbler and pressure transducer are located in the flow stream, whereas the ultrasonic level sensor is a top-down sensor that measures the distance to the water surface from a mounting location in the airspace above the flow path.

All of these level sensors provide reliable operation and are capable of sensitivities of ±0.1 inch in typical applications.

Water Quality Sampling for Analytical Characterization

Because of the time variation of both flow rate and water quality constituent concentrations that occur in stormwater runoff during storm events and in the outflow from treatment structures, pollutant control performance monitoring requires the collection of flow-weighted composite samples over both the inflow and outflow hydrographs. Additionally, if dry weather inflow is present, inter-event (between storms) flow monitoring and sampling is required for on-line structures such as wet-detention basins in order to quantify water quality constituent flux under dry weather-baseflow conditions.

Storm Event Monitoring. Flow-weighted composite samples should be collected using an automatic sampler driven by time integrated flow measurements (flow paced) to produce either a single collection container direct composite sample or to produce flow-paced discrete samples in separate containers. Both methods have distinct advantages. Direct compositing allows for frequent flow-paced samples to be taken over a storm hydrograph to assure development of an event mean concentration (EMC) composite that is based on many sample aliquots throughout the rising, falling and peak flow periods of the runoff hydrograph or treatment structure discharge hydrograph. Laboratory analytical costs are minimized in comparison to discrete sampling since only a single composite requires analytical characterization.

In comparison, discrete sampling allows the characterization of pollutograph effects during storm events because the individuality of each flow-paced sample aliquot is maintained by separate containers. This permits water quality constituent characterization of each individual sample to identify the time variation of concentration (pollutograph) and/or the mathematical compositing of individual sample aliquot analytical values to produce EMC values. This method also allows for the flexibility to prepare a flow-weighted, manually composited sample from a portion of the individual sample aliquots and reservation of the aliquot remainder for individual analytical characterization. As an example, this approach can be used to produce pollutographs for lower cost indicator parameters such as conventional pollutants and making a manual composite EMC determination for the more costly toxic organic constituents.

A good target for hydrograph water quality constituent characterization is to collect aliquots over at least 80 percent of the total storm hydrograph volume.

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The initial sample of treatment structure inflow should be collected early in the rising limb of the hydrograph to capture any initial flush effects. Automated sampling systems incorporate the ability to initiate sampling at a predetermined depth level and to convert level into flow rate for flow-paced sampling throughout the inflow or outflow hydrograph. The pacing of sample collection should be based on anticipated storm runoff volume conditions. This can be accomplished by developing a table of flow-pacing rates (i.e. cubic feet of flow/ sample aliquot) as a function of anticipated rainfall amount to produce the desired direct composite volume or number of discrete sample aliquots. It is important that the sample aliquot collection rate not exceed the mechanical capacity of the automatic sampler. Typically, samplers can cycle (system purge and sample collection) as often as once every 60 seconds. It is also recommended that a minimum of eight (8) aliquots be collected of treatment structure storm related inflow and outflow for meaningful EMC or pollutograph characterization. It is best if these samples represent the initial, peak and recession regions of the hydrograph.

Since treatment structure outflow rates are attenuated from inflow rates because of storage volume dampening, outflow hydrographs can be extended over significantly longer time periods than inflow hydrographs, so sample aliquot collection must occur over a longer time period.

It is recommended that minimum analytical characterization include TSS, BOD, COD, nutrients (total phosphorus, dissolved phosphorus, TKN, NO_3+NO_2), and total and dissolved metals (copper, lead, zinc, cadmium).

Inter-Event Monitoring. For wet-detention basins, significant outflow flux of algal materials and associated oxygen demand, nitrogen and phosphorus can occur under inter-event baseflow conditions. Therefore, for structural treatment basins which are subject to significant inter-storm event baseflow throughput, it is important to gain an understanding of water quality constituent flux during these low flow periods. This can be accomplished by collecting weekly or daily inflow and outflow flow composite samples during inter-event periods using the same automated monitoring system put in place primarily for storm event monitoring. Sample collection flow-pacing parameters can be reset during inter-event periods to collect adequate characterization samples. These long-term inter-event monitoring activities typically target a limited number of indicator pollutants.

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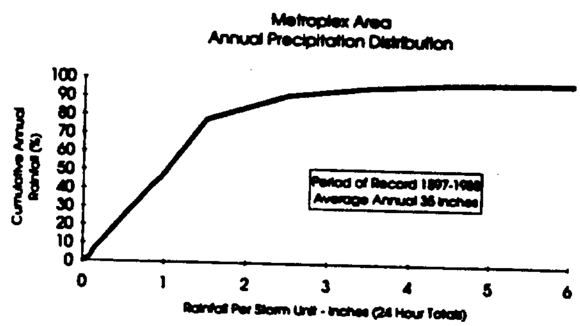
<u>Monitoring Period of Record and Storm Event Distribution</u>

It is desirable that the monitoring program include a distribution of sampled events that is representative of the average annual rainfall event depth distribution. The following figure is an example 24-hour total rainfall event distribution for Dallas, TX which illustrates that 50% and 90% of average annual rainfall occurs for storms of a depth less than 1 inch and 2½ inches, respectively.

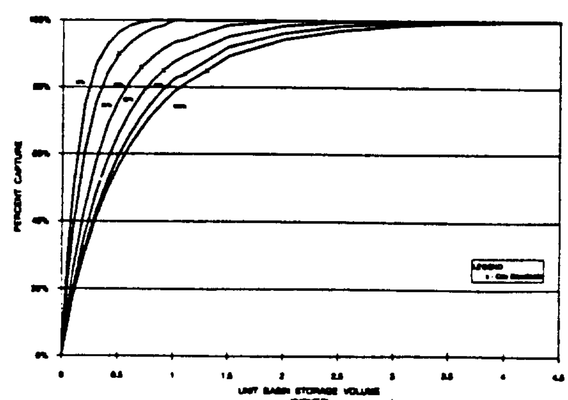


Having actual monitored event-specific rainfall data at hand, the investigator can make astute decisions on future target storms for priority monitoring, or to assess what the previously accumulated control performance data set represents with respect to average annual conditions. Target storm identification should also address identification of seasonal storms (wet/dry, winter/summer) for monitoring through review of long-term monthly average rainfall totals.

Although it is always desirable to acquire as much treatment structure inflow and outflow data as possible, allowable study time and fiscal constraints must be considered in setting realistic data acquisition targets. It is recommended that monitoring programs target acquisition of between 10 and 20 storm event inflow/outflow and baseflow data sets over a two- to three-year period. In the urban land use environment, storm depth must typically exceed 0.2 inch before sufficient runoff/inflow is produced to allow treatment structures inflow/outflow automated sample collection. Of course, this generalization is influenced by site-specific land use/impervious cover conditions. The collected treatment performance data should be reviewed for consistency (i.e. good inflow/outflow water balance, storm volume characterization >80%) and representation of local hydrologic conditions; then, judgements made for future monitoring data needs as necessary.

Effects of Treatment Structure Overflow and Bypassing on Monitoring Requirements

Treatment structure overflow and bypassing impact long-term pollutant control performance. Off-line structures such as extended detention basins and filtration basins are designed to isolate and treat a specific design volume of stormwater runoff. Runoff volumes which exceed the storage volume capacity of the structure are bypassed untreated. In assessing the long-term control performance of off-line structures, bypassing must be taken into consideration. To illustrate this impact, the following figure presents annual capture efficiency curves for off-line basins with 40-hour basin drawdown as a function of storage volume and tributary area percent impervious cover.



These curves were developed for Austin, TX using 50 years of hourly rainfall data and field-verified runoff coefficients. The percent of annual runoff that is not captured is bypassed untreated. This can be addressed in a monitoring program by conducting inflow/outflow water balance calculations to quantify bypasses, or a third flow monitor can be installed downstream of the off-line flow splitter to quantify bypasses directly.

As previously mentioned, wet-detention basins typically function in an on-line configuration and, as such, all surface discharge from the basin is overflow. Since hydraulic residence time affects the dissolved pollutant conversion processes associated with rooted plant and algal biological uptake, water column chemical conversion, and water column/sediment interaction, it is important that performance monitoring programs target a range of storm event and inter-event sample collection activities to address this highly varied range of basin operating conditions. This is important in order to establish the average and expected variation in control performance under the influence of the local hydrologic cycle. For example, extreme events which produce high flow rates can resuspend settled materials and produce "negative" pollutant removal efficiencies, hydraulic short-circuiting of flows can occur if basins are designed without sufficient baffling or length to width ratios and, thus, greatly reduce pollutant control performance. Additionally, inter-event flows can convey significant pollutant mass loads.

Also, dry basins such as extended detention and filtration basins which are configured on-line are also subject to resuspension/washout during extreme storm events and target storms for the monitoring program should attempt to quantify this occurrence. *Therefore, the performance variability associated with on-line treatment structures is much higher than off-line systems and this should be addressed through more extensive monitoring plans.*

Data Analysis

Basic data analysis for each monitored storm event should include: 1) water quality constituents inflow/outflow EMC determination from the analytical laboratory results in combination with the inflow/outflow flow data if time-paced discrete sample collection was employed, and 2) performance of an inflow/outflow water mass balance calculation to assure that inflows and discharges have adequately accounted for any gains or losses and to make any necessary assumptions. All storm data sets are then used together to calculate period of record pollutant removal control efficiency.

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EMC Determination. Determination of EMC is a straightforward procedure. Obviously, for direct composite sampling, the analytical laboratory results are the EMCs. For discrete aliquots that are equally flow-paced, EMC is determined by summing the discrete concentration values and dividing by the total number of samples. Time-paced or variable flow-paced discrete aliquots must be mathematically weighted by the percentage of total flow each represents over the hydrograph.

Water Balance. Inflow/outflow water balance calculations allow the investigator to determine if flow monitoring equipment is operating accurately and to account for miscellaneous inflows and losses such as groundwater infiltrative losses or gains, evaporation in wet ponds, and any tributary drainage area between the inflow and outflow monitoring locations. Each of these considerations is site-specific; however, water balance accounting and subsequent follow-up investigation and subsequent assumptions to establish the fate or source of flows and associated water quality constituent loads is important when establishing accurate pollutant load reductions for treatment structures.

Pollutant Control Performance. Ideally, monitoring studies will generate a flow and water quality constituent database consisting only of paired inflow and outflow data resulting from the same storm events or baseflow periods. For characterization of long-term control performance, it is important that evaluation be based on long-term data (multiple years) which quantifies pollutant loadings at the inflow and outflow points over a wide range of hydrologic conditions. Although single event removal efficiencies can be calculated, it is strongly recommended that long-term inflow and outflow records be combined to establish representative long-term performance.

Calculation of Removal Efficiencies. The effectiveness of treatment structures is usually expressed as an efficiency in terms of the relative change between input and output of the structure. As an equation, it takes this form:

$$\text{Efficiency} = \left(1 - \frac{\text{output}}{\text{input}}\right) \times 100$$

There are several methods for developing removal efficiencies. Each method is dependent on the monitoring arrangement for the treatment structure site, as well as the suitability of the data set for analysis.

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Where possible, paired inflow and outflow storm data should be used in computing pollutant removal rates for the selected constituents. Before calculating removal efficiencies, it is useful to assess the monitoring data and eliminate storms with anomalous data. Data inspection can be performed graphically (histograms, box plots, scatter plots, etc.) and/or through the use of simple statistics such as mean, median, standard deviation, and coefficient of variance.

Data should be reviewed for any inconsistencies between inflow and outflow volumes and concentrations. A storm may be eliminated if there are documented monitoring problems. Note other outlying data points and eliminate those events from analysis.

Long-Term Removal Efficiency. Of greatest interest to engineers and planners is the typical long-term removal efficiency for a given treatment structure, since the variation in efficiency for individual storm events can often be significant. Mass loadings measured entering and leaving the pond over the entire monitoring interval are summed separately and evaluated using the formula:

$$\text{Efficiency} = \left(1 - \frac{\text{total outflow load}}{\text{total inflow load}}\right) \times 100$$

This method is only appropriate for storm events and baseflow periods with paired inflow and outflow data which exhibit an accurate flow balance. Significant error can be introduced by using unpaired data and/or data records which have significantly different inflow and outflow volumes (poor water balance).

Median Loading Rate Reduction. Past experience has shown that most runoff processes are lognormally distributed and that comparisons of the median values will provide an adequate estimate of the pollutant removal efficiency. An alternative approach for calculating removal efficiencies also uses the entire paired storm data set generated at each monitoring station. In this method, the event mean concentration (EMC) for each storm is multiplied by the total storm flow. Statistically analyze the entire population of inflow and outflow storm loads for all events to determine the median storm event loading at the inlet and outlet of the treatment structure. Removal rates are computed using the following formula:

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$$\text{Median Efficiency} = \left(1 - \frac{\text{median outflow load}}{\text{median inflow load}}\right) \times 100$$

Accounting for Bypasses. To estimate control performance for off-line treatment structures, the effects of bypassing must be taken into consideration. If the inflow and outflow monitoring data is solely for the treatment structure and does not include quantification of bypass flows, then long-term pollutant control efficiencies should be reduced based on estimates of percent annual runoff bypassed developed from estimates of percent annual capture for treatment as presented previously. Using this technique, measured basin efficiency is reduced by the product of basin average annual runoff volume capture fraction, as follows:

$$\text{Actual Efficiency} = \text{Basin Efficiency} \times \begin{matrix}\text{Annual Runoff}\\ \text{Capture Fraction}\end{matrix}$$

Summary

Monitoring the pollutant control performance of structural treatment controls for stormwater runoff quality management is a complex process which requires simultaneous measurement of flow rates into and out of the structure, with concurrent collection of water quality samples. Typically, monitoring stations must be retrofit to existing inflow and outflow structures and site physical constraints may not allow for "ideal" flow metering conditions to be attained. Under these conditions, development of *in situ* primary flow measurement device rating curves is recommended. Also, if there are significant water gains or losses between the inflow and outflow monitoring locations, flow and quantity estimating techniques should be employed to "close" the water balance for each monitored event or monitoring period if baseflow is included.

In comparison to off-line structures, on-line structures require more extensive monitoring to characterize performance under the normal range of hydraulic residence time variations and both extreme storm high flow and low flow dry weather conditions to which these devices are exposed under local hydrometeorological conditions. Off-line structures, while not subject to the full range of hydrologic variation of an on-line device, do allow bypassing of untreated runoff in excess of basin storage volume. Bypass must be taken into consideration when establishing effective pollutant reduction efficiency for off-line devices.

Establishing long-term pollutant control performance for structural treatment controls requires a long-term paired inflow and outflow database. There are no shortcuts. Monitoring plans should consider the local average annual depth distribution of rainfall events to identify "target" storm magnitudes and wet/dry seasonal differences. Dry weather baseflow, if significant, requires a sampling plan for inter-event periods to quantify pollutant inflow/outflow flux during non-storm periods.

Control performance should be evaluated based on reduction in water quality constituent mass loads from long-term paired inflow and outflow data sets with good water balance data or with water balance resolved through accounting estimates for water quantity and quality.

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SESSION VIII: Protocols for Monitoring Non-Structural BMPs

DISCUSSION

Monitoring BMP Effectiveness at Industrial Sites
Roger Bannerman

Site selection required so that each area tested drains to a single inlet.

Testing of sampling methods showed that flow composite, time discrete, and time composite sample gave nearly identical values of geometric means for constituents, but first 30 minutes sample was always higher (first flush).

Reproducibility of first 30 minute samples turned out to be poor.

Conclusions:

- If sampling is close to the source, Source Area Method of sampling is best.
- If sampling is at end-of -pipe, Time Composite Method is best.

Questions/Comments

Question: Did list of industries include industries only or construction also?
Answer: Industries only.

Question: How many samplers are being built and who is going to pay for them?
Answer: Still need to test these and see how many are needed per site for reproducibility. Expect cost to be about $750/sampler. Industry will bear the cost.

Question: Why was H flume selected over others?
Answer: Provided better flow conditions, and cost was not a factor. Flume was calibrated, and they found the manufacturer's curve was wrong. Had to develop our own rating curve.

Question: With source area samplers is plugging a problem?
Answer: Yes that's a problem, but with redundant samplers, not all of them plug.

Question: Do heavy solids go in and light solids not? Is there a size preference?

Answer: We will look at this more carefully, but have assumed that it is not a problem.

Comment: (Bannerman) We were surprised that timed composite samples gave comparable results, at less cost. A practical exercise to find most economical and easiest method which still gives reasonable results.

Monitoring of Wetlands, Wet Ponds, and Grassed Swales
David Green, Thomas Grizzard and Clifford Randall

EPA has not established standard protocols for field methods using remote sampling/analysis. Problem is measuring multiple inflows, identifying a pollutant of concern, and recognizing that pollutants aren't removed from the system, but simply change medium.

There is no QA program for monitoring BMPs. A QA program should be developed in order to lend validity to findings. Need to integrate QA and QC.

Need QA practices for sensor validation and time controls. Account for drift over time to establish precision and accuracy.

Must include short duration, high intensity storms, which carry a lot of TSS and other pollutants.

A long term data record of pollutant flux in and out is necessary to determine BMP efficiency.

Calibration of flow measuring devices is a must using dilution methods like salt or dyes, injection methods, etc..

Flow weighted composite samples are preferred.

Questions/Comments

Comment: One of the most difficult parameters to measure is rainfall. Storms have preferential directions, and rain gauge network must be oriented to allow for this. There are models which can interpret what a storm looks like from a limited set of samples. Radar measurements my be a solution.

Comment: Remember that in assessing BMPs, it is the flow hydrograph, not the rainfall, that drives the system.

Comment: Caution on use of lithium chloride for a tracer. Be certain it gets adequate mixing (this is true of any dye tracer), or it will selectively absorb to solids

Comment: Need to check the equation for mass flux.

Comment: BMPs include structural controls and non-structural controls -- usually thought of as source controls; but some source controls use structures as part of the control, e.g. building covers over chemical storage areas, or spill containment devices, and one always wonders if a swale or buffer strip is a structural or non-structural control. Therefore, it is recommended that we cease to use the terminology "structural" and "non-structural" controls, and instead use the terminology "source" control BMPs and "treatment" control BMPs.

Comment: (Green) Not taking the step of doing toxicity testing - instead are measuring total metals.

Monitoring the Effectiveness of Structural BMPs
George Oswald and Richard Mattison

To adequately monitor these devices, an automated sampling station must be used.

Cannot ignore a water balance around the BMP.

Questions/Comments

Comment: I am glad to see that you recommend use of modeling to evaluate BMP performance.

Comment): (Huber) Using a model to help develop monitoring protocol is a good idea.

Comment: Temperature should be considered - not difficult to collect the data (available from pressure transducers that are temperature compensated!).

Question: Should quality of flows that are bypassed during large storms be monitored?
Answer: No, it is the same as the inflow upstream of the diversion.

Question: What about measurement of temperature?
Answer: Can't recall if temperature is measured.

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Comment: There is some disagreement about whether event-by-event measurement is the way to go. Some believe that we should do probability distributions on the inflow and the outflow; the difference is the efficiency. Oswald believes paired data is the proper way to measure efficiency.

Question: What is the accuracy of the electromagnetic flow measurement device?

Answer: They rely on turbidity and bubbles and are good, but require calibration.

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SESSION IX: Closing Session

DISCUSSION

There were no formal papers in this session, but the following summarizes closing remarks, as well as questions/comments from the participants.

Mike Cook

Flexibility versus direction - best is probably clear direction combined with flexible implementation:

- Maximum extent practicable - needs definition.
- Water quality standards - depends on CWA, but if no reauthorization, will be considering again, as a matter for EPA policy.
- Monitoring requirements - watershed approach/indicators, are good ideas, but what should be emphasis? In long run shift away from loadings and more toward watersheds and national indicators.

Monitoring - EPA is probably requiring too much, and some monitoring could be redirected to watershed protection. EPA should require less chemical and more biological monitoring. We need to develop measures that give confidence. Expect that this will be an important subject at the next conference.

BMPs - There is, in effect, widespread experimentation. We need much more engineering work on design, performance, and cost-effectiveness.

Illicit connection programs are well developed.

Broader federal action needed on:

- Diazinon

- Copper from brake pads
- Atmospheric deposition - nitrogen in lakes, maybe pesticides; need liaison with air programs.
- Need standardized approach to research and reporting - something like that proposed by Ben Urbonas.

Selling the program:

- Need indicators of progress in short term.
- Clear targets and measures - not sure EPA should set them; initially may be left to state and local permit writers, nationalizing them later.
- Outreach to electorate and elected officials.
- Citizen monitoring could have a place with proper direction, which increases their interest; such monitoring is spreading rapidly with emphasis on a watershed approach.

Future directions - Documenting Performance of BMPs and Monitoring Techniques

- Effective BMPs and monitoring are heart of success
- Funding should come from regulated parties; not more money, just use for more coordinated effort.
- Set priorities for evaluating BMPs and monitoring - by regulated parties.
- Agree who will do what - by regulated parties.
- Agree on format and medium for communicating results - by regulated parties.
- Ensure peer review - by regulated parties.

Future directions for EPA:

- Better training on the flexibility (in monitoring requirements/programs) that exists in current regulations.
- Support studies of BMPs and monitoring - 104b(3) was hard to get through Congress but being well used.
- Identify indicators of progress.

- Integrate stormwater management into watershed approach.

Christine Andersen

The greatest difficulty we face is that we are learning while we are doing.

Issues of monitoring driven by:

- Need for understanding of the system we are trying to regulate.
- Regulatory requirements.

The best solution is for regulators and regulatees to work together, but since we are learning as we go, this has been problematic.

Water quality standards are a red herring - such standards not used in Canada and New Zealand. They are an energy drain, and are not supported by anybody as being cost effective, which harms communication between regulators and the regulated community, and confuses what research should be done.

What we're talking about with BMPs is not the elimination of pollution, but rather changing the disposal means.

BMP monitoring is important. We need a better mechanism to report information (including standardized reporting) so it can be widely used. Would like to see focus of energy, using resources going into municipal permits to generate this information, especially information on how we have improved the environment - relate any performance information back to resource gain. Utilize resources so that required information in permits supports research efforts, and vice versa.

Source control most critical fundamental need. Analogy to what lead-free gas did for us - federal action could help here. Would avoid dilemma about groundwater as we install stormwater retention facilities - need to understand before communities go heavily into this.

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Funding constraint at local and state levels is impediment to goal of better environment. Funding situation is often worse than EPA's, but EPA is in the driver's seat with NPDES.

Need flexibility on both sides.

Larry Roesner

Throughout the course of this conference, it has become increasingly apparent to me that the course we are taking with the NPDES stormwater permitting program is going to cost municipalities a lot of money, but is not going to result in any significant improvement in the quality of our urban receiving water systems. This is due principally to the fact that the control strategy singularly targets chemical constituent reduction in urban runoff. It completely neglects the effects of flow on ecosystem integrity, and relies on presumed, rather than documented, cause-effect relationships between chemical concentrations in stormwater and damage to, or degradation of, the receiving water ecosystem.

I strongly believe that reestablishment of urban streams can most cost-effectively be accomplished with the following prioritized approach.

- Reestablish aquatic habitat and implement flow management in urbanized areas. Our urban streams have been decimated by past and present drainage, which is concerned with flow control only of the large storms - those that occur with a recurrence interval of 5 years or more. To re-establish aquatic habitat requires that the pre-development frequency distribution of runoff peaks for small storms must be reestablished in urbanized areas, and preserved in developing areas. This means drainage controls for new development that require control of the runoff from all storms, large and small. In existing areas, some control may be provided by instream flow controls for small storms such as drop structures that retard velocities and provide in-stream storage. Bank stabilization and habitat creation are other practices that should be investigated.

- Apply housekeeping (source) controls on new and existing urban areas and treatment controls on new development. It seems that toxic concentrations do occur in stormwater, but there is a question about the degree of stress they cause because of the short-term exposure of the biota to these toxicant concentrations. Our inability to show cause-effect relationships between urban runoff quality and the health of the biota is for one of two reasons: Either the flow impacts of urbanization are so great that they overshadow the adverse chemical effects, or the adverse chemical effects are, in general, small. Until we know, we should not expend large sums of money controlling the chemical quality of urban runoff. These dollars should go instead toward recreation of habitat in the urban receiving waters. Control of chemical pollutants should be limited to source control through good housekeeping practices, which includes spill management, removal of illicit connections, and control of illegal dumping into drainage systems.

- Establish a public awareness/education/participation program on urban aquatic ecosystem improvement and management. Unless the public supports the protection and enhancement of urban stream environments, it will never happen. The public must police itself with regard to proper chemical handling, litter, and illegal dumping, both at home and at work. Education and awareness are key ingredients to achieving this, and should be a priority program for municipalities.

- Develop baseline sampling programs to document improvement in the ecologic system resulting from the above activities. The NPDES stormwater monitoring requirements need to de-emphasize chemical monitoring and add bioassessment and habitat assessment. We should adopt a chemical parameter list similar to that proposed by Eric Strecker in the Session VI workshop, and turn our attention to bioassessment and habitat assessment. Eric Livingston is developing an excellent protocol; or maybe we can use a simplified procedure, such as the one suggested by Earl Shaver and John Maxted, for use in urbanized areas that will give us direction for short term improvements in urban aquatic systems. Receiving water sampling should emphasize:

- Standard biological surveys on a biannual basis to document improvement or degradation in the aquatic ecosystem.
- Some tissue sample analyses for selected toxic or carcinogenic constituents that bioaccumulate and are known to be present in stormwater.
- Sediment sampling for selected constituents known to be in stormwater to trace illegal connections and/or dumping, and to monitor trends in sediment concentrations of herbicides, pesticides, PAHs, etc.

This information can be used to develop targeted enforcement actions to protect and/or enhance the quality of receiving water ecosystems.

In order for this approach to work, the permitting and enforcement approach of federal and state agencies must change fro a command and control approach, using strict effluent limits and technology-based permit language, to a softer approach where compliance is measured in terms of documented improvement in the aquatic ecosystem. Permit criteria for judging the success or failure in achieving permit goals should be negotiated with the permittee, and should include such things as biodiversity indices, and limiting or reducing chemical concentrations in animal tissues and sediments, as required to protect human health and the ecosystem. To accomplish this, permit writers will need additional training and experience to deal with the technical and administrative complexities that are inherent in such an approach. I see no other affordable way to improve our urban receiving water systems.

<u>Comments/Questions</u>

Comment: It seems that if EPA is to be successful, the key person is the local administrator. These administrators need to be viewed by the public as in charge of a local effort to improve the environment.

EPA needs a complete restructuring - combine various wastewater programs rather than continue the present balkanized system.

EPA should demand and support local water management as a unified effort.

Comment: Oregon has a state committee, like the one in California, which is pro-active and which goes to the state legislators with recommendations on what the state regulations should say.

Comment: Agree with enforcement comment, but how to get the message across to those who do enforcement? They need to be in the loop in a positive, rather than just punitive, way. What is the reality of what is achievable?

Comment: Communication gaps between regulators at different levels a problem. EPA would appreciate advice on how to improve permit writer training.

Comment: Disagrees with statement that EPA should not set standards.

Comment: Agrees with shifting money from monitoring to good housekeeping.

Comment: Our city has <100,000 population, so we are not regulated yet. We do have, however, the same goals as the law - to improve the environment.

It is important to integrate urban watershed managememt into stormwater, rather than vice-versa.

The one place we get a lot of support is with public education. It is more profitable and less costly than BMPs.

Comment: Suggest a national demographic analysis/survey - show who's there and what's exposed (in a chemical or water quality sense). This could be done through EPA.

Note also that we've gotten into some CSO concepts, and we need to look at which, if any, of those concepts are applicable to stormwater. In this light, could include treatability studies - implies stormwater treatment. Should we accept dry weather flow in treatment plants? Should we use pipes for storage? Should we put in flow control devices?

Comment: Treatability analysis of runoff is needed, maybe using innovative settling velocity procedures.

Comment: We should shift more to biological criteria; need to be cautious since big chemical increases could occur without being noticed.

Question: Will flexibility in monitoring requirements filter down to permit writers?

Answer: (Mike Cook) - already exists and will try to emphasize to permit writers, especially biological vs. chemical monitoring.

Question: On the tie between monitoring results and enforcement, can it be written in to avoid use of results in third-party law suits?

Answer: (Mike Cook) - Does not know of any permits being written that will require monitoring results to be used in enforcement.

Comment: EPA should restructure program to integrate all of wastewater management; should require states to develop comprehensive basin management plans; EPA should redirect 319 funds to support this.

Comment: Regulated parties could develop compliance check lists without waiting for regulator.

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Comment: Florida has not found any BMP negatively affecting groundwater, but is site-specific and the potential for problems should not be ignored.

Comment: Florida has almost never found hazardous waste problems in residues, but also is site-specific and can't be forgotten.

Comment: We need to get quantitative data on effectiveness of source controls.

Comment: Supports data collection for evaluating source controls, and for setting up pilot areas to apply source controls and monitoring - Portland, OR is planning exactly this.

Comment: EPA should have general monitoring requirements but leave it to local government how to allocate monitoring resources to chemical, physical, biological.

Comment: Should integrate water quality, habitat, and flood control efforts.

Comment: Use education and other source controls, if they will work, rather than building unneeded (and expensive) structural controls.

Comment: Would like coverage of the ad-hoc session on relationships of watershed conditions and aquatic ecosystem response (Editor's note - this has been included in proceedings).

12 programs doing it - should pull together what is in the literature already.

Comment: Residuals are a problem that we need to learn how to manage.

Comment: Pathogens are a big unknown; need to determine the correct indicators and epidemiology; also need to look at viruses in groundwater.

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Comment: How do we do drainage design in new areas?

Comment: Water reuse is important and needs to be studied and made more prominent.

Comment: Need better understanding of cause and effect (biological) in order to know what to treat.

Comment: Common pesticides have not been looked at in stormwater. Is diazinon an outlier or the tip of the iceberg? Quality control is very important because pesticide manufacturers will take a lot of interest. Concluded that source control is the only way to go with pesticides.

Comment: We can use event-based monitoring to test BMP effectiveness, but can't use this approach to see trends. Biological monitoring should be regarded as long-term strategy. Questions Cook's recommendation to use in short term, except as political strategy.

Comment: Should consider increased joint use of monitoring and modeling (reinforced by another comment). Can also use modeling to help you determine what to monitor.

Comment: Support for standardizing what we report and how we do it, but not much said about standardizing data bases, which is also necessary.

Comment: Need to learn how to maintain BMPs, especially for mosquito prevention.

Comment: Should standardize statistical approaches.

Comment: Industry can be involved in documenting BMP effectiveness, especially source controls. Industry can also help in standardization. Need to determine standards for selection of outfalls to be monitored when there are multiple discharges. Need to share costs of rain gages

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among public and private sources. Industry should work with regulators and public on bioassessments. Industry can also help in education.

Comment: Source control was endorsed over structural BMPs by a large vote.

Comment: Public education should build on existing programs.

Comment: If we standardize reporting procedures for BMP assessments, should this group be a focus for reviewing and disseminating results?

Comment: There is a lot of overlap in studies (some overlap needed because of site-specificity), but should we set priorities and then allow local authorities to could select from these as long as procedures are standardized?

In the San Francisco Bay area, 5 programs now coordinate monitoring and meet with regulators to set priorities and minimize overlap. Parts of the monitoring program are allocated to various participants.

Comment: During the interval between these conferences we could recommend that the UWRRC sponsor sessions (at least annually) at other related conferences (WEF, WRPM Div. of ASCE).

Comment: Issue of fairness in monitoring should be addressed. Measure close to the source or at the outfall? Need to decide the best approach, assuming the goal is to get contaminants out of the receiving waters. Recommend monitoring close to the source (although this may be unfair to industry).

Comment: Enforcement should consider rewards, not only punishment; an example of incentives and punishments exists; regulator could adopt an attitude of helpfulness, as is the case in other countries.

Comment: What we need out of conferences is a synthesis of what we have learned and what we should do next - what is our level of knowledge (and uncertainty), and where are we in various areas. For example, we learned that we don't have to redo NURP.

Comment: Need specific recommendations on water quality standards applied to stormwater. We may be better off with such standards if they can be made appropriate. Also, agreement with earlier comment that existing water quality standards are an impediment.

Comment: Most permit holders will never hear what we have learned, and it is up to EPA to disseminate. NPS News and Notes could be the vehicle.

Comment: Regulators will never solve the problem of "pointless personal pollution." There is an initiative to learn how to change behavior (National Geographic NPS Forum).

Comment: It is disappointing how poorly we have articulated the NPS problem and solutions. Without it we can't achieve our goals.

CHAIRMAN'S CLOSING COMMENTS

How do we communicate what we have discussed this week? The Proceedings will convey the presentations and summaries of the discussions. The challenge to you, the attendees, is to further expand the information learned in a way that goes beyond what is contained in the Proceedings.

Regarding Mike Cook's challenge to the UWRRC to coordinate research activities; not determined how we will do it, especially flow of money. This is a step in right direction. NAFSMA is very interested and represented by managers; they are hopeful that we, the Urban Water Resources Research Council, can join with them and APWA.

Tremendous progress has been made in finding illicit connections thanks to Field's and Pitt's efforts; nevertheless, issues still remain on eliminating these connections.

I believe we have characterized runoff well enough, and don't have to do more in small cities. Any further activity along these liens will not reveal anything new.

Everyone is afraid of compliance monitoring for stormwater discharges - afraid the effort will be concentrated on end-of-pipe monitoring (which would only be a rehash of the current water quality stormwater characterization).

Monitoring of receiving waters is the toughest problem - we've already seen regulatory requirements which do nothing to improve the environment. Need to develop protocols for biological, chemical, and physical monitoring. Protocols should not be specifically dictated but set appropriately for each site. Need multidisciplinary approach.

Reiterated systemization of reporting, but not suggested for compliance monitoring.

Finally, it should be pointed out that the attendees at this conference have training and experience that far exceeds that of the majority of the people in the field. This fact alone makes conferences such as this vital sources of information for practitioners. It is equally important for us to devote some resources to the training of our own professionals.

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APPENDIX A

POSTER SESSION

This Appendix includes all papers originally submitted as poster papers, in addition to those papers received too late for incorporation into the main body of the Proceedings. These papers were accepted without review, although they are still eligible for publication in the journals of the American Society of Civil Engineers.

CDOT HIGHWAY STORMWATER RUNOFF MONITORING RESULTS

Philipp Sieber*

Abstract

Extensive stormwater monitoring efforts have been undertaken by municipalities and transportation agencies. The Federal Highway Administration (FHWA) and the Colorado Department of Transportation (CDOT) have been involved in such monitoring.

Findings and conclusions from the FHWA and CDOT monitoring efforts, and comparisons between the two are presented in this document.

Introduction

The National Pollutant Discharge Elimination System (NPDES) stormwater regulations have required municipalities and transportation departments across the country to recently engage in extensive stormwater monitoring efforts.

The intent of the NPDES regulation is to characterize pollutants present in stormwater runoff. For transportation departments, the above translates to pollutants present in highway runoff.

CDOT compiled highway stormwater runoff characterization data collected in the past by FHWA. In addition, CDOT performed highway runoff monitoring during 1993 in Denver, Colorado.

Background data

Most of the existing background data characterizing highway stormwater runoff is from studies performed by FHWA in the mid-seventies and eighties. These

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studies included monitoring data from 993 separate storm events including 16 events in Denver, Colorado. A summary of the FHWA data (shown as median values for highway site median concentrations) is included in Table 1.

Table 1
Highway Site Median Concentration (FHWA[4], 1990)

POLLUTANT (mg/L)	ADT* < 30,000	ADT* > 30,000
Total suspended solids	41	142
Chemical oxygen demand	49	114
Nitrate + Nitrite	0.46	0.76
Total Kjeldahl Nitrogen	0.87	1.83
Total phosphorus	0.16	0.40
Copper	0.022	0.054
Lead	0.080	0.4
Zinc	0.080	0.329

*ADT = Average Daily Traffic

Highway Stormwater Runoff

FHWA defined common sources, and types of pollutants found in highway stormwater runoff, and these are listed in Table 2.

Table 2
Sources of Common Highway Pollutants (FHWA[3], 1984)

POLLUTANT	SOURCE
Particulates	Pavement wear, vehicles, atmosphere, maintenance
Nitrogen, Phosphorus	Atmosphere, roadside fertilizer application
Lead	Leaded gasoline, tire wear, lubricating oil and grease, bearing wear
Zinc	Tire wear, motor oil, grease
Iron	Autobody rust, steel highway structures, moving engine parts
Copper	Plating, bearing/bushing/brake wear, engine parts, insecticides
Cadmium	Tire wear, insecticide application
Chromium	Metal plating, moving engine parts, brake lining wear
Nickel	fuels, oils, metal plating, bushing wear, brake lining wear, asphalt
Manganese	Moving engine parts
Bromide	Exhaust
Cyanide	Anticake compound used to keep deicing salt granular
Sodium, Calcium	Deicing salts, grease
Chloride	Deicing salts
Petroleum	Spills, lubricants, antifreeze and hydraulic fluids, asphalt
P-chlorinated biphenyl	Pesticides, atmospheric deposition, PCB catalyst in synthetic tires
Pathogenic bacteria	Soil, litter, bird droppings, livestock and stockyard waste
Rubber	Tire wear
Asbestos	Clutch and brake lining wear

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The concentration of pollutants in highway stormwater runoff is affected by factors such as: precipitation intensity, duration, and volume; temperature; surface wind speed and direction; highway configuration, design, geometrics, and drainage features; pavement composition, condition, and quantity; traffic characteristics (Average Daily Traffic - ADT); vehicular transported, generated, and deposited inputs; maintenance practices; and surrounding land use (urban vs rural). ADT was identified as one variable having a significant impact on pollutant concentrations.

Some overall conclusions reached by FHWA on highway stormwater runoff and its effects on receiving waters were:

- Highway stormwater runoff for highways with ADT < 30,000, with no curb and gutter design, exerts minimal to no impact on the aquatic components of most receiving waters.
- Annual pollutant loads from highways are low relative to loads from entire watersheds.
- Of five species (mayfly, isopod, water flea, gammarid, fathead minnow) used in acute laboratory bioassays, only the gammarid exhibited a toxic response to undiluted highway runoff.

CDOT Monitoring

Location

Initially, CDOT considered using the same site that had been used by FHWA, which was located on interstate I-25, extending from just south of fully directional interchange with interstate I-70 to Fox street. This site had an ADT of 149,000 with a drainage area of 14.29 Ha. The monitoring period was between August 1976 and July 1977 during which data from 16 events was collected. Using this site was, however, not possible due to the I-25 re-construction work currently in progress where the site used to be.

CDOT therefore evaluated several other alternatives, and selected a new site for the monitoring. The site was located on Interstate 225 (I-225) at milepost 2.25. ADT for I-225 is 95,000. Drainage area for this outfall was 7.59 Ha of CDOT's right-of-way (ROW), starting at milepost 2.35 just east of Cherry Creek and ending at milepost 3.07 further east. The drainage area includes paved surfaces (six highway lanes plus shoulder) as well as vegetated surfaces (median and areas between the edge-of-oil and the ROW fence). Stormwater runoff from this area discharges into Cherry Creek through a 60.96 cm outfall.

The following criteria were used to select the monitoring site:

- Location: The site should be located within the cities of Denver, Lakewood, or Aurora.
- Type of runoff: The drainage area had to be exclusively CDOT's ROW with a minimum or no outside contributions. Also, the conveyance for the highway runoff should not have any connections with conveyances draining water from areas outside CDOT's ROW.
- Safety: The site had to have an area to install the monitoring equipment in such a way that no safety hazards were created for the traveling public, nor for personnel operating and servicing the monitoring equipment.
- Accessibility: The area should have easy access to facilitate sample collection.
- Drainage area: The drainage area for the site had to be 4.05 Ha or more.

Equipment

The following equipment was used for the monitoring:

- Automatic sampler with power supply
- Relay to drive autosampler
- Data logger with power supply
- Data storage module
- Pressure transducer
- Con-a-flow bubbler system
- Rain gauge

Description

Surface drainage for the monitored area is collected by inlets located in the median and the roadway ditch, and is conveyed through a storm drain. The storm drain runs in the median on a 3% slope.

Sampling occurred at the last inlet located in the median, just prior to the outfall to Cherry Creek. The inlet is located at milepost 2.25, 30.48 m upstream from the outfall. Because the outfall is actually located outside CDOT's ROW, it was not possible to perform the sampling at the outfall.

A shelter was constructed to house the monitoring equipment which was installed about 4.57 m from the sampling point.

To provide flow measuring ability, a 60.96 cm Palmer-Bowlus flume was constructed just upstream of the outlet of the storm drain into the inlet. Samples were collected just downstream of the flume.

A base flow existed in the storm drain, however its magnitude was so minimal (0.0001 m^3/s) that it was considered negligible. It was assumed that the source of this baseflow is groundwater seepage into the storm drain.

CDOT contracted with the U.S. Geological Survey (USGS), Water Resources Division, Colorado District Office to perform the monitoring. Most samples were analyzed by the USGS National Water Quality Laboratory in Denver; analysis of fecal coliform, fecal streptococcus, and specific conductance was performed by USGS field personnel; analysis for Biochemical Oxygen Demand (BOD) was contracted with the Metro Wastewater Reclamation District laboratory.

Procedure

According to the regulation, samples were to be collected from three storm events occurring at least one month apart and with a preceding 72 hour dry-period. However, due to Colorado's climatic conditions, CDOT used (with previous approval from the Colorado Department of Health) a variance in the sampling requirements according to the following criteria:

- A 7 day separation between storm events.
- A change in the 72 hour dry-period as follows:

Preceding Storm Depth	Dry Period
≤ 5.08 mm	24 hours
≤ 12.70 mm	48 hours
> 12.70 mm	72 hours

Collected samples were analyzed for the constituents listed in the NPDES stormwater regulation [40 CFR 122.26 (d)(2)(iii)(A)].

From the data collected at the I-225 monitoring site, estimates of annual pollutant loads and Event Mean Concentrations (EMCs) were calculated for the following constituents: total suspended solids, total dissolved solids, biochemical oxygen demand, chemical oxygen demand, total nitrogen, total Kjeldahl nitrogen, nitrate plus nitrite, total phosphorus, dissolved phosphorus, cadmium, copper, lead, and zinc.

Individual EMCs were combined and a runoff-volume-weighted average EMC was calculated for each constituent. The calculated EMCs represent Site-average EMCs for the I-225 monitoring site. These EMCs do, however, not account for runoff volumes lost due to storage, infiltration, or evaporation.

Since CDOT has only one land use (highway), in addition to the Site-average EMCs, the calculated EMCs represent the Land-Use average EMC.

Estimated pollutant loads from the state highway system were estimated for the cities of Denver, Lakewood, Aurora, and Colorado Springs. The pollutant loads were calculated as:

Drainage area × Rainfall × Runoff coefficient × EMC

Drainage areas for the state highway system within Denver, Lakewood, Aurora, and Colorado Springs were calculated based on CDOT's highway database. This database contains information on pavement widths and lengths.

Drainage areas were calculated as:

Pavement width × Pavement length

Information regarding median widths, or edge-of-oil-to-ROW-fence widths, is not available, and therefore was not included as part of the drainage area computations. Only pavement area was used for the calculations. However, the pavement is where most of the pollutants are expected from.

Using criteria established by Urban Drainage and Flood Control District for the Denver Metro area, and rainfall data submitted by the city of Colorado Springs, an annual runoff producing precipitation of 327.66 mm was selected for the four cities.

A runoff coefficient of 0.90, which is standard for paved highway surfaces, was selected.

Results

Table 3 includes CDOT's monitoring results for the I-225 site (only for those constituents that were detected). Table 4 includes calculated EMCs for both the FHWA I-25/I-70 site and the CDOT I-225 site. For comparison purposes, the EMCs for the I-25/I-70 site were also calculated as runoff-volume-weighted average EMCs using the same procedure as the one used to calculate the I-225 EMCs.

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Table 3
I-225 Monitoring Data

CONSTITUENT	UNITS	STORM 1	STORM 2	STORM 3
Date		07/20/93	08/05/93	08/30/93
Rainfall	mm	10.41	10.16	3.81
Storm runoff	m^3	47.86	48.14	25.49
Storm duration	hours	2.58	0.92	0.58
Dry period	hours	144.00	120.00	48.00
Drainage area	Ha	7.59	7.59	7.59
Storm runoff	mm	0.63	0.64	0.34
Total Suspended Solids	mg/L	2910.00	628.00	114.00
Total Dissolved Solids	mg/L	158.00	170.00	119.00
Biochemical Oxygen Demand	mg/L	31.00	34.00	40.00
Chemical Oxygen Demand	mg/L	380.00	180.00	220.00
Total Nitrogen	mg/L	4.70	5.80	5.90
Total Kjeldahl Nitrogen	mg/L as N	3.10	4.10	4.30
Nitrate plus nitrite	mg/L as N	1.60	1.70	1.60
Phosphorus, total	mg/L as P	0.43	0.88	0.27
Cadmium, total recoverable	ug/L as Cd	3.00	1.00	N/A
Copper, total recoverable	ug/L as Cu	75.00	32.00	34.00
Lead, total recoverable	ug/L as Pb	260.00	53.00	24.00
Zinc, total recoverable	ug/L as Zn	690.00	290.00	400.00
Oil and grease	mg/L	9.00	2.00	11.00
Fecal coliforms	cols/100 ml	1680.00	1650.00	38000.00
Fecal streptococci	cols/100 ml	9200.00	10500.00	15000.00
pH	S.U.	8.10	7.90	7.70
Bis(2-ethylhexyl)phthalate	ug/L	N/A	9.00	25.00
Arsenic, total	ug/L as As	4.00	2.00	1.00
Chromium, total recoverable	ug/L as Cr	27.00	8.00	4.00
Mercury, total recoverable	ug/L as Hg	N/A	0.20	N/A
Nickel, total recoverable	ug/L as Ni	22.00	10.00	7.00
Phenols, total	ug/L	7.00	9.00	21.00
Sodium, dissolved	mg/L as Na	20.00	20.00	13.00
Potassium, dissolved	mg/L as K	3.60	7.20	2.20
Alkalinity	mg/L (CaCO3)	46.00	59.00	14.00
Sulfate, dissolved	mg/L as SO4	16.00	16.00	16.00
Chloride, dissolved	mg/L as Cl	14.00	21.00	14.00
Nitrite	mg/L as N	0.08	0.07	0.06
Ammonia	mg/L as N	1.90	1.40	3.40
Total organic carbon	mg/L as C	80.00	55.00	61.00
Specific conductance	us/cm	177.00	228.00	172.00
Magnesium, dissolved	mg/L as Mg	0.97	2.00	1.50
Calcium, dissolved	mg/L as Ca	9.50	16.00	11.00

Table 4
EMCs I-225 and I-25/I-70

CONSTITUENT	EMCs I-225	EMCs I-25/I-70
Total suspended solids (mg/L), TSS	1419.138	344.737
Total dissolved solids (mg/L), TDS	154.573	N/A
Biochemical oxygen demand (mg/L), BOD	34.077	33.293
Chemical oxygen demand (mg/L), COD	267.179	207.632
Total nitrogen (mg/L), TN	5.388	N/A
Total Kjeldahl nitrogen (mg/L), TKN	3.748	2.835
Nitrate plus nitrite (mg/L), NO2+NO3	1.640	N/A
Total phosphorus (mg/L), TP	0.575	0.649
Dissolved phosphorus (mg/L), DP	0.458	N/A
Cadmium, total recoverable (ug/L), Cd	1.578	17.137
Copper, total recoverable (ug/L), Cu	49.359	108.664
Lead, total recoverable (ug/L), Pb	128.462	579.323
Zinc, total recoverable (ug/L), Zn	470.653	477.256

Comparison

The I-225 data obtained by CDOT, and the I-25/I-70 data obtained by FHWA are graphically compared in Figure 1.

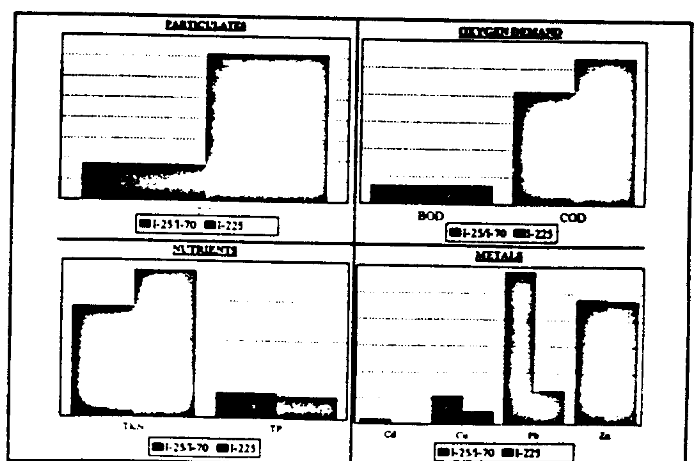

Figure 1: I-225 vs I-25/I-70

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By comparing CDOT's data vs FHWA's data it can be concluded that:

- No major differences are observed in oxygen demand or nutrients.

- The most noticeable differences are in Total suspended solids (TSS) and in Lead (Pb).

  The difference in TSS is mostly due to a very high EMC recorded for storm #1 at the I-225 site (2910 mg/L). Values for storm #2 and #3 are much lower (628 mg/L and 114 mg/L) which are more in line with the values recorded at the I-25/I-70 site. The high TSS value recorded at storm #1 could be due to a special condition that day which caused an increase in sediment loads, or it could be also due to a human or mechanical error during the sampling. However, no sufficient data exists which could justify the discarding of this value.

  The difference in Pb is most probably due to the change in gasoline from leaded to unleaded.

- In general, a reduction in metals is observed which could be due to: improvements in refining processes producing cleaner motor oils and greases; reduction in insecticide applications due to environmental concerns; elimination of leaded gasoline; and improvements in tire manufacturing processes.

__Future CDOT Monitoring__

From a regulatory perspective, CDOT does not expect at this time to engage in additional stormwater monitoring efforts for several reasons:

1. Existing data. Much data already exists that characterizes highway stormwater runoff. Additional data will not show different results than those already obtained.

2. Cost/benefit ratio. Benefits of new data will be very low when compared with the high cost of monitoring.

3. Current monitoring efforts by other DOTs. Other transportation departments (i.e. Texas, Washington, Oregon) across the country are still involved in highway runoff monitoring efforts . In the future, CDOT expects to compile this data and compare it versus CDOT's and FHWA's data. After evaluating this data, CDOT will be in a better position to assess any further monitoring needs.

From a research perspective, CDOT expects to engage in monitoring efforts

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with specific goals:

1. Goal 1: Monitor three (out of 13) permanent sediment ponds that were constructed as part of CDOT's Straight Creek Water Quality and Erosion Control project. The intent is to assess the efficiency of those ponds in removing sediments in highway and snow-melt runoff, which are caused by sanding from CDOT's winter operations, and by erosion in cut slopes.

2. Goal 2: Monitor highway snow-melt runoff during winter in several locations where various de-icers will have been applied. The intent is to assess impacts to receiving waters from these various de-icers.

Conclusion

CDOT performed monitoring as required by the NPDES stormwater regulation. EMCs and pollutant loads of highway stormwater runoff discharges were estimated.

Data collected during monitoring at I-225 adds more data to that available from FHWA. However, this new data may not be very representative due to the small number of events sampled. According to FHWA: "because of the inherent variability in EMCs, a limited sampling effort consisting of only a few storm events may produce a poor estimate of site characteristics[4]."

Monitoring requirements such as the ones included in the NPDES regulation result in high costs with little benefits due to: the lack of defined and specific goals and guidelines; the existing data; and the high cost of monitoring equipment and sample analyses. It is expected and hoped that in the future, regulatory agencies will assess the above prior to require the regulated community to engage in costly monitoring efforts which will produce little benefits towards the improvement of stormwater quality.

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Methods for Assessing Urban Storm Water Pollution

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Abstract

This paper presents methods for quantifying urban development conditions and characterizing the impact of urbanization on storm water pollution. Based on data collected by the City of Austin (COA), it was found that storm water pollutant mean concentrations can be correlated with development indices and watershed sizes. Use of the arithmetic mean of event mean concentrations (EMCs) to characterize storm water pollution may lead to biased results if the EMC data set is not large enough or not carefully reviewed.

Introduction

The City of Austin (COA) has had several storm water monitoring programs since 1975. The objectives of the programs are to evaluate the impacts of urban development on storm water pollution and to identify Best Management Practices (BMPs) for mitigating these impacts. Based partially on the findings (COA, 1984) of the monitoring programs, the City has implemented a series of watershed ordinances (COA, 1986-92) and protection programs.

Funded by the City's Drainage Utility (COA, 1992), the COA currently has two storm water monitoring programs (COA, 1993). One program is establishing a network of forty-five (45) runoff monitoring stations to test land use and structural BMPs. The other program monitors in-stream storm water quality at eleven (11) creek locations through a COA/USGS (U.S. Geological Survey) cooperative project. Of these fifty-six (56) stations, data for twenty-nine (29) stations were available for this study and are shown in Table 1. This study proposes methods to characterize urban storm water pollution using concentration data and information generated from previous COA studies.

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TABLE 1

DESCRIPTION OF MONITORING STATIONS

Watershed Description	No. of Stations Monitored	Drainage Area (acres)	Impervious Cover (%)	No. of Storms Adequately Sampled
Size:				
Large Watershed	12	1,416 - 79,300	3 - 47	7 - 25
Small Watershed	17	1 - 371	3 - 97	7 - 29
TOTAL*	29			
Land Use:				
Undeveloped	6	3 - 79,300	3 - 5	7 - 20
SF Residential	6	26 - 371	21 - 39	7 - 29
MF Residential/Office	4	1 - 3	50 - 88	9 - 25
Commercial/Industrial	5	3 - 197	65 - 97	8 - 25
Transportation	1	30	81	22
Mixed	7	1,416 - 32,832	12 - 47	12 - 25
TOTAL*	29			
Watershed Type:				
Urban	8	3 - 7,572	43 - 97	9 - 25
Suburban	15	1 - 32,832	12 - 39	7 - 20
Rural	6	301 - 79,300	3 - 5	7 - 20
TOTAL*	29			

* 29 monitoring stations listed by watershed size, land-use, and watershed type.

TABLE 2

STATISTICS FOR THE REGRESSION* OF INSTANTANEOUS CONCENTRATIONS ON STORMWATER RUNOFF FLOW RATES

Watershed	Drainage Area (acres)	Imp. Cover (%)	Pollutant Parameters: TSS R-square**	TOC R-square	TKN R-square	TP R-square
Walnut Ck @ Webberville Rd.	14,272	25	**0.43**	**0.42**	**0.08**	**0.20**
Shoal Creek @ 12th St.	7,808	47	**0.67**	**0.33**	**0.23**	**0.35**
Waller Creek @ 38th St.	1,416	43	**0.63**	**0.18**	**0.34**	**0.53**
Hart Lane @ NW Austin	371	39	**0.30**	0.01	0.02	**0.09**
Lost Creek @ SW Austin	160	27	**0.30**	0.02	0.04	**0.29**
Barton Creek Square Mall	47	86	**0.21**	0.007	0.001	0.02
Lavaca St.	14	97	**0.35**	0.0007	**0.06**	**0.23**

* A normal error regression represents $C = a_1 Q^{a_2}$, where C is instantaneous concentration, Q is the corresponding flow rate, and a_1 and a_2 are regression coefficients.
** R-square is the coefficient of determination. Bold R-square values indicate a significant regression.

Previous Studies

Previous COA studies (COA, 1990) on storm water pollution indicated that for most of the runoff pollutant parameters, there is no significant difference in the average event mean concentrations between residential and adequately-maintained commercial sites. However, some differences exist between undeveloped, residential, and less-maintained commercial sites. The average EMCs for large, mixed land-use, creek basins are generally greater than those of small, single land-use watersheds. Most of the City's creeks are affected primarily by storm water pollution because there are few significant point sources. In order to compute runoff pollutant loads, a relationship between basin runoff coefficient (Rv, the ratio of the average annual runoff to average annual rainfall depth) and percent impervious cover was developed. This relationship can be described by a quadratic polynomial equation (COA, 1992). The equation was substantiated by additional data from this study. In general, a linear approximation of the runoff coefficient versus imperviousness relationship tends to overestimate Rv values, especially for low impervious cover sites. For any low to medium impervious cover site, the single event runoff coefficient generally increases with increasing depth of storm rainfall. The average Rv for this site should not be calculated as the arithmetic mean of all Rv values unless there is a sufficient number (to be described later) of these values. Gilbert (Gilbert, 1987) suggested that the arithmetic mean may be a biased estimation of the population mean if the coefficient of variation of the data is greater than 1.2.

Definitions of Variables

Mean concentration (MC): MC is either the arithmetic mean of event mean concentrations or the flow-weighted mean of instantaneous concentrations for a pollutant parameter for any specific watershed. Flow-weighted mean is the flow-volume weighted average of instantaneous concentrations corresponding to different classes of runoff flow rates (to be further explained).

Percent impervious cover (IC): IC is the ratio of gross impervious area in a watershed to the drainage area of the watershed, expressed as a percentage of the drainage area.

Undeveloped site (UNDS): UNDS is a basin or watershed in which little area has been disturbed by human activity. The ground of the basin is mostly covered by natural vegetation.

Development index (DI): DI is a quantity that represents one or any combination of three variables, including percent impervious cover, land use index, and watershed type index. Land use is classified into five types: undeveloped; single family residential (SF); office or multi-family residential (MF); commercial and industrial (Com/Ind); and roadway. Watershed type means the degree of cleanliness which is determined mainly by the age of roads and structures, and the housekeeping practices in the area. In addition, it may also be identified by the watershed's relative location in the metropolitan area. For the Austin area, the watershed-types are urban, suburban, or rural watershed which correspond to the definitions used in Austin's Comprehensive Watershed Ordinance (COA, 1986).

Mean Concentrations for a Specific Site

The use of the average of event mean concentrations (EMCs) for characterizing storm water pollution for a specific site may lead to biased results if the EMC data are not carefully reviewed and treated. Primarily, it is important to determine whether or not the EMC values represent the average concentrations of the corresponding storm runoff. The majority of the runoff volume (e.g., 80% or more) from a rainfall event should be sampled in order to provide sufficient data for the estimation of an EMC. For any monitored rainfall event, the number of samples should range from three (3) to as many as sixteen (16) depending on the complexity of the hydrograph. An EMC value should not be used if the sampling does not cover the full range of the hydrograph. Secondly, the flow measurement system should be designed carefully and the quality of the data thoroughly reviewed. The measurement of flow in a storm drain system is fairly difficult considering the changing flow conditions during a storm. Inaccurate discharge values can result in erroneous flow volume calculations, which will impact the EMC estimation for the storm. Finally, the flow-weighted mean concentration (FWMC) can be computed as a verification. The FWMC should be approximately the average of EMCs if there is sufficient flow and instantaneous concentration data. In order to calculate the FWMC, the flow rate of runoff should be divided into several classes (e.g., 0.003-0.3, 0.31-1.50, 1.51-3.00, and 3.01-9.00 cubic meter per second). Corresponding to each flow rate class, there is a concentration value and a measurement of percent volume of the average annual flow. The FWMC is the sum of the products of the concentration values and the percent volumes of the average annual flow.

If the average of the EMCs is used to represent watershed mean concentrations, the number of the sampled events should be sufficient to cover the entire range of rainfall classifications. As shown in Figure 1, EMC values decrease with an increase in storm runoff volume. This relationship is not clearly shown unless the number of sampled events are sufficient and the corresponding EMC values are grouped. Also, the EMC values may be dependent on build-up conditions at the onset of rainfall events. Based on the SWMM Manual (U. of Florida, 1988), a COA study (COA, 1994) derived the relationship between load and the number of dry days for specific land uses. As shown in Figure 2, the total suspended solids (TSS) load accumulated at a roadway site is significantly related to the number of dry days before a storm, although there is considerable scatter in the data.

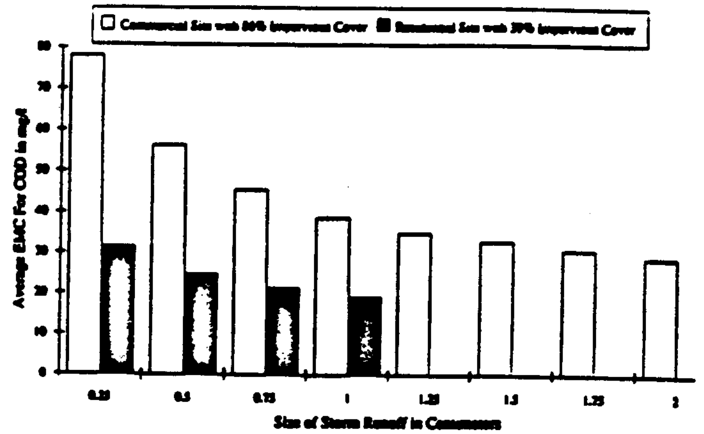

FIGURE 1. RELATIONSHIP BETWEEN AVERAGE EMC AND SIZE OF STORM RUNOFF

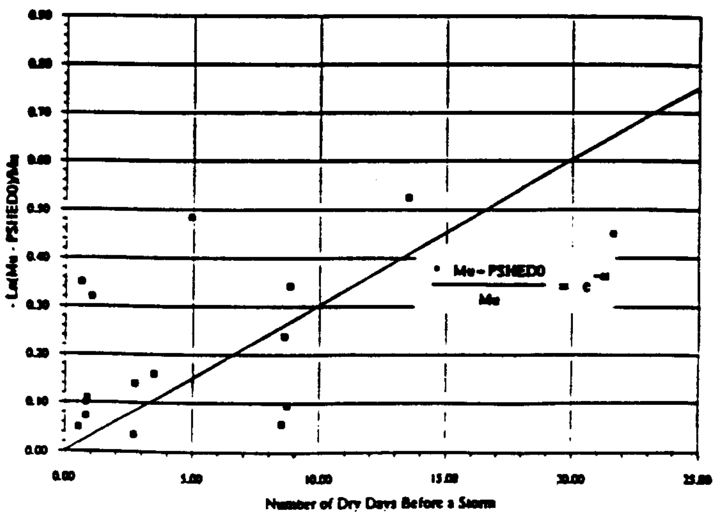

FIGURE 2. AN EXPONENTIAL TYPE BUILD - UP EQUATION DERIVED FOR A ROADWAY LAND USE SITE - FOR TSS

* An exponential type build-up equation (as shown in SWMM manual) was assumed, where Mo is the upper limit of load which can be accumulated on the ground, t is the number of dry days before a storm, PSHED0 is the load on the ground before a storm corresponding to t, and a is regression coefficient.

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The EMC values can also vary with the runoff flow rates during rainfall events since the instantaneous concentration for some parameters is related to the flow rate (Table 2). The relationship tends to increase with the increase in of drainage area, and is probably the result of increases in peak flow in relation to both drainage area and growing urbanization. The increases in peak flow typically result in increased channel and bank erosion (COA/ECSD, 1992; Schueler, 1987). If the relationship between instantaneous concentration and flow rate is significant, the mean concentrations of a site should be represented by the flow-weighted mean concentrations. The average EMCs can represent the site mean concentrations only if the EMCs were computed from a sufficient number of storms which cover the full range of flow rates.

For the Austin area, a storm water monitoring period should generally run between two (2) to four (4) years in order to adequately represent the entire range of classifications of rainfall events. Typically this would provide about twenty to thirty (20-30) EMCs. To ensure accurate representation of the different classifications of storm event, the number of dry days before a storm should be divided into a minimum of two (2) classes (e.g., less or equal than two dry days and greater than two dry days) and the size of storm divided into a minimum of three classes (e.g., less or equal than 1.90 cm, 1.91 to 4.50 cm, and greater than 4.5 cm). Therefore the number of combinations of these two factors (the number of dry days and the size of storm) is six (2 x 3). Considering that a minimum of three replicates is needed for each class of events, the number of adequately-sampled events should be at least eighteen (18). For the rainfall conditions in the Austin area, this will require a minimum of two (2) years of monitoring to satisfy. Because of the difficulty of maintaining and operating a large number of monitoring stations, and the potential for drought conditions to occur during the sampling period, this minimum time requirement of two years is typically not sufficient. Therefore it is prudent to plan for storm water monitoring over at least a three (3)-year period.

<u>Derivation of Development Index</u>

The development index (DI) represents watershed development conditions which can be quantified using one or any combination of three variables: percent impervious cover, land-use index (LI), and watershed-type index (WTI). In this study, DI is assumed to be a linear combination of LI and WTI. The following is an example of computation for obtaining DI:

Step one: Develop a matrix of mean concentration (MI) values for the relationship of land-use types to pollutant parameters. Given five (5) pollutant parameters, the matrix is as follows:

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Land-use	TSS	TOC	NO_3	TKN	TP
Undeveloped	77	7	0.13	0.32	0.04
SF Residential	151	12	0.70	1.60	0.28
MF Res./Office	97	14	0.63	1.76	0.38
Com./Ind.	216	14	0.61	2.24	0.46
Roadway	320	25	0.40	1.20	0.22

Step two: Standardize all mean concentration values to a dimensionless variable which has a randomly-assigned arithmetic mean and standard deviation (in this example, M = 3, and S = 1.581 for a series of numbers 1, 2, 3, 4, and 5). Using SAS STANDARD procedure (SAS Institute, 1987), the standardized mean concentration is

$$\text{Stan MC} = [(MC - \overline{MC}) / \sigma_{MC}][S] + M \qquad [1]$$

where $\overline{MC}$ is the arithmetic mean of MC values for the five land use types for each of the five pollutant parameters, and σ_{MC} is the standard deviation of these five MC values. Corresponding to the MC matrix above, the standardized MC matrix is:

Land-use	TSS	TOC	NO_3	TKN	TP	Avg.
Undeveloped	1.47	1.23	0.52	0.58	0.68	0.90
SF Residential	2.67	2.42	4.38	3.39	3.06	3.18
MF Res./Office	1.80	2.85	3.95	3.74	3.99	3.27
Com./Ind.	3.70	2.94	3.79	4.79	4.82	4.00
Roadway	5.37	5.55	2.36	2.51	2.44	3.65

The values in the matrix above are the land-use indices for each pollutant parameter. The values in the column labeled "Avg." are the overall land-use indices for each of the land-use types.

Step three: The watershed-type index (WTI) can be derived in the same manner as steps 1-2. In this case the matrix of MC values consists of watershed types (rural, suburban, and Urban) and pollutant parameters.

Step four: Assuming the development index is a linear combination of LI and WTI in the following form:

$$DI = (LI + WTI)/2, \qquad [2]$$

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then the development index of a watershed can be computed for each of the pollutant parameters in the matrix.

Assessing Storm Water Pollution

The values of mean concentrations and development indices for several pollutant parameters and for all twenty-nine monitoring sites were computed. The pollutant parameters evaluated using local data are total suspended solids (TSS), chemical oxygen demand (COD), 5-day biochemical oxygen demand (BOD5), total organic carbon (TOC), total phosphorus (TP), total nitrogen (TN), nitrite plus nitrate (NO_2+NO_3), total kjeldahl nitrogen (TKN), ammonia (NH_3), total lead (TPb), fecal coliform (Fe. Col.), and fecal streptococci (Fe. Stp.). These are standard parameters considered in assessing non-point source pollution from storm water (EPA, 1983; Shueler, 1987).

Mean concentrations for some parameters such as TP, TKN, TN, COD, and TPb can correlate well with the development indices. As shown in Figure 3, the TP mean concentration for any specific watershed in the area can be reasonably estimated from the development condition of the watershed, i.e., the land-use index and the watershed-type index of TP. Additionally, the percent watershed imperviousness is also an adequate index for estimating mean concentrations for the above mentioned pollutant parameters. On the other hand, regressions of mean concentrations on development indices for other parameters are less significant. As shown in Figure 4, the mean concentration values of nitrite plus nitrate corresponding to the higher values of the development indices vary independently from the development index. There are no significant differences in concentrations among watersheds of all the development conditions except for the undeveloped sites. To further review the data, the NO_2+NO_3 concentrations are generally higher for the SF residential land-use sites, probably because of fertilizer applications.

For the TSS-related parameters such as TSS, TP, TKN, and TOC, the mean concentrations are significantly related to the drainage area of the watershed, as described earlier in this paper. As shown in Figure 3, the relationships between TP concentrations and development indices are represented by two separate regression lines [for watershed size $\leq$ 405 hectares (1000 acres) and $>$ 405 hectares (1000 acres)].

Conclusions

Based on the findings, the following conclusions can be drawn:

1. This study used data collected from the City of Austin's storm water monitoring programs. Although the data is preliminary, its quantity and quality are

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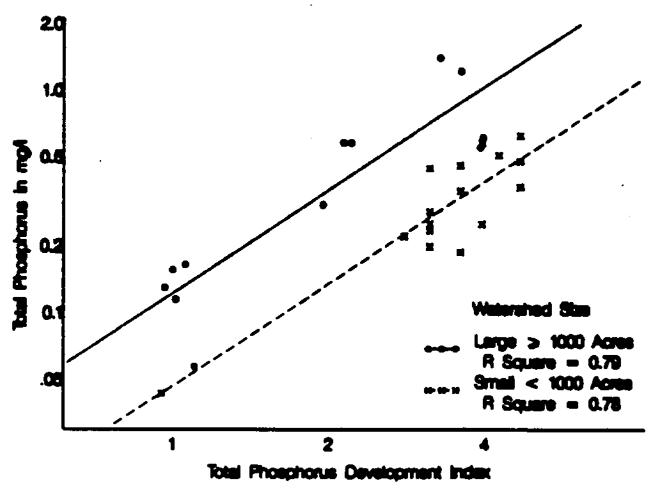

FIGURE 3. RELATIONSHIP OF MEAN CONCENTRATION OF TOTAL PHOSPHORUS TO DEVELOPMENT INDEX

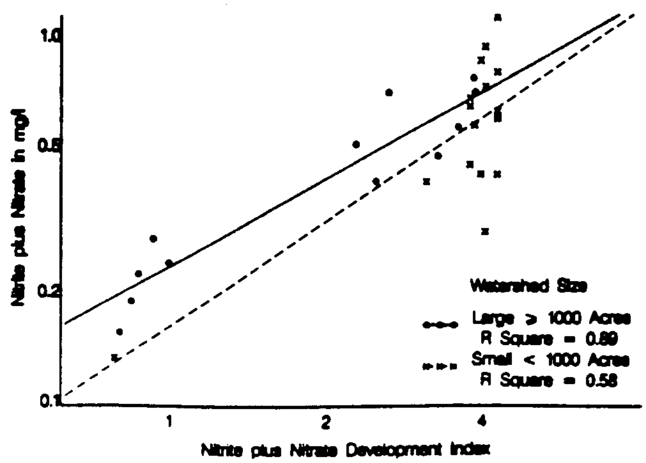

FIGURE 4 RELATIONSHIP OF MEAN CONCENTRATION OF NITRITE PLUS NITRATE TO DEVELOPMENT INDEX

sufficient for the development of a simplified method to characterize urban storm water pollution.

2. The impacts of urban development on storm water quality can be identified by the relationships of watershed mean concentrations to development indices. A development index may be a linear combination of land-use and watershed-type indices which characterize basin development conditions. This index correlates well with the percentage of impervious cover. For some parameters such as TSS, TP, TKN, and TOC, the described relationships also depend on the sizes of watersheds or drainage areas.

3. The use of average EMCs to represent watershed mean concentrations is adequate only if the sizes and antecedent conditions of the sampled events adequately represent the entire range of the rainfall event classifications. It is recommended that the EMC data presented by different organizations not be combined for analysis unless the methods and procedures for obtaining such data are carefully reviewed.

4. The use of arithmetic means to characterize average conditions of EMCs and runoff coefficients may be biased if the size of data sets is insufficient or the coefficients of variation are large (greater than 1.2). This is particularly true in computing the average runoff coefficient for a watershed since the runoff coefficient generally increases with increasing depth of storm rainfall. It is suggested that the population mean of the EMCs or runoff coefficients for any watershed can be best represented by the median, the adjusted geometric mean (Gilbert, 1987), or the flow-weighted mean of the observed EMC or runoff coefficient values.

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Other City staff members who contributed significant work to this paper are: William Burd, Scott Mittman, Baolin Bai, Richard Robinson, Kathy Luo, Suzanne Rogers, James Lewis, Ellen Wadsworth, P.E., and Lelia Gosselink, P.E.

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Practical Experience with Filippi Flow Limiters

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Abstract

The Filippi stormwater flow limiter belongs to the group of "weirs" of the type "one side overflow weir." The Filippi limiter, due to its specially profiled shape, allows for excellent hydraulic control of flow, but has little effect on solid/particulate separation.

There are many potential applications for the Filippi limiter:

- In combined sewer systems
- Upstream wastewater treatment plants or runoff storage tanks
- Surface water collection (first flushes of concentrated runoff) to be diverted to wastewater treatment facilities.

The excellent hydraulic control is obtained by its unique configuration - venturi channel at the inlet, changes in flow direction, short specially-shaped single-sided overflow edge, and guiding grooves at the outlet to prevent blockage.

The Filippi limiter is patented in most countries, and has successfully been used in various European countries since 1982.

Introduction

Stormwater overflow, overflow weirs, regulators, rainwater overflows, etc. are commonly used technical terms. The most appropriate term to describe the Filippi device is "flow limiter." These flow limiters may not only be used in combined sewers to avoid flooding, but also upstream of wastewater treatment facilities and runoff storage tanks or settling basins. Another potential application for such precise flow limiters would be to divert the first flush of concentrated runoff to a wastewater treatment plant.

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As an active rural engineer, Mr. R. Filippi realized the importance of precise flow limitations at various points in the sewerage systems to improve wastewater treatment, and thus improve water quality. Mr. Filippi began his development work on a flow limiter in 1975, and the Filippi flow limiter was finally patented in most countries in 1982.

The Filippi Storm Water Flow Limiter

Before beginning design, Mr. Filippi defined the following criteria which should be met:

- Flow limiting action with highest possible accuracy.
- Exchangeable - to allow for changes in flow rate over time.
- Shortest possible overall length.
- Blockage- and maintenance-free without moving parts.
- Minimize receiving water pollution.

Mr. Filippi realised early that no theoretical hydraulic calculations would provide a device meeting these criteria, so the development was done on a full-scale outdoor testing apparatus (with all of its inherent shortcomings). The first full-scale testing device was installed alongside a small river near Lausanne, Switzerland. Unfortunately, this device was carried away during a sever storm. The current testing device is installed on the grounds of the University and the École Polytechnique Fédérale de Lausanne. The installation includes a dam with two large manholes for demonstrations and development of additional models.

Testing consisted of a large number of trials and hydraulic testing, which resulted in the development of the first model, designed for a flow through the device of 62 litres per second. Subsequent development resulted in the creation of a total of 15 models, covering a range of flows between 3 and 205 litres/second. Today, there are more than 600 devices, with varying capacities, installed throughout Europe.

The main characteristics which account for the Filippi limiter's excellent hydraulic control are (see Figure 1):

- The venturi channel at the inlet with its two changes in flow direction.
- The specially-shaped "outcaster" which throws out all flow exceeding the design throughput.
- The overflow edge (weir) has a special hydraulic shape which is not horizontal.
- The guiding grooves at the end of the overflow edge (which have no hydraulic function, but which prevent adhesion of debris which could create blockages).

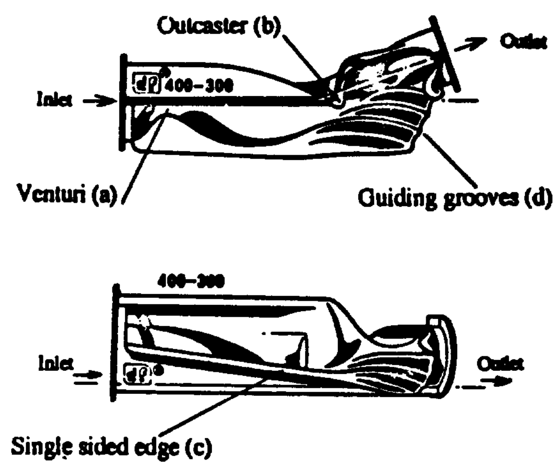

Figure 1: Fillippi Characteristics

Each Filippi model is characterized by two flow rates:

- The flow rate at which the limiter begins to overflow (the first spilling point).
- The guaranteed maximum throughput flow rate.

At flow rates up to the first spilling point, the limiter operates as an open channel. Between this flow rate and the maximum rate, the limiter operates as an overflowing single-sided weir. When flow rates exceed the guaranteed maximum throughput, the outcaster discharges all excess stormwater flow.

It is interesting to note that, within a range of gradients which are appropriate for each model, the first spill point and the maximum throughput do not change. All sizes have the same proportions, and have equal changes in the direction of the overflow.

The creation of additional sizes of Filippi devices can be easily done, and is simply a matter of cost and amortization of the Filippi mold. To date, the existing range has satisfied all requirements.

Hydraulic Flow Graphics of Filippi Flow Limiters

Since the full-scale testing apparatus is installed at the École Polytechnique, specialists on the hydraulic faculty in the Department of Civil Engineering have approved the method of measuring flow rates. Measurement accuracy has been with 1 liter/second.

In addition, hydraulic performance tests have been carried out by other specialists and laboratories, such as:

- The Thames Polytechnic in London in 1984 (model 200/150/200).
- The University of Manchester in 1983 (model 300/250).
- The Centre Technique de Caluire (France) in 1992 (model 300/250).

Test results agreed with those obtained during testing in Lausanne. A suggestion was made to conduct wind tunnel tests to improve device performance, but this was rejected because full-scale test results were satisfactory.

Selection and Design of the Layout for the Filippi Model

Filippi models are designated by their inlet and outlet diameters. Thus the model 300/250 is designed for the first spill at a flow rate of 14 litres/second, and a maximum throughput of 18 liters/second (produced with inlet and outlet diameters of 300 mm and 250 mm, respectively).

The choice of a suitable model is made by establishing the maximum flow rate (as a multiple of dry-weather flow). When receiving water pollution is an important issue, the selection of a suitable limiter should be done by:

- Establishing the first spilling point of the appropriate model.
- By selecting a larger size, the overflow will only occur at higher flow rates, and thus be less frequent.

It is therefore necessary to have good information about the wastewater collection system, and the future population and land use changes.

In the flow graph (Figure 2) each Filippi model is allocated to a range of gradients. For example, for model 300/250, the allowable gradient range is 0.5 - 2.0 percent. The device must be installed within this range if guaranteed flows are to be achieved. It is evident that, as gradient increases, there is less likelihood of having deposits upstream or downstream of the Filippi limiter. The

Overflow-weir and flow limiter **FILIPPI**
Hydraulic flow graphics
of the 14 standard units

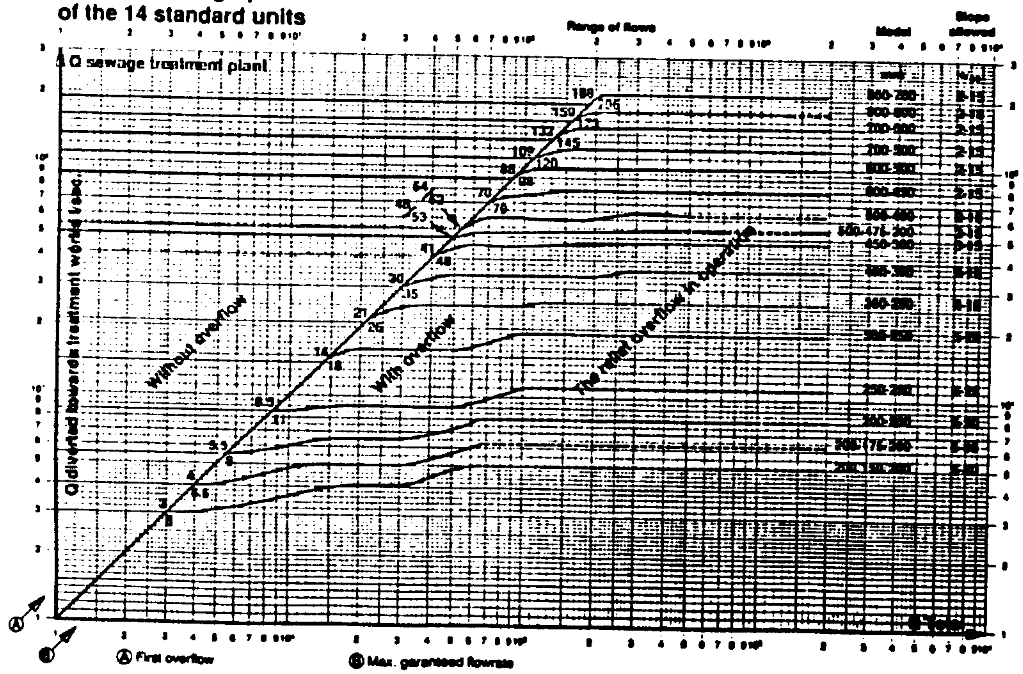

Figure 2: Flow Graph

same is true within the limiter itself, because the venturi effect will increase the flow velocities through the Filippi channel.

If the gradient upstream is higher than that allowed for a given device, it is important to modify the incoming gradient within a distance of not less than 5 meters upstream. The loss in grade is compensated for within the Filippi manhole (see Figure 3). The use of an "energy breaker" upstream is suggested if the gradient of the incoming sewer is very high.

The device can also be used with shallow slopes. When designing for such cases, there is no loss of level in the overflow sewer, and therefore no design problems. The overflow must be allowed to flow out of the Filippi manhole to avoid flow back into the limiter, and to guarantee the maximum throughput. One possible solution (Figure 5) is the use of a larger pipe section, or a rectangular runoff channel (Figure 4).

If overflow must be diverted to the left, it is feasible to allow this flow to pass under the limiter, or alternatively, to use a special overflow chamber, installed at the outlet of the limiter.

The Filippi flow limiter is often installed in combination with a tapered pressure-relief unit, which is installed in the same manhole to avoid any build up of water pressure upstream during heavy storms.

The Filippi limiters are installed in circular or rectangular manholes. For the smaller units, prefabricated GRP (glassfiber reinforced polyester) units are also used. When using the smaller units, it may be advisable to add an automatic rinsing system to avoid blockages. A solenoid-operated valve on a timer (to allow, say, for two rinsings per day), employing two spray nozzles, has been used successfully for this purpose. The valve can be battery-operated, if necessary.

Blockage of the smallest Filippi limiters can occur because gradients are low, or because dry-weather flows are only a few liters/second. No rinsing is required for the larger models.

Typical Applications with the Filippi Flow Limiter

The Filippi flow limiter has been used in the following types of installations:

- As a flow limiter in a combined sewer to avoid both upstream and downstream flooding.
- As a flow diverter or limiter upstream of a stormwater basin where the through flow bypasses the basin.

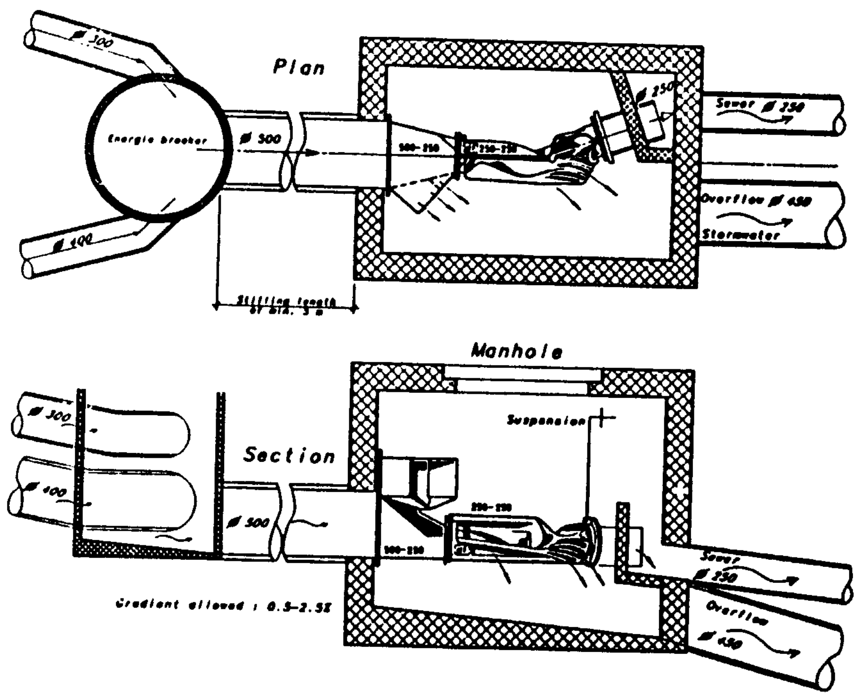

Figure 3: Fillippi Fitted in an Overflowing System with a High Gradient

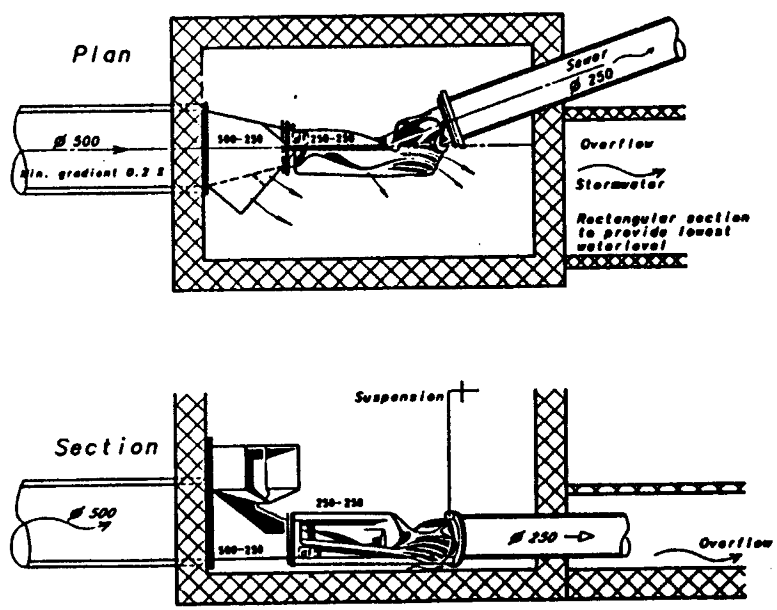

Figure 4: Fillippi Fitted in an Overflowing System with a Shallow Gradient

- As a flow limiter to avoid variations in inflow rates to a wastewater treatment facility.
- As a flow limiter in surface drainage systems, where polluted water ("first flush") is collected as concentrated wastewater, and then passed through the limiter to a downstream treatment facility.

All of these applications have been used in Europe for many years, and they have resulted in:

- Cost reduction - due to smaller spill water pipe downstream.
- Improved efficiency of wastewater treatment works.
- Reduced treatment costs for oil and gas separators.
- Reduced flooding of basements - with consequent savings in cleanup costs and decreased maintenance requirements.
- Reduced receiving water pollution because concentrated first flushes are routed to special treatment (settling basins).

The Filippi Flow Limiter as a Solids and Particle Separator

Due to its hydraulic shape the Filippi limiter also has a positive influence on solids separation. The shape improves the throughput of solids, provided that the inflow does not exceed 15 percent of the maximum throughput. Solids separation efficiency is also dependent on the specific gravity of the solids. "Sinkers" are more easily carried forward than "floaters," which are more likey to follow the overflowing water. If flows exceed 15 percent of maximum throughput, or if upstream turbulence has already suspended the solids, there will be little solids separation.

Limitations on the Use of the Filippi Limiter to Measure Flow Rates

The monitoring of flowrates with the Filippi limiter is possible only when the limiter is overflowing. In these cases a humidity sensor is installed on the overflow edge, and connected to a clock which will allow recording the total time of overflow. Incoming total flow must be measured in the upstream sewer. The overflow itself must be measured in the downstream sewer.

Operational Conditions

Only two operational conditions must be satisfied to ensure functioning of the Filippi limiter:

- The device must be correctly fitted into the manhole, and be rigidly fixed to achieve the proper rotational positioning of the limiter and to ensure the correct gradient.

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- Free flow out of the limiter must be assured, so as not to disturb the important venturi effect. No flow restrictions or decreases in gradient are allowed at the outlet (although an increase in the gradient is allowed).

Advantages in Using the Filippi Flow Limiter

The following are the advantages in using the Filippi limiter:

- Absolute guarantee of flow rates - both first spilling point and throughput.
- No additional downstream flows during heavy storms.
- No flooding problems (if an integrated pressure-relief valve is used upstream).
- Extra capacity of the downstream sewer is available.
- Large range of sizes/capacities (15) available.
- Ability to capture highly polluted first flush.
- Can be used on a wide range of gradients.
- Easy installation and fitting - prefabricated components.
- No moving parts or electrical requirements.
- Virtually no maintenance needed - self cleaning.
- No corrosion problems (devices made of stainless steel and GRP).
- Minor engineering of manholes.
- No hydraulic computations required for selection of proper device.
- Easy retrofitting in existing overflow systems.

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RCRA IMPLICATIONS FOR SEDIMENTS IN STORMWATER BMPs

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ABSTRACT

This paper discusses the circumstances under which sediments that accumulate in municipal and industrial best management practices (BMPs) can be classified as hazardous waste under the Resource Conservation and Recovery Act (RCRA). Under certain circumstances, such sediments, when discarded, can be classified as hazardous waste per the "mixture rule," "derived-from" rule and/or the USEPA's "contained in" policy. Many of the compounds specifically listed as hazardous waste under RCRA have been detected in municipal and industrial stormwater runoff. Simply because a chemical regulated by RCRA is detected in the BMP sediments, the sediments are not necessarily hazardous, as explained herein. Facility designers can call for an array of source control techniques to reduce the probability that RCRA-listed wastes will enter BMPs; however, such pollutants will inevitably find their way into BMPs on occasion. This must be recognized and planned for.

Under what circumstances, if any, can sediments that accumulate in municipal and industrial "best management practices" ("BMPs") be classified as "hazardous waste," as defined by the Resource Conservation and Recovery Act ("RCRA")? Stormwater BMPs include such facilities as retention ("wet") ponds; detention ("dry") ponds; infiltration basins; buried concrete vaults; and created wetlands. This paper provides an overview and recommendations for an issue that will increasingly confront designers and owners of industrial and municipal stormwater management facilities. In brief, key findings are as follows:

1. Under certain circumstances, sediments that accumulate in either municipal or industrial facilities, when discarded, may be classified as hazardous waste.

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2. Under current RCRA regulations, the "mixture" rule and "derived-from" rule can cause sediments with extremely low concentrations (barely above the detection limit) of one or more listed hazardous wastes to be classified as hazardous waste when those sediments are discarded. Perhaps of greater significance, under Environmental Protection Agency's ("EPA's") "contained-in" policy, environmental media (like water, soil, and sediment) that contain a listed hazardous waste must be handled as if a hazardous waste.

3. Many of the compounds specifically listed as hazardous waste under RCRA have been detected in municipal and industrial stormwater runoff. For example, chemical compounds that are commonly used for automobile maintenance (certain solvents, degreasers, hydraulic fluids, etc.) and yard care (selected herbicides, insecticides, fungicides and other pesticides) have been detected in stormwater runoff samples throughout the United States.

4. The chemicals of concern will mix with total suspended solids ("TSS") in the stormwater and a certain portion of these solids will "settle out" (be deposited) in the BMP. As will be discussed below, it is an open question as to when, if ever, such sediments become solid waste regulated under RCRA.

5. Simply because a chemical regulated by RCRA is detected in BMP sediments, ***the sediments are not necessarily hazardous***. If, for example, a spent halogenated solvent listed as hazardous waste is detected in detention pond sediments, those sediments would be hazardous waste under the mixture rule only if the source of the spent solvent contained more than ten percent of that solvent by volume (40 CFR §261.31 (F001 wastes)). If a potential source is located, there must also be a way for precipitation/runoff to come into contact with the chemical. If no product containing greater than ten percent of the listed solvent is found, or if contact with precipitation/runoff (including via spills) is unlikely, the pond sediments would *not* be classified as hazardous waste per RCRA.

   The distinction between having one or more discernable "point" sources of hazardous waste (with suitable characteristics) versus no clearly defined sources with suitable characteristics is a critical one.

6. Municipal and industrial stormwater designers should specify an array of source control techniques to reduce the probability that RCRA-listed wastes will enter BMPs.

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7. Despite aggressive source control efforts, in most municipal and industrial settings, pollutants that are "listed" under RCRA will inevitably find their way into BMPs on occasion. This *must* be recognized and planned for, as should the fact that most BMPs will cause some sediment/pollutant deposition, thereby triggering the potential problem. It is not feasible to design facilities to allow listed hazardous compounds to assuredly pass through, nor would this be desirable from a receiving water impact perspective.

8. There are many ameliorating factors to which regulators may be receptive. For example, appropriate facility analysis may demonstrate that the sediments pose little risk to humans or to aquatic or terrestrial life forms. For BMPs that are "onstream" (in "waters of the state/United States"), it may be feasible to show that the sediment will not cause use impairment or lead to numeric stream standards violations. Lack of clearly defined hazardous waste sources can add considerable uncertainty to this process. (see No. 5, above).

   In short, there are logical arguments that can be offered as to why BMP sediments should not be classified as hazardous waste, even if there are detectable concentrations of hazardous chemicals within the sediments.

9. Ironically, certain federal and state regulations (under the Clean Water Act) call for the implementation of BMPs, which can create regulatory difficulties under RCRA. Stated another way: to comply with one regulation potentially opens the door for violation of another regulation.

10. Pending regulatory modifications and new legislation offer the potential to ameliorate this situation, which could otherwise impose a significant economic burden when viewed from a national perspective.

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THE BASIS FOR, NATURE AND IMPORTANCE OF STORMWATER BEST MANAGEMENT PRACTICES (BMPs)

Typical stormwater BMPs include, as examples:

- **"Dry" detention ponds.**
- **"Wet" retention ponds.**
- **Artificial wetlands.**
- **Infiltration practices.**
- **Specially designed stormwater inlets.**
- **Grass-lined swales and other water quality conveyances that promote extended flow time, infiltration, and interaction of pollutants with channel vegetation.**

Facilities of this kind are commonly installed as stormwater quantity and quality mitigation measures. When properly designed and operated, they can reduce peak rates of runoff from developed lands to predevelopment levels and can reduce pollutant loads in stormwater runoff. One common (and desirable) feature of these BMPs is that they promote the sedimentation and deposition of TSS that are commonly found in municipal and industrial stormwater runoff. For example, EPA has determined that the median concentration of TSS in "typical" urban runoff is 100 mg/L (EPA, 1983). Such references as Metropolitan Washington D.C. Council of Governments, 1992; California State Water Resources Control Board, 1993, and Urbonas and Stahre, 1993 indicate that BMPs can attain TSS removal efficiencies of 70 percent or higher.

The important aspect of TSS removal within BMPs (in terms of RCRA regulations) is that many of the chemical compounds regulated by RCRA tend to adsorb onto sediments. As noted by Urbonas and Stahre (1993): "Most pollutants appear to have strong affinity to TSS, and the removal of TSS will often remove many of the other pollutants found in urban stormwater." Therefore, BMPs accumulate in sediments within retention/detention ponds, wetlands, infiltration basins, etc. Proper maintenance practice indicates that sediments should be periodically removed to assure that the facilities properly function, maintain longevity and assure that facilities are attractive.

Historically, and in most instances, the disposal of sediments removed from BMPs has posed no special regulatory or legal difficulty. Instead, industries and municipalities have disposed of such sediments in the same way that they would any uncontaminated soil. Frequently, in fact, upon drying, the sediments have been mixed with other soil and reused as backfill on construction projects, or disposed of in conventional sanitary landfills.

To comply with local, state and federal mandates related to drainage and flood control and stormwater quality management, the past decade (and particularly the past two to three years) has been a period of rapid growth in the numbers and kinds of BMPs used. The 1987 Clean Water Act and the accompanying National Pollutant Discharge Elimination System ("NPDES") stormwater regulations (issued in 1991 and subsequent years) have prompted numerous industries, cities, counties, and businesses to implement BMPs. Those states with authority to administer the Clean Water Act (NPDES permits) have state regulations for runoff quality control. Most local governments have drainage and flood control regulations (which call for BMPs) and many have adopted localized stormwater quality and erosion/sediment control regulations. In short, at multiple levels, there is the necessity to construct BMPs to comply with regulations. In addition, standard civil engineering practice (ASCE and WEF, 1993) mandates the installation of stormwater control measures. Detention ponds, infiltration practices, grass-lined channels, etc., are common elements of nearly every drainage system.

COMPOSITION OF STORMWATER RUNOFF

"Typical" stormwater runoff from urban areas contains a wide array of pollutants. Table 1 summarizes USEPA Priority Pollutants detected in urban runoff samples in the Denver area, according to the Denver Urban Runoff Program (Denver was one of the 26 cities that participated in the National Urban Runoff Program) (DRCOG, 1983).

Many chemicals in urban and industrial stormwater runoff are periodically detected which are RCRA-listed compounds. Excessive herbicide or pesticide use contributes toxic chemicals to the stormwater (California SWRCB, 1993). Household toxics such as oil/grease, paint, antifreeze, cleaner and solvents are widely used and may be improperly used, stored and disposed of which can lend to stormwater pollution (Berman et al., 1991). Atmospheric deposition contains appreciable quantities of pesticides and organic compounds (Novotny and Chesters, 1981). Other toxic pollutants occur through the use of products for de-icing and weed, rodent and insect control (Beaton et al., 1972) Hydrocarbons can come from spills, leaks or blow-off of motor lubrications, antifreeze, hydraulic fluid and asphalt surface leachate (Schueler, 1987). The City of Seattle (1989) found low concentrations of various EPA Priority Pollutants including pesticides, phenols, and polynuclear and polycyclic aromatic hydrocarbons.

In certain municipal and industrial settings, the probability of *detecting* RCRA-listed chemicals in stormwater runoff is significant. We emphasize the word *detect* because the detection limits for many RCRA-listed substances are measured in parts per billion. Practically, this can mean that a few tablespoons of a solvent in the runoff from a large industrial site will be detected by standard gas chromatograph/mass spectrometer ("GC/MS") lab methods. Consider the example of municipal or industrial vehicle equipment maintenance facilities. Even with good housekeeping practices and source controls in place, it is virtually inevitable that certain hydraulic fluids, degreasers, solvents and other RCRA-listed chemicals will sporadically come into contact with stormwater and that they will be detected in sediments in on-site BMPs, assuming that such sediments are monitored.

In larger municipal settings, the probability of RCRA-listed chemicals entering stormwater is high, because it is not practical to implement rigorous source control measures uniformly over vast areas. The benefit of increased dilution flow is not great enough to overcome the problem because detection levels for the relevant constituents are so low. Pesticides, particularly herbicides and insecticides, other chemicals commonly used by homeowners, the wide array of chemicals associated with automobiles and others can enter typical urban drainage systems at innumerable locations and, with appropriate monitoring, they will be detected.

In summary, municipal and industrial stormwater runoff can contain chemicals that are listed under RCRA as hazardous wastes. These chemicals will be found in sediments that accumulate in BMPs.

EFFECTIVENESS OF BMP AT REMOVING SEDIMENTS/PARTICULATE MATTER THAT CONTAIN CHEMICALS OF CONCERN

Typical stormwater BMPs can be quite effective at pollutant removal via sedimentation (the settling out of particulate matter from the water column onto the bottom of the BMP, such that the particulate matter becomes a deposit).

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Based upon the work of EPA (1983), Grizzard et al. (1982) and Whipple and Hunter (1982), extended dry detention ponds have been observed to remove 50 to 70 percent of TSS. The EPA (1983) reported that wet retention ponds could remove 60 to 90 percent of TSS. Monitoring of constructed wetlands in Florida (USGS, 1986) indicated a TSS removal efficiency of 41 percent. Modular block porous pavement (Schueler, 1987) can remove 80 to 90 percent of TSS. An excellent summary of TSS removal efficiencies for the most commonly utilized stormwater BMPs is provided on pages 105 through 112 of the Metropolitan Washington D.C. Council of Governments 1992 publication, *The Current Assessment of Urban Best Management Practices - Techniques for Reducing Non-Point Pollution in the Coastal Zone.*

Most of the RCRA-listed chemicals that have been detected in stormwater runoff can be associated with TSS; therefore, they are subject to sedimentation. This is why sediments in BMPs can contain RCRA-listed compounds.

THE KEY RELEVANT ASPECTS OF RCRA

Congress passed the RCRA 42 USC §§6901-6991i to require generators of hazardous waste to manage those wastes from their creation to their ultimate disposal, i.e., "from cradle to grave." RCRA requires every American industry and municipality which generates hazardous wastes to monitor and manage hazardous wastes in accordance with specified procedures.

Wastes can be defined by RCRA as hazardous because they either: (1) have certain *characteristics* (ignitability, corrosivity, explosivity or toxicity) or (2) because they contain constituents specifically *listed* in RCRA regulations. In nearly all cases involving stormwater BMP sediments, the reason that such sediments would be classified as hazardous wastes is because they contain *listed* chemicals rather than because the sediments are hazardous by *characteristic.*

It is not feasible to review RCRA in detail within this paper, but the key aspects of that law and its accompanying regulations for this issue include the following:

- The Mixture Rule (40 CFR § 261.3(a)(2)(iv))

  RCRA regulations include lists of a number of chemicals and their by-products that are considered per se hazardous wastes when used and discarded. Under the mixture rule, a mixture of any solid waste (including such ordinary wastes as dirt, paper, rags or plastics) and the listed waste is considered by regulation to be a hazardous waste. Even small concentrations of a listed waste can render large volumes of material "hazardous waste," as that term is defined under RCRA.

- The Derived-From Rule (40 CFR §§261.3(c)(2)(i) and 261.3(d)(2))

  If solid waste is considered hazardous waste, even if by operation of the mixture rule, then any residue from the treatment, storage or disposal of the hazardous waste is also considered hazardous waste.

- The Contained-in Policy

  Under existing EPA policy, environmental media -- such as soil or debris -- that "contain" a hazardous waste must be handled as if a hazardous waste. It is the contained-in policy, rather than the mixture or derived-from rules, that is most likely to bring BMP sediments within the scope of RCRA regulations. A de minimis exception to the contained-in principle can be made on a site-specific basis (57 FR 37194, August 18, 1992). EPA bears the burden of demonstrating that contaminated media do, in fact, contain hazardous waste before subjecting those media to the panoply of RCRA regulations. See, e.g., Chemical Waste Management v. EPA, 869 F.2d 1526, 1537-40 (D.C. Cir. 1989).

- The Nature of the Source Material

  Simply because a chemical regulated by RCRA is detected in BMP sediments, *the sediments are not necessarily hazardous even after discarded*. If, for example, a spent halogenated solvent listed as hazardous waste is detected in detention pond sediments, those sediments would be hazardous waste under the mixture rule only if the source of the spent solvent contained more than ten percent of that solvent by volume (40 CFR §261.31 (F001 wastes)). If a potential source is located, there must also be a way for precipitation/runoff to come into contact with the chemical. If no product with greater than ten percent of the listed solvent is found, or if contact with precipitation/runoff (including via spills) is unlikely, the pond sediments would *not* be classified hazardous waste.

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- <u>Exceptions to the Definition of Hazardous Waste</u>

  There are numerous exceptions to the definition of hazardous waste, and these exceptions must be considered on a site-specific basis. For example, certain mining and mineral processing wastes -- known as Bevill wastes -- are not regulated by RCRA (40 CFR §§ 261.3(a)(2)(i) and 261.4(b)(7)). Also, waste waters containing certain listed wastes are not subject to RCRA regulations if those waste waters are discharged under an NPDES permit or are subject to pretreatment standards.

These examples make it clear that *the distinction between having one or more discernable, "point" sources of a hazardous waste (with suitable characteristics) versus no clearly defined sources with suitable characteristics is a critical one.* Convincing the relevant regulators that there are not definable sources with relevant characteristics is the responsibility of the facility owner.

The mixture and derived-from rules do not apply to BMP sediments until those sediments are removed from the BMP, for it is only then that the sediments are "discarded." See <u>American Mining Congress v. EPA</u>, 824 F.2d 1177, 1192-93 (D.C. Cir. 1987) ("AMC"). The D.C. Circuit's decision in AMC has been limited by later decisions of that same court addressing sludges in sediment ponds that are reprocessed by the metals industry. See <u>American Petroleum Institute v. EPA</u>, 906 F.2d 729 (D.C. Cir. 1990) ("API"); <u>American Mining Congress v. EPA</u>, 907 F.2d 1179 (D.C. Cir. 1990) ("AMC II"). In <u>API</u> and <u>AMC II</u>, the court upheld EPA regulations extending RCRA to sediments in process sediment ponds: No court has yet decided whether a similar extension of RCRA's scope could apply to sediments in ordinary BMPs.

The mixture and derived-from rules do not logically fit with <u>in situ</u> BMP sediments. EPA might, however, apply the contained-in policy to <u>in situ</u> BMP sediments. That policy, as applied to contaminated medium, is not yet a rule. EPA proposed a rule that would codify the contained-in policy (Land Disposal Restrictions ("LDRs") for Newly Identified and Listed Hazardous Wastes and Hazardous Soil, Proposed Rule, 58 FR 48092 (September 14, 1993)). EPA recently gave notice, however, that it intends to tie the codification of the contained-in policy to the promulgation of a hazardous waste identification rule that abandons the strict mixture and derived-from rules for a more flexible approach to identify hazardous wastes (Land Disposal Restrictions ("LDRs") for Newly Identified Hazardous Wastes and Hazardous Soil, Clarification, 59 FR

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10778 (March 8, 1994)). The contained-in policy, as it now exists, could require that sediments of BMPs be managed as hazardous waste. Given the uncertainties of strict enforcement of a policy (as opposed to a rule) and EPA's intent to revise the regulatory framework in the foreseeable future, EPA may not wish to test the scope of its enforcement powers by seeking to regulate BMP sediments under RCRA.

If *water* stored in the BMP is regulated by an NPDES permit, RCRA may *not* apply to the water. Under all but the most unusual cases, RCRA will not supersede Clean Water Act jurisdiction over waters found in BMPs. Currently, however, sediments in stormwater facilities are a different matter and they may become subject to regulation under RCRA.

Detection limits and the distinction among the terms "practical quantitation limit" ("PQL"), "lower limit of detection" ("LLD"), "method detection limit" ("MDL") and others is critical on many issues involving RCRA. This subject is also beyond the scope of this document. This paper has simplified this subject greatly by indicating that measured concentrations are greater than the "detection limit."

RECOMMENDATIONS TO REDUCE THE POTENTIAL PROBLEM

BMP designers and facility owners are advised to take the following steps to reduce the probability that sediments will be classified as hazardous waste under RCRA:

1. Take all steps reasonable to reduce the likelihood that chemicals listed as hazardous waste under RCRA will come into contact with precipitation or stormwater. These measures are well documented in the contemporary stormwater quality literature and they can include:

   a. Educating workers/public.

   b. Placing hazardous materials indoors or covering them.

   c. Connecting floor drains and sumps to the sanitary sewer rather than the drainage system.

   d. Inventorying hazardous chemicals on a regular basis and keeping track of their usage.

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e. Discouraging the use of hazardous chemicals and emphasizing replacement compounds that are not listed by RCRA.

f. Formulating, implementing and regularly monitoring an aggressive spill control program.

2. In small drainage areas, the prospects for strictly controlling the kinds of chemicals that enter the drainage system are better than in larger areas with multiple property owners. This states the obvious; however, it is a point that merits emphasis. To provide an example, a vehicle maintenance facility that is three acres in size, and which receives no runoff from adjoining properties, should be able to implement rigorous source controls without difficulty. All work on vehicles can occur indoors. Floor drains and sumps should be connected to pretreatment facilities, which in turn would discharge to the sanitary sewer. Thoughtful drainage design decisions can be made. For example, vehicle parking areas can be separated from stormwater conveyances with vegetated "filter strips" and the conveyances can be lined with vegetation. Both of these practices will promote the interaction of chemicals of concern with vegetation and soils, and will also encourage infiltration.

3. To "localize" the problem, stormwater "pretreatment" facilities should be considered. For example, immediately upstream from a stormwater wetland, it may be feasible to install a sedimentation basin. Even with a retention time of as little as 15 minutes (where soil conditions are favorable), a significant fraction of the total sediment load can be removed from the stormwater prior to discharge into the wetland. This not only localizes sediments and the pollutants that adsorb to them, but also benefits the wetland and results in decreased long-term maintenance costs.

4. Adopt measures to reduce the quantity of sediment that will enter the BMP over time. The smaller the sediment load that accumulates, the less frequently the sediment has to be removed. This is of vital importance because RCRA in most instances becomes relevant *only* when sediments actually need to be removed. Rigorous erosion and sediment control practices, both

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during and after construction, are mandatory. Judicious use of sand during the winter months is necessary.

5. Thoughtfully evaluate BMP facility design characteristics and implement techniques that will enhance the likelihood of pollutant "loss" within the BMP. For example, incorporating fountains into retention ponds enhances the volatilization of many volatile and semi-volatile organic compounds that are listed by RCRA. Note, however, that a permit is required to treat a RCRA hazardous waste.

6. Designers are well advised to discuss potential problems with regulators and their clients from the outset of an assignment. By discussing potential problems with the BMP facility owner, professional liability is reduced and the owner and engineer can agree, in advance, on mitigation measures.

   Discussions with regulators are equally important. Generally, the authors recommend that the design engineer: (a) cite regulations that are forcing the implementation of stormwater BMPs in the first place (typically municipal or industrial NPDES regulations); (b) delineate the full range of functions that the BMP will fulfill (flood hazard reduction, stormwater quality management and others specific to the given facility); (c) describe structural and nonstructural measures that will be taken to reduce the probability that hazardous chemicals will enter the BMP; and (d) suggest a regulatory agreement, in advance, that will address the issue in a reasonable, cost-effective manner if and when the sediments do need to be removed, under the assumption that they contain one or more RCRA-listed chemicals.

   The nature of discussions with the BMP owner and regulators are highly specific to the circumstances at hand.

7. Intentionally oversize the sediment storage volume in the BMP. Instead of assuming that the BMP should have its sediments removed once every 5 to 10 years, assume that sediment removal should occur no more frequently than once every 20 to 30 years. This will be impractical and excessively expensive in certain

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instances, but in situations where additional sediment storage can be achieved economically, this step should be taken.

It is essential to recognize that in most instances RCRA will not be triggered until sediments need to be removed from the BMP. Therefore, every reasonable step should be taken to avoid the need to remove sediments from stormwater facilities.

8. Where feasible, construct facilities that are "off-line" rather than "on-stream." This is certainly not a panacea, but at least off-line facilities are not subject to the criticism that stormwater facility sediments classified as hazardous waste by RCRA are located in "waters of the state/United States."

It will not always be feasible to avoid RCRA regulations by implementing the measures listed above. Furthermore, existing BMPs may contain sediments that have RCRA-listed chemicals in them *now*. When confronted with the knowledge that BMP sediments do contain RCRA-listed wastes, the facility owner and the designer should consider the following steps:

1. Conduct additional sampling to confirm the presence of the contaminants. Also, sample at multiple locations to assure adequate horizontal and vertical coverage. Critically analyze the data collected and determine if additional actions are required.

2. If the drainage area is small, thoroughly search the area for potential distinct sources of the chemical or chemicals that have been detected in the sediments. If distinct potential sources are noted, their ability to be transported into the stormwater BMP needs to be established.

   Once potential sources are noted, their characteristics should be checked against the RCRA definition of hazardous waste (40 CFR Part 261) to assure that they are, in fact, RCRA-regulated wastes.

   A thorough search of this kind is obviously feasible only in smaller drainage basins.

3. If the search for sources indicates that there are sources regulated by RCRA which have entered the stormwater facility sediments, actions should be immediately taken to assure that the chemical will not continue to be discharged into the stormwater drainage system.

   If no distinct source or sources with the requisite characteristics (as defined by RCRA) are located, this is very important information to be conveyed to the regulators. All other things being equal, RCRA-regulators will be less inclined to rigorously control "contaminated" sediments that have been affected by diffused sources rather than distinct sources with the requisite characteristics.

   The ideal outcome is to identify probable sources that do *not* comply with RCRA requirements. For example, if the trichlorethylene sources in a drainage area that are in contact with precipitation/runoff are less than 10 percent pure, the sediments should not be classified as hazardous wastes.

4. In many cases, a risk assessment will demonstrate that there is no practical risk posed to the public or other life forms by constituent levels within the sediments. This is important information to provide to the regulators because they can exercise a certain amount of judgment when evaluating regulatory options. If volatile or semi-volatile compounds are in the sediments, the risk assessment should account for the sediment dredging and disposal process, because these actions will normally cause substantial volatilization, thereby reducing the risk.

5. Evaluate modifications to the stormwater facility that will avoid the need to excavate the contaminated sediments. For example, it may be reasonable to raise a detention pond outlet structure, thereby increasing sediment storage space. This action could reduce the flood attenuation and water quality enhancement characteristics of the facility, but the reduction, if significant, can be offset with other BMPs in the basin.

6. There is some merit to the argument that the Clean Water Act (NPDES permitting program) forced the construction of stormwater BMPs that would not otherwise have been installed. Consequently, it is unfair to then come back with RCRA requirements for facilities that are functioning in exactly the manner that they were intended.

Irrespective of which of these options (or others) are implemented, the authors suggest that qualified, specialized legal counsel be obtained so that appropriate steps are taken.

UNKNOWNS AND FUTURE CONSIDERATIONS

The subject of potential RCRA regulation of stormwater facility sediments is in its infancy and much is not known. Examples of major unknowns are as follows:

1. The authors are not sure how frequently stormwater BMP sediments actually contain RCRA-listed wastes with requisite characteristics. Common sense tells us that this could be a typical problem, but relevant data are presently lacking. The authors know of three industrial complexes in different states that are currently faced with this situation and that are proceeding under the assumption that the relevant sediments are subject to RCRA regulation.

2. Semantics and design decisions could play a key role in the future. For example, some might argue that "formal," structural BMPs are subject to RCRA regulation while "informal," less significant BMPs are not. Examples of "formal" facilities are wet ponds, dry ponds, artificial wetlands and infiltration basins. Examples of "informal" facilities are small swales and "porous" check dams. In any event, the distinction among different kinds of BMPs, if any, relative to RCRA needs to be defined.

3. Most stormwater conveyance channels, including storm sewers, exhibit sediment deposition -- consequently, can they be regulated under RCRA?

4. The authors have not asked a representative sampling of regulators for their opinion on this issue. We also cannot speculate as to the probable posture of the regulators when it comes to this subject. We suspect that the reaction would be highly dependent upon the person asking the question and the person answering the question.

As of the summer of 1994, there are potential regulatory changes that could be very helpful relative to this situation. Also, RCRA is now in the reauthorization process, and there is the potential for language in the updated law which would specifically exempt stormwater BMPs from RCRA coverage. Important considerations include:

Revisiting the Mixture and Derived-from Rules

In 1991, the United States Court of Appeals for the District of Columbia vacated EPA's mixture and derived-from rules (Shell Oil Company v. EPA, 950 F.2d 741 (D.C. Cir. 1991)). The Court vacated these rules only because EPA failed to follow appropriate notice and comment rulemaking procedures when promulgating the rules; the Court did not reach substantive challenges to these rules. After Shell Oil, EPA repromulgated the mixture and derived-from rules on an interim basis (57 Fed. Reg. 7,628 (March 3, 1992)). Thus, the mixture and derived-from rules are at present the law of the land. In the Bush Administration, EPA proposed a new "Hazardous Waste Identification Rule" ("HWIR") that would have abandoned the mixture rule in favor of concentration-based standards for hazardous wastes (57 FR 21450, May 20, 1992; 57 FR 7636 March 3, 1992). The Bush Administration abandoned this promising approach prior to the 1992 election, but the Clinton Administration has promised to pursue rulemaking that would replace the mixture and derived-from rules with a more reasonable rule defining hazardous waste. (It is also important to note that the DC Circuit's opinion affected only the federal mixture and derived-from rules. Many states have similar or identical rules. A recent court decision, however, invalidated a State's mixture rule based on Shell Oil). The benefits of the revision of these rules are likely to spill over to the contained-in policy and should relax the overly rigid regulation of contaminated environmental media.

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- RCRA Reauthorization

RCRA is overdue for reauthorization, and Congress is likely to amend RCRA substantially when that reauthorization finally occurs. Early indications are that most of the action in RCRA reauthorization will be over the regulation of nonhazardous waste. Nonetheless, reauthorization will provide to Congress the opportunity to address the definition of hazardous waste, including the mixture and derived-from rules and the contained-in policy. If EPA promulgates replacement rules before reauthorization, Congress may well stay its hand on these issues.

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KEYWORDS

Best Mangement Practices; Hazardous Waste; RCRA; Sediments; Mixture Rule; Derived From Rule; Contained in Policy; RCRA-Listed Wastes; Urban Runoff Quality; BMP Facility Maintenance; Settleability of Pollutants; NPDES Permits; Urban Runoff Pollutants

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"Low Cost Automatic Stormwater Sampler"

Lynn A. Dudley[1]

Abstract

The Vortox Co. of Claremont, CA., has developed and applied for patents on a method of sampling stormwater sheetflow, outfalls (from end of the pipe) and "in-the-pipe" during partial or full flow. This unique method is automatic, 100% mechanical and inexpensive when compared to other automatic samplers. The Vortox sampler is finding widespread acceptance among state regulators, environmental consultants, industrial sites, municipalities, as well as military bases.

Introduction

Who is Vortox? How did we become involved in the design and manufacture of a stormwater sampler?

The Vortox Company has been in the business of manufacturing air cleaners for internal combustion engines for 76 years. We held one of the first patents for the oil bath air cleaner. Vortox supplies to OEM's such as Chrysler, Peterbilt, Kenworth as well as some aftermarket applications in alternate fuel conversions. We also lend our expertise in design and sheet metal fabrication to the jobshop market.

Our involvement in stormwater sampling was the result of studying the CWA regulations as it pertained to our industrial site. This led us into an investigation into the accepted methods of sampling stormwater and a

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determination that no one method of sampling was convenient, simple, safe, obtained a quality sample and was cost effective. At the Vortox plant site we have three (3) points which must be sampled. After determining that we could not sample manually we obtained quotes on electronic samplers which would cost several thousand dollars for three (3) machines. At this point, Vortox was determined to develop a simple sampling concept and gain acceptance from the Los Angeles Regional Board for its use at Vortox. We built a prototype and submitted it to the board with a request to use the method for collecting stormwater samples at the Vortox plant. The regulators at the Los Angeles region not only gave us approval but thought enough of the method to ask us to show the prototype to the other Regional Boards throughout the state. All the Regional Boards in California stated they would accept this method of sampling, including the man credited with writing most of California's stormwater regulations, Tom Mumley from the San Francisco Bay Region. Vortox made the decision to patent the concept and enter into manufacturing and marketing the sampler. We traveled to adjoining states asking regulators, chemists and consultants to critique the approach we had taken.The feedback was always positive and in addition to California's acceptance, we obtained acceptance from Utah, Colorado, Oregon, Wisconsin, Washington and South Carolina. After 2½ years of production, we have over 350 samplers operating in the field which includes military bases (Navy and Air Force), airports (Santa Barbara & Los Angeles County, CA), municipalities (City of San Diego, CA, City of San Francisco, CA, Counties of Orange and San Bernardino CA). The U.S.G.S. has officially recommended the Vortox sampler be used in some of their stormwater responsibilities for the military. Industrial site applications range from the very largest corporations (CocaCola) to the small businessman.

We demonstrated the sampler for Bill Swietlik, Rod Fredrick, Kim Hankins and Nancy Cunningham of U.S.E.P.A. in Washington, DC, with very positive feedback and a request to have an independent laboratory run a test comparing the results of an electronic automatic sampler setting next to a Vortox automatic sampler in a spiked stream of water collecting samples at different flow rates. The results from the two samplers were virtually the same. Copies of the laboratory report is available upon request.

Figure 1, will identify the key components of the samplers as all the samplers work on one basic principle.

How does the Vortox sampler work? The primary design of this product is to capture grab samples and/or composite

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(continuous collection) samples. The type 316 & type 304 stainless steel sampler is manufactured in three (3) configurations: Figure 1, The 3 liter (.8 gallon) sampler for surface flow. Figure 2, The 21 liter (5.5 gallon) sampler for surface flow. Figure 3, The 3 liter (.8 gallon) "In-The-Pipe" sampler for end of pipe or underground stormwater systems. The 3 liter (.8 gallon) is sufficient for the standard tests for Ph, TSS, TOC, metals and specific conductivity. The 5.5 gallon sampler is used for applications requiring larger sample volumes (i.e. bio-assay tests) such as stream beds.We have had requests for a more inert surface than stainless steel. To meet this request, we developed an FDA approved Teflon coating which is applied, as an option, to most of the internal parts of the sampler.

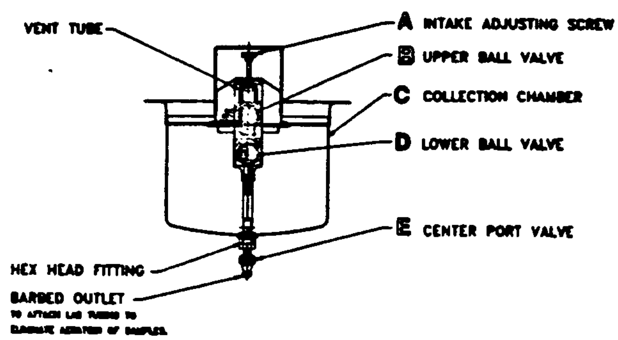

FIGURE 1
3 LITER (.8 GALLON) STORM WATER SAMPLER

FIGURE 2
21 LITER (5.5 GALLON) SAMPLER PLACED INTO SUMP HOUSING

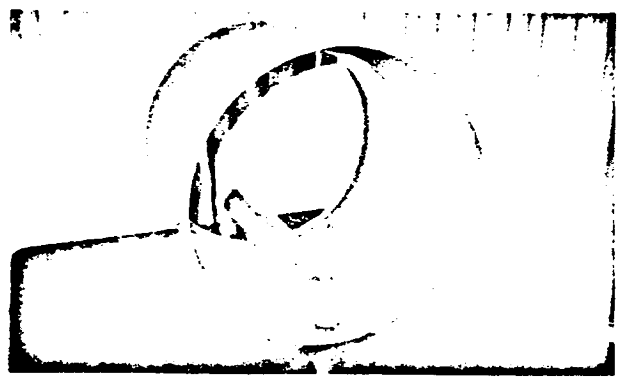

FIGURE 3
"IN-THE-PIPE" 3 LITER (.8 GALLON) SAMPLER
IN 610MM (29 INCH) PIPE

The three (3) configurations are available with a dam around the orifice (Fig. 4) to allow heavy particles in the effluent to settle out in the sediment pan before entering the sampler <u>or</u> without the dam (Fig. 5) so the fluid flows immediately into the sampler.

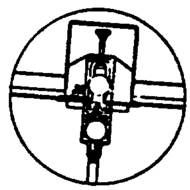

FIGURE 4

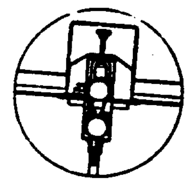

FIGURE 5

Each design has an intake adjusting screw at the top of the ball valve for controlling the rate at which the liquid enters the sampler. As the adjusting screw is turned downward, the ball is restricted in its vertical lift and throttles the orifice opening. When the adjusting screw is adjusted down against the ball, the valve is closed and this is the reference point for all adjustments. When the intake adjusting screw is opened one-half (1/2) turn from the fully closed position it will take <u>clean water</u> approximately 20 minutes to fill the 3 liter (.8 gallon) sampler and shut off the internal ball valve. When the intake adjusting screw is fully open, the 3 liter (.8 gallon) sampler will fill in approximately two (2) minutes. The 21 liter (5.5 gallon) sampler will fill in approximately 10 minutes when the adjusting screw is fully open and well over three and one-half hours (3½ hrs) when throttled down. The adjusting screw is a precision machined screw with slight resistance so as not to slip from its selected position. Because the effluent is site specific, some experimenting might be required to obtain the desired setting.

With the centerport valve closed, top orifice closed by the ball and vent tube open, the sampler is ready to collect samples. The upper ball valve will stay closed (B, Fig.1) keeping contaminants out of the sampler until liquid causes the ball to lift and expose the orifice. This allows liquid to enter the collection chamber (D, Fig.1). As the chamber fills the lower ball valve (C, Fig.1) rises, air is forced from the head space above the liquid and the orifice is closed by the lower ball, preserving the sample. If flow stops and only a partial sample is collected, the upper ball returns to the closed position, preserving the sample.

<u>Transferring the sample</u>

To transfer the sample to laboratory bottles (Fig. 6,7,8) simply attach a flexible tube to the barbed outlet at the end of the center port valve,(E Fig.1) place the opposite end of the tube in the bottom of your laboratory sample bottle and open the valve. The sample will be transferred with very little exposure to the air. Occasionally shake the sampler to keep the heavy particles in suspension and insure equitable transfer of all particulate material.

FIGURE 6

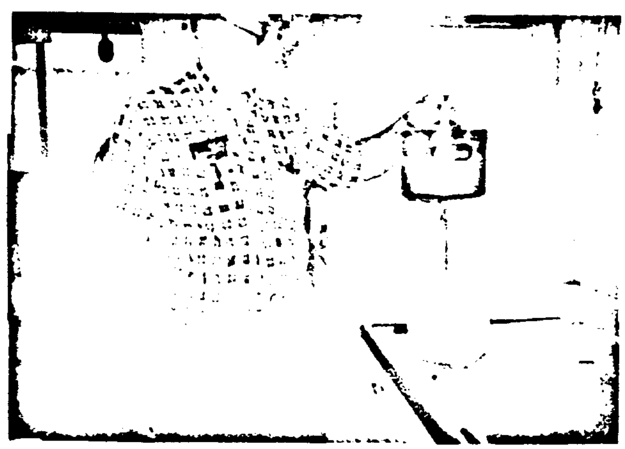

FIGURE 7

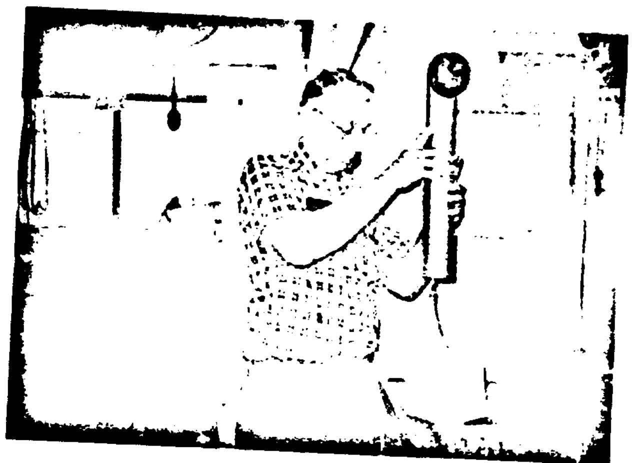

FIGURE 8

Cleaning the sampler

After transferring the sample, the sampler can be disassembled for clean up by turning the hex head of the centerport valve (Fig. 1) clockwise. This disengages the centerport valve from the double ball valve head and separates the sampler into three (3) components; valve, collection chamber and the double ball valve head. These parts can be placed in a container of hot water and non phosphate detergent and scrubbed with a brush to remove any heavy soils. Rinse with deionized water, dry and reassemble. Before placing the sampler into service, blow air through the vent tube to ensure free passage of air, check that the centerport valve is closed and the intake adjusting screw is positioned in the desired position.

Applications

The 3 liter (.8 gallon) sampler can be suspended by stainless steel cable beneath existing grates with a drop box depth of approximately 406 mm (16 in). The cable is laced through the openings in the grate and attached to the eyebolts on the sampler. (The cable and eyebolts are available as an option). As the grate is lowered into place (Fig. 9) the sampler is located at the low point on the grate, when in place. The sample is collected as sheet flow moves across and through the grate into the top of the sampler. Note: The 21 liter (5.5 gal) sampler cannot be suspended due to the weight when full.

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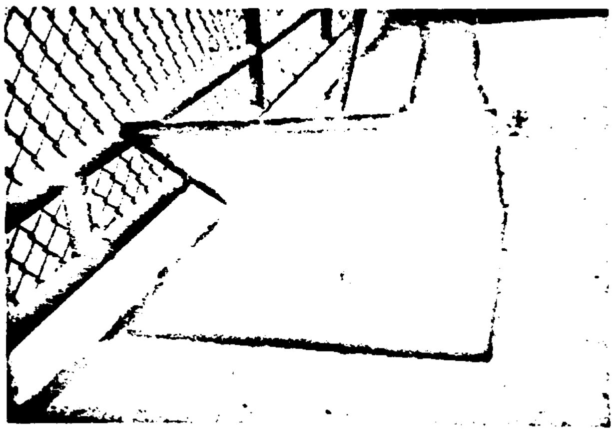

FIGURE 9
SUSPENDED 3 LITER (.8 GALLON) SAMPLER
IN EXISTING DROP BOX WITH GRATE

In situations where there are no existing drop boxes (Fig. 10), we have a kit approach in both the 3 liter (.8 gallon) and 21 liter (5.5 gallon) sampler (Fig. 11) which includes the sampler, sump housing and a traffic rated grate for below grade installation. You simply dig or bore a hole in the ground (508 mm)(20 inches) in diameter and 610 mm (24 inch) deep for the 3 liter (.8 gallon) sampler or 559 mm (22 inch) in diameter and 838 mm (33 inch) deep for the 21 liter (5.5 gallon) sampler to accommodate the sump. The sump is placed in the hole and the grate rests on the top flange of the sump. The top surface of the grate should be at grade level or slightly below. The sump and grate can be a permanent installation by pouring concrete around them or they can be portable, as in stream beds (Fig. 12) by using soil or gravel around the sump. Field experience has shown these installations take a little over one hour.

Once the sump housing and grate rim are in place, the sampler drops inside the sump (Fig. 10) and locks in place by aligning two (2) keyhole slots in the flange of the sampler with welded studs located on the horizonal surface of the sump collar. A slight turn of the sampler will engage the stud and lock the sampler in place. Replace the grate plate in the rim, secure with two (2) Allen screws and you are ready to collect your sample.

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FIGURE 10
3 LITER (.8 GALLON) SAMPLER WITH SUMP AND GRATE

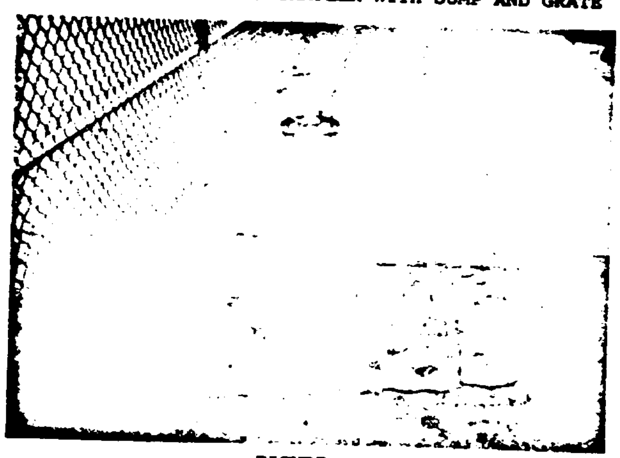

FIGURE 11
21 LITER (5.5 GALLON) SAMPLER
WITH SUMP (IN THE GROUND) AND GRATE

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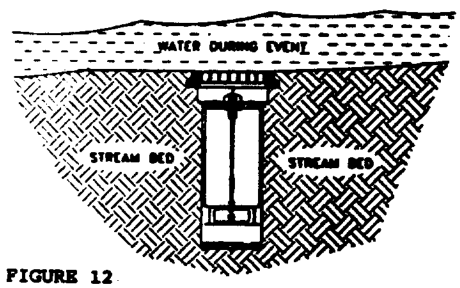

FIGURE 12

The "in-the-pipe" sampler was developed out of requests from California municipalities to be able to bypass a small base flow and catch samples at high or full flow. We were asked to accommodate pipe sizes from 305 mm (12 inches) diameter to 914 mm (36 inches) diameter. The concept we developed uses the same double ball valve, intake adjusting screw and outlet valve (Fig. 8) packaged in a 76 mm (3 inch) diameter stainless steel pipe. The device for anchoring the sampler (in-the-pipe) is an expanding stainless steel band which is locked into place by an inflatable bladder or a mechanical turnbuckle. The expanding band can remain in-the-pipe and the sampler simply disengages by sliding out the open end of the pipe.

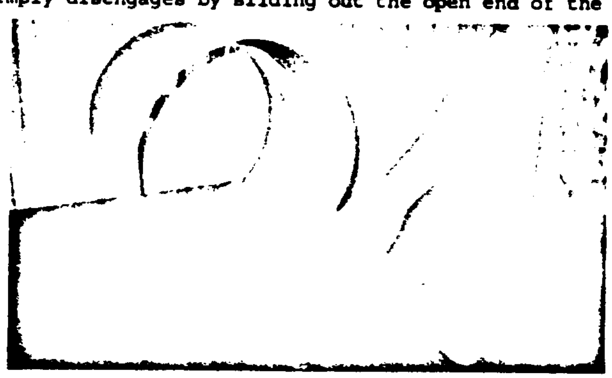

FIGURE 13
3 LITER (.8 GALLON) "IN-THE-PIPE SAMPLER

What we have presented is a brief description of a family of liquid samplers which offers a variety of methodology for sampling. The equipment is simple, durable, 100% mechanical and user friendly at an affordable cost.

HIGH-ACCURACY CSO AND STORMWATER FLOW MONITORING

Terrance L. Burch[1] and Joanna M. Phillips[1]

Abstract

Growing concern over Combined Sewer Overflow (CSO) discharges has led to the U.S. Environmental Protection Agency's new CSO Overflow Control Policy for incorporation into the National Pollutant Discharge Elimination System (NPDES) permit process. The policy creates a new emphasis on comprehensive CSO system discharge monitoring and documentation programs. Acoustic transit-time flowmeters can be used to meet these monitoring and documentation requirements by providing high-accuracy and continuous flow data during dry- and wet-weather conditions in conduits that flow partially full and/or surcharged. Transit-time flowmeters provide bi-directional flow measurement capability and can be configured for multiple acoustic paths, making them highly accurate over a wide range of changing water level and flow conditions, as well as in locations where other flow measurement methods cannot be used reliably. This paper provides an introduction to the acoustic transit-time technique and its applicability to a wide range of difficult measurement sites and includes descriptions of existing CSO flow monitoring installations.

Introduction

The U.S. Environmental Protection Agency (EPA) is adopting a new Combined Sewer Overflow (CSO) Control Policy for incorporation into the National Pollutant Discharge Elimination System (NPDES) and Municipal Discharge permitting processes. This action is being taken in response to growing public concerns and Clean Water Act requirements for attaining minimum water quality standards in the receiving waters affected by CSO discharges. In many cases, the new CSO Policy and permitting process will require municipalities to develop and implement CSO system monitoring programs for planning, compliance, and reporting purposes.

The new regulatory focus on long-term CSO control programs increases the need for accurate flowrate measurement and monitoring systems that may be deployed at multiple locations within municipal networks. Flow monitoring data collected from key locations over a range of CSO system loadings frequently reveal significant

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differences in comparison to flow predictions resulting from computer models such as the Stormwater Management Model (SWMM). Such data is valuable for verification of the overall modeling approach and specific system features to be analyzed, and for calibration of the CSO flow network response to inflow events. However, achieving high accuracy with flow measurements is critical to meaningful system modeling and analysis since the propagation of uncertainties (errors) through flow networks can rapidly grow to unmanageable proportions.

Ultrasonic transit-time flowmeters can be used to meet these CSO monitoring and documentation requirements by providing highly accurate and continuous flowrate measurement during dry- and wet-weather conditions. Transit-time flowmeters include bi-directional (reverse flow) measurement capability and can be configured for multiple acoustic paths, making them highly accurate over a wide range of changing water level and flow conditions, as well as in locations where other measurement methods cannot reliably function.

In addition to providing the data needed for system modeling and evaluation, accurate flow information is valuable for:

- Regulatory reporting and compliance documentation
- Planning and evaluation of CSO control alternatives
- Alerting operators to CSO system malfunctions
- Optimizing operation of treatment facilities
- Allocating user costs and billings
- Pacing chemical treatments for CSO discharges

Requirements for CSO and Stormwater Flowmeter Systems

Flowmeters for CSO monitoring typically are required to operate under both free-flowing (i.e., in partially-filled conduits or open channels) and surcharged (pressurized) conditions. Additional measurement requirements can arise at locations subject to backflow, reverse flow, or tidally governed hydraulics. The need to accurately determine flowrates over such a wide range of conditions places stringent requirements on the methods and technology that can be successfully utilized in CSO applications. Methods that derive flowrate from measurements of water level only (using stage vs. flowrate relationships) are simply not capable of meeting these requirements.

A more suitable approach is developed from consideration of the hydrodynamic continuity equation, with a derived principle that applies to flow through any conduit section; i.e., flowrate is equivalent to multiplication of a true average current profile velocity times the cross-sectional area of the conduit flow. Since flows in conduits range from partially full through surcharged conditions, measurement of water level is used to determine the cross-sectional flow area (based upon the geometry of the conduit), and water velocities are measured to estimate the corresponding true average flow velocity.

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Since flow velocity profiles in surcharged conduits are significantly different than under free-flow conditions, a "compound" approach that automatically selects an appropriate integration method for computing representative velocity profiles and resultant averages will provide better flowrate accuracy. Conduit sections that are well-removed from upstream bends, obstructions, or other flow disturbances will exhibit "fully developed" flow velocity profiles; as will be discussed below, the multi-path transit-time method can provide accurate flowrate information even at sites where flow profiles are not well developed.

Ultrasonic Transit-Time Flow Measurement Principles

The Accusonic multi-path transit-time flowmeters discussed in this paper have been installed worldwide for high-accuracy flow measurement in over 1000 large pipes, open channels, and conduits that flow partially full to surcharged. The flowmeters, which operate in clean or "dirty" water environments, have been used in hydroelectric and water system applications since the 1960s. The flowmeters have been installed in numerous large CSOs and wastewater treatment plant influent and effluent channels for high accuracy and reliable flow measurement. Because the flowmeters use relatively low-frequency, high-power ultrasonic pulses for flow measurement, they are capable of operating in water with relatively high concentrations of suspended sediments, as is common in CSO environments.

The transit-time acoustic technique is based on the principle that an acoustic pulse traveling at an angle across a pipe will be accelerated in the downstream direction by the water flowing through the pipe and will arrive at a receiving transducer in less time than an acoustic pulse traveling in the upstream direction, which is decelerated. By mounting transducers to define a path crossing the pipe or channel at an angle to the flow axis (Figure 1) and measuring the difference in acoustic transit times in the upstream and downstream directions, an average flow velocity at the level of the acoustic path is calculated according to the following formula.

$$V = \frac{(T_1 - T_2)}{T_1 T_2} * \frac{L}{2 \cos \theta}$$

where:
- V = average fluid velocity at the level of the path,
- T_1 = acoustic transit time in the upstream direction,
- T_2 = acoustic transit time in the downstream direction,
- L = acoustic path length between transducers, and
- θ = acoustic path angle relative to flow axis.

In the multiple-parallel-path method, average velocity is measured nearly simultaneously at more than one elevation in the flow. These simultaneous velocities define a velocity profile throughout the flow cross-section for use in calculating an integrated flowrate. This should be contrasted with the use of a single-point or single-path velocity to estimate the average velocity throughout the cross-section. The use of multiple simultaneous velocities also makes the method responsive to changing flow profiles associated with quickly changing CSO flow regimes, which can go from completely dry to surcharged within minutes during a rain event.

In addition to the multiple flow velocities, water level within the conduit is measured. With the Accusonic multi-path acoustic technique, as the water level rises above each acoustic path, additional velocity information becomes available. The flowmeter computer changes integration method as appropriate to the number of submerged paths. The highest accuracy is available when the conduit becomes surcharged, and a full-pipe integration technique is applicable. Numerous independent field and laboratory tests have shown that accuracies of ± 0.5 to 1% of actual flowrate can be achieved in surcharged conduits with a 4-path configuration. These accuracies can be maintained even at sites with poor hydraulic conditions by adding a second plane of transducers in a cross-path configuration. The crossed-plane approach compensates for any errors due to cross-flow through the measurement section caused by upstream disturbances.

Under free-flowing (non-surcharged) conditions, flowrate accuracies of ± 2.0 to 3.0% of true flow are typically achieved with a 3-path system. The increased uncertainties are generally associated with determining the flow cross-section area and estimating an average velocity for the region above the highest operating acoustic path. The uncertainty can be minimized by adding acoustic paths (i.e., average velocities) at additional elevations and by averaging redundant level measurements.

For very low flows where the water level is below the lowest acoustic path, the meter can automatically switch to the Manning method (where applicable) to compute flowrate using level data only. Typically, however, an acoustic path is placed very low in the conduit to ensure that velocity data becomes available early in a rain event.

An additional advantage of the acoustic transit-time technique is that the system is "dry calibrated", based on measurement of as-built path lengths and angles at the time of transducer installation. Because the transducers are typically permanently installed, once these path lengths and angles are known and are entered into the flowmeter console as parameters, there is no need to recalibrate the system over time. The multiple-path method also obviates the need for flow profile calibrations that are required for single-point or single-path flowmeters.

Another feature of the multi-path transit-time technique is that it measures bi-directional flow, which can be particularly important in tidally influenced CSOs. For example, at New York City's Fresh Creek CSO, negative velocities occur on the lowest path during the periods of incoming tide while velocities on the higher paths indicate an outward flow. The meter determines the net flow through the CSO even during these periods of bi-directional flow profiles. A single-point, single-path, or acoustic Doppler-type velocity flowmeter cannot resolve true net flowrates under these conditions and can even indicate the wrong direction of flowage! This is of critical concern for control of tide gates or other CSO flow diversion mechanisms.

A general arrangement drawing showing a multiple-path flowmeter configuration installed in the City of Philadelphia's Cottman Avenue CSO is shown in Figure 2.

Transducer Selection for CSO/Stormwater Applications

Important considerations in choosing flowmeter transducers for CSO applications are cost, conduit shape, protrusion into the flow, ease of installation, and whether the transducers need to be certified for use in a hazardous location. Any transducer selected for CSO monitoring use should be constructed of durable, non-corrosible components for trouble-free, long-term operation.

A variety of ultrasonic transit-time transducers have been developed for use in a wide range of measurement applications, including buried and exposed steel pipes, concrete pipes and trapezoidal channels, and open channels. Internal mount transducers are often used in CSO and wastewater applications (Figure 3). Accusonic has developed a dual-element, internal-mount transducer providing a completely redundant back-up capability to the primary sensor. Low-cost, array-mount PVC transducers and explosion-proof transducers are also available. Transducers for mounting on the inside of pipes or channels have generally been designed to minimize protrusion and to direct flow around the transducer. At sites where large items of debris might be expected to damage anything mounted on the channel walls, transducers have been recessed in blockouts in the channels walls, or protective "deflectors" have been mounted upstream of the transducers to prevent damage.

Several different types of water level sensors can be used with the flowmeter--an acoustic "downlooking" transducer, which is mounted above the flow and measures level by the time it takes to receive an acoustic signal bounced off the water surface, an acoustic uplooking transducer (mounted on the channel bottom and reflecting an acoustic pulse off the water surface), or a submerged pressure sensor. Because of the possibility that debris could settle on an acoustic uplooking transducer and obscure the signal, a downlooking sensor is often recommended in CSO applications, with an uplooker or pressure sensor used for redundancy. The downlooking transducer is often recessed in a manhole for continued operation during surcharged conditions.

Recent Flow Monitoring Installations

Massachusetts Water Resources Authority

Accusonic flowmeters are currently operating for the Massachusetts Water Resources Authority (MWRA) in the Somerville, Commercial Point, and Constitution Beach CSOs. All three sites are instrumented with redundant internal mount transducers. The Somerville and Commercial Point sites are large rectangular box conduits (15' x 7' and 15' x 15', respectively) configured with three or four acoustic paths, and both are instrumented with an uplooking transducer for water level measurement. The flowmeter at Constitution Beach CSO is located in a 36-inch-diameter buried concrete pipe. Two acoustic paths and an uplooking level sensor are used here because of space constraints. The flowmeters at all three MWRA sites are used to pace chemical metering pumps for treatment of CSO discharges.

New York City Department of Environmental Protection

An Accusonic flowmeter was installed in one of four 9' x 15' rectangular outfalls at the New York City DEP's Fresh Creek CSO Flow-balanced Storage project as part of a flow study in the early 1990s. The multi-path transit-time method was ideally suited to this site because of the capability to measure simultaneous bidirectional flow at various levels. This site often experiences salt water flowing upstream on the incoming tides near the bottom of the outfalls while fresh runoff flows downstream at

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higher elevations. In 1993 the remaining three outfalls were instrumented with 3-path Accusonic flowmeters using low-cost array-mount transducers and an uplooking level sensor.

City of Philadelphia

A 3-path Accusonic flowmeter was installed in the City of Philadelphia's Cottman Avenue CSO in mid-1993 as part of an extensive CSO flowmeter intercomparison study. Low-cost array-mount transducers were installed in this rectangular 9' x 6'9" conduit. Four separate level sensors were included in the flowmeter configuration to measure water level at various locations in the CSO regulator, influent, and interceptor lines. Flow data is logged on a diskette in the flowmeter computer and is downloaded to the City's computers via dial-up modem. Data from several rain events exhibit rapidly changing flow conditions and demonstrate the need for simultaneous multiple-path measurement throughout the channel to provide accurate flow data (Figures 4, 5). Review of the velocity data simultaneously collected at the different levels in the flow during these events has demonstrated the superior flowrate accuracy and resolution provided by the multi-path technique. Flowrates derived from single-path velocity measurements, via use of a "meter factor" to calculate an average velocity representing the flow profile, are found to result in significantly greater uncertainties for flowrates measured over the wide range of conduit flows observed.

Summary and Conclusions

Multiple-path acoustic flowmeters provide capabilities for acquiring high-accuracy flow data in wide-ranging CSO system monitoring applications. New CSO control policies and regulations are increasing the need for flow monitoring by municipalities to meet the new regulatory requirements. Major features and advantages offered by multiple-parallel-path, transit-time flowmeter systems for CSO monitoring applications are summarized below.

- Capability to continuously measure, record, and transmit flow data
- Superior accuracy over complete range of changing flow and water levels
- Compound flow profile integration for free-flow or surcharge conditions
- No required "flow profile" calibration or recalibration over time
- Rugged, streamlined transducer design with minimal flow intrusion
- Multi-level, bi-directional flow measurement capability
- Remote system data access and control via telemodem
- Field-proven, long-term operating performance

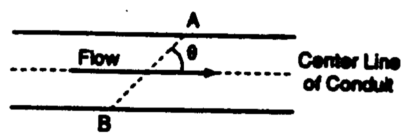

Figure 1 - Transducers mounted diagonally across a pipe or channel create an acoustic path (A-B).

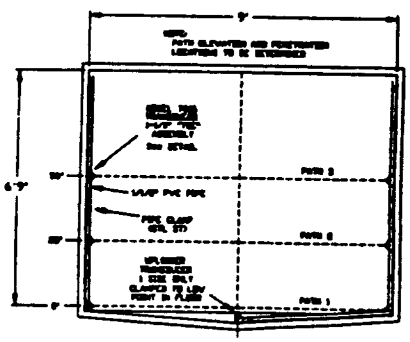

Figure 2 - Three-path acoustic transit-time configuration with water level sensors

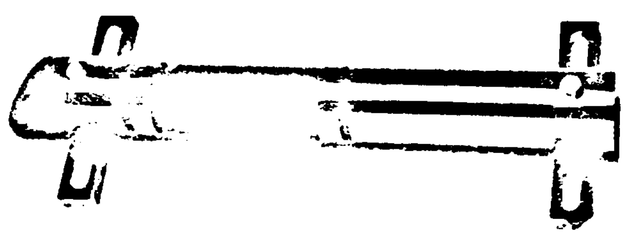

Figure 3 - Internal mount transducer and mounting assembly for long-term CSO monitoring applications

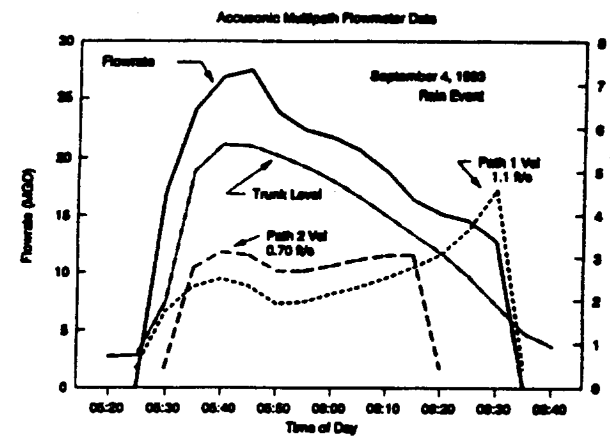

Figure 4 - Individual path velocities with measured stage (water level) and calculated flowrate information during a rain event at Cottman Avenue CSO, City of Philadelphia

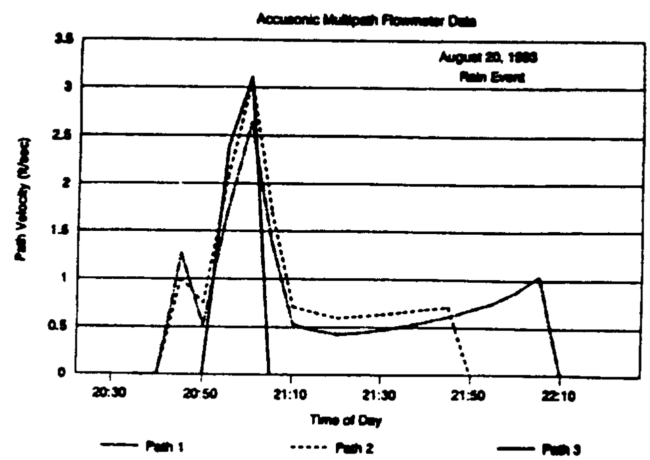

Figure 5 - Individual path velocities during a separate rain event at Cottman Avenue CSO

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STORMWATER INFILTRATION EFFECTS ON GROUNDWATER

Keith Parmer[1], Robert Pitt[2], Richard Field[3], Shirley Clark[4]

ABSTRACT

The research summarized here was conducted during the first year of a 3-yr US Environmental Protection Agency (EPA) cooperative agreement to identify and control stormwater toxicants, especially those adversely affecting groundwater. The purpose of this research effort was to review the groundwater contamination literature as it relates to stormwater. Potential problem pollutants were identified, based on their mobility through the unsaturated soil zone above groundwater, their abundance in stormwater, and their treatability before discharge. This information was used with earlier EPA research results to identify the possible sources of these potential problem pollutants. Recommendations were also made for stormwater infiltration guidelines in different areas and monitoring that should be conducted to evaluate a specific stormwater for its potential to contaminate groundwater.

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INTRODUCTION

Prior to urbanization groundwater is recharged by rainfall-runoff and snowmelt infiltrating through pervious surfaces including grasslands and woods. This infiltrating water is relatively uncontaminated. Urbanization, however, reduces the permeable soil surface area through which recharge by infiltration occurs. This results in much less groundwater recharge and greatly increased surface runoff. In addition the waters available for recharge carry increased quantities of pollutants. With urbanization, waters having elevated contaminant concentrations also recharge groundwater including effluent from domestic septic tanks, wastewater from percolation basins and industrial waste injection wells, infiltrating stormwater, and infiltrating water from agricultural irrigation. This paper is a condensation of a detailed report (Pitt, *et al.*, 1993) and addresses potential groundwater problems associated with stormwater toxicants and describes how conventional stormwater control practices can reduce these problems.

METHODOLOGY

An extensive literature review (Pitt, *et al.*, 1993) of stormwater pollutants that have the potential to contaminate groundwater was obtained by searches of prominent databases. Areas of particular concern were sources of pollutants, stormwater constituents having high potential to contaminate groundwater, and treatment of stormwater.

RESULTS

Sources of Pollutants

High bacteria populations have been found in stormwater sheetflow samples from sidewalks, roads, and some bare ground (collected from locations where dogs would most likely be "walked"). Tables 1 and 2 summarize toxicant concentrations and likely sources or locations having some of the highest concentrations found during an earlier phase of this EPA-funded research (Pitt and Field, 1990). The detection frequencies for the heavy metals are close to 100% for all source areas and the detection frequencies for the organics ranged from 10% to 23%. Vehicle service areas had the greatest frequencies and concentrations of observed organics.

TABLE I. Concentrations of Metals in Observed Areas (μg/L)

Toxicant	Highest Median	Source	Highest Observed	Source
Cadmium	8	Vehicle service area runoff	220	Street runoff
Chromium	100	Landscaped area runoff	510	Roof runoff
Copper	160	Urban receiving water	1250	Street runoff
Lead	75	Vehicle service area runoff	330	Storage area runoff
Nickel	40	Parking area runoff	130	Landscaped area runoff
Zinc	100	Roof runoff	1580	Roof runoff

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TABLE II. Maximum Concentrations of Toxic Organics from Observed Sources

Toxicant	Maximum µg/L	Detection Frequency,%	Significant Sources
Benzo(a)anthracene	60	12	Gasoline, wood preservative
Benzo(b)fluoranthene	226	17	Gasoline, motor oils
Benzo(k)fluoranthene	221	17	Gasoline, bitumen, oils
Benzo(a)pyrene	300	17	Asphalt, gasoline, oils
Fluoranthene	128	23	Oils, gasoline, wood preservative
Naphthalene	296	13	Coal tar, gasoline, insecticides
Phenanthrene	69	10	Oils, gasoline, coal tar
Pyrene	102	19	Oils, gasoline, bitumen, coal tar, wood preservatives
Chlordane	2.2	13	Insecticide
Butyl benzyl phthalate	128	12	Plasticizer
Bis(2-chloroethyl)ether	204	14	Fumigant, solvents, insecticides, paints, varnishes
Bis(2-chloroisopropyl)ether	217	14	Pesticide manufacturing
1,3-Dichlorobenzene	120	23	Pesticide manufacturing

STORMWATER CONSTITUENTS HAVING HIGH POTENTIAL TO CONTAMINATE GROUNDWATER

Nutrients

Nitrates are one of the most frequently encountered contaminants in groundwater (AWWA 1990). Nitrate has leached from fertilizers and affected groundwaters under various turf grasses in urban areas, including golf courses, parks, and home lawns (Petrovic 1990; Ku and Simmons 1986; and Robinson and Synder 1991). Significant leaching of nitrates occurs during the cool, wet seasons. Cool temperatures reduce denitrification and ammonia volatilization and limit microbial nitrogen immobilization and plant uptake.

Residual concentrations of nitrate in soil vary greatly and depend on the soil texture, mineralization, rainfall and irrigation patterns, organic matter content, crop yield, nitrogen fertilizer/sludge application rate, denitrification, and soil compaction. Nitrate is highly soluble (>1 kg/L) and will stay in solution in the percolation water. If it leaves the root zone without being taken-up by plants, it will readily reach the groundwater (AWWA 1990).

Pesticides

Pesticide contamination of urban groundwater can result from municipal and homeowner use for pest control and the subsequent collection of the pesticide in stormwater runoff. Pesticides that have been found in urban groundwaters include: 2,4-D, 2,4,5-T, diazion, ethion, malathion, methyl trithion, silvex (German 1989), atrazine, simazine (Domagalski, *et al.* 1992) and chlordane (Greene 1992). Fungicides and nematocides must be mobile to reach the target pest, and hence, they generally have the highest groundwater contamination potential. Pesticide leaching depends on patterns of use, soil texture, total organic carbon content of the soil,

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pesticide persistence, and depth to the water table (Shirmohammadi and Knisel 1989).

The greatest pesticide mobility occurs in areas with coarse-grained or sandy soils without a hardpan layer, and with soils that have low clay and organic matter content and high permeability (Domagalski, *et al.* 1992). Structural voids, generally found in the surface layer of finer-textured soils rich in clay can transmit pesticides rapidly when the voids are filled with water and the adsorbing surfaces of the soil matrix are bypassed. The slower moving pesticides that may better sorb to soils have been recommended for use in areas of groundwater contamination concern.

Literature half-lives for pesticides generally apply to surface soils and do not account for the reduced microbial activity found deep in the vadose zone (Bouwer 1987). Pesticides with a 30-day half life can show considerable leaching. An order-of-magnitude difference in half-life results in a five- to ten-fold difference in percolation loss (Knisel and Leonard 1989). Organophosphate pesticides are less persistent than organochlorine pesticides but they also are not readily adsorbed by the sediment and are likely to leach into the vadose zone and the groundwater (Norberg-King, *et al.* 1991).

Other Organics

Groundwater contamination from organics, like that from other pollutants, occurs more readily in areas with sandy soils and where the water table is near the land surface (Troutman, *et al.*, 1984). Organics can be removed from the soil and recharge water by volatilization, sorption, and degradation (Crites 1985; and Nellor, *et al.*, 1985). Hydrophobic sorption onto soil organic matter limits the mobility of less soluble base/neutral and acid extractable compounds through organic soils and the vadose zone (German 1989). Organic resolubilization can occur during wet periods following dry periods. Temperature, pH, moisture content, ion exchange capacity of the soil, and air availability may limit the microbial degradation potential for even the most degradable organic compound (Crites 1985).

Microorganisms

Viruses have been detected in groundwater where stormwater recharge basins were located short distances above the aquifer (Vaughn, *et al.* 1978). Enteric viruses are more resistant to environmental factors than are enteric bacteria, and they exhibit longer survival times in natural waters. They can occur in potable and marine waters in the absence of fecal coliforms. Enteroviruses are also more resistant to commonly used disinfectants than are indicator bacteria (e.g., fecal coliforms), and they can occur in groundwater in the absence of indicator bacteria (Marzouk, *et al.* 1979).

The factors that affect the survival of enteric bacteria and viruses in the soil include pH, antagonism from soil microflora, moisture content, temperature, sunlight, and organic matter (Jansons, *et al.* 1989; Tim and Mostaghim 1991). The two most important attributes of viruses that permit their long-term survival in the environment are their structure and very small size. These characteristics permit virus occlusion and protection within colloid-size particles. Viral adsorption is promoted by increasing cation concentration, decreasing pH, and decreasing soluble organics (EPA 1992a).

The major bacterial removal mechanisms in soil are straining at the soil surface and at intergrain contacts, sedimentation, sorption by soil particles, and inactivation. Because their size is larger than viruses, most bacteria are retained near the soil surface because of this straining effect. In general, enteric bacteria survive in soil between 2 and 3 months, although survival times up to 5 yr have been documented (Crites 1985).

Metals

From a groundwater pollution standpoint, the metals in stormwater presenting the most concern are aluminum, arsenic, cadmium, chromium, copper, iron, lead, mercury, nickel, and zinc. These metals with the exception of zinc are however, associated with particulate fractions and potentially can be removed by either sedimentation or filtration processes (Armstrong, *et al.*, 1992).

Studies at recharge basins in Fresno California found that lead, zinc, cadmium, and copper accumulated at the soil surface with little downward movement over many years (Nightingale 1987a). At a commercial site, however, nickel, chromium, and zinc concentrations have exceeded regulatory limits in the soils below a recharge area (Wilson, et al. 1990). Allowing percolation ponds to go dry between storms can be counterproductive to the removal of lead from the water during recharge (Hampson 1986).

Similarities in water quality between runoff water and groundwater have shown that there is significant downward movement of copper and iron in sandy and loamy soils. Arsenic, nickel, and lead, however, did not significantly move downward through the soil to the groundwater. The exception to this was some downward movement of lead with the percolation water in sandy soils beneath Fresno stormwater recharge basins (Nightingale 1987b). Zinc which is more soluble than iron, has been found in higher concentrations in groundwater than iron. The order of attenuation in the vadose zone from infiltrating stormwater is: zinc (most mobile) > lead > cadmium > manganese > copper > iron > chromium > nickel > aluminum (least mobile) (Harper 1988).

Salts

Soil is not very effective at removing salts. Salts that are still in the percolation water after it travels through the vadose zone will contaminate the groundwater (Sabol, *et al.* 1987; and Bouwer 1987). Infiltration of stormwater has led to increases in sodium and chloride concentrations above background concentrations. Fertilizer and pesticide salts also accumulate in urban areas and can leach through the soil to the groundwater (Merkel, *et al.*, 1988). Studies of depth of pollutant penetration in soil have shown that sulfate and potassium concentrations decrease with depth, whereas sodium, calcium, bicarbonate, and chloride concentrations increase with depth (Close, 1987; Ku and Simmons, 1986). Once contamination with salts begins, the movement of salts into the groundwater can be rapid. The salt concentration may not lessen until the source of the salts is removed (Higgins, 1984).

TREATMENT OF STORMWATER

Table 3 summarizes the filterable fraction of toxicants found in storm runoff sheetflows from many urban areas found during an earlier phase of this EPA-funded research (Pitt and Field 1990). Pollutants in dry-weather storm drainage flows, however, tend to be associated with filtered sample fractions and would not be readily controlled with the use of sedimentation. (Pitt, et al. 1993)

Sedimentation is the most significant removal mechanism for particulate-related pollutants. Detention ponds are probably the most common management practice for the control of stormwater runoff. If properly designed, constructed, and maintained, wet detention ponds can be very effective in controlling a wide variety of pollutants. The monitored performance of wet detention ponds indicates more than 90% removal for suspended solids, 70% for BOD, and COD, about 60% to 70% for nutrients, and about 60% to 95% for heavy metals (EPA 1983). Catchbasins are very small sedimentation devices. Adequate cleaning can help reduce lead and total solids in urban runoff by between 10% and 25%, and COD, total Kjeldahl nitrogen, total phosphorus, and zinc by between 5% and 10% (Pitt 1984; and Pitt and Shawley 1981).

TABLE III. Reported Filterable (Dissolved Solids) Fractions of Stormwater Toxicants from Source Areas

Constituent	Filterable (Dissolved Solids) Fraction (%)
Cadmium	20 to 50
Chromium	<10
Copper	<20
Iron	Small amount
Lead	<20
Nickel	Small amount
Zinc	>50
Benzo(a)anthracene	None found in filtered fraction
Fluoranthene	65
Naphthalene	25
Phenanthrene	None found in filtered fraction
Pyrene	95
Chlordane	None found in filtered fraction
Butyl benzyl phthalate	Irregular
Bis(2-chloroethyl)ether	Irregular
Bis(2-chloroisopropyl)ether	None found in filtered fraction
1,3-Dichlorobenzene	75

Volatilization and photolysis are other important pollutant removal mechanisms in wet detention ponds. Biodegradation, biotransformation, and bioaccumulation (into plants and animals) may also occur in larger and open ponds.

Upland infiltration devices (e.g., infiltration trenches, porous pavements, percolation ponds, and grass roadside drainage swales) are located at urban source areas. Infiltration (percolation) ponds are usually located at stormwater outfalls or at large paved areas. These basins, along with perforated storm sewers, can infiltrate

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flows and pollutants from all upland sources combined. Infiltration devices can safely deliver large fractions of the surface flows to groundwater, if carefully designed and located (EPA 1983). Grass swales allow the recharge of significant amounts of surface flows. Swales can also reduce pollutant concentrations because of filtration. Soluble and particulate heavy metal (copper, lead, zinc, and cadmium) concentrations can be reduced by at least 50%, COD, nitrate nitrogen, and ammonia nitrogen concentrations can be reduced by about 25%, but only inconsistent concentration reductions can be expected for organic nitrogen, phosphorus, and bacteria (EPA 1983).

CONCLUSIONS

This entire research project will provide guidance on critical source area treatment (EPA 1992b), especially for the protection of groundwater quality. Much of the information will also be useful for analyzing stormwater problems and needed controls for surface water discharges. Table 4 is a summary of the pollutants found in stormwater that may cause groundwater contamination problems for various reasons. This table does not consider the risk associated with using groundwater contaminated with these pollutants. This table is appropriate for initial estimates of contamination potential because of the simplifying assumptions made, (e.g., the worst case mobility conditions assumed: sandy soils having low organic content). When the soil is clayey and has a high organic content, then most of the organic compounds would be less mobile than as shown in this table. The abundance and filterable fraction information is generally applicable for warm weather stormwater runoff in residential and commercial areas. The pollutant concentrations and detection frequencies, however, would be greater for critical source areas (especially vehicle service areas) and critical land uses (especially manufacturing industrial areas).

The stormwater pollutants of most concern (those that may have the greatest adverse impacts on groundwaters) include:

- Nutrients
- Pesticides
- Other organics
- Pathogens
- Metals
- Salts

Pollution prevention can also play an important role in minimizing groundwater contamination problems, including reducing the use of galvanized metals, pesticides, and fertilizers in critical areas. The use of specialized treatment devices (e.g., those being developed and tested during this research (EPA 1992b) can also play an important role in treating runoff from critical source areas before these more contaminated flows commingle with less polluted runoff from other areas.

TABLE IV. Potential of Stormwater Pollutants to Contaminate Groundwater

Pollutant	Compound	Mobility	Abundance	Fraction filterable	Potential: surface infiltration	Potential: subsurface disposal
Nutrients	nitrate	mobile	low-moderate	high	low	low
Pesticides	2,4-D	mobile	low	low	low	low
	Lindane	intermediate	moderate	low	moderate	moderate
	malathion	mobile	low	low	low	low
	atrazine	mobile	low	low	low	low
	chlordane	intermediate	moderate	very low	moderate	moderate
	diazinon	mobile	low	low	low	low
Other organics	VOCs	mobile	low	very high	low	low
	1,3-dichloro benzene	low	high	high	low	high
	anthracene	intermediate	low	moderate	low	low
	benzo(a) anthracene	intermediate	moderate	very low	moderate	moderate
	bis(2-ethylhexyl) phthalate	intermediate	moderate	low	moderate	moderate
	butyl benzyl phthalate	low	low-moderate	moderate	low	low-moderate
	fluoranthene	intermediate	high	high	moderate	high
	fluorene	intermediate	low	low	low	low
	naphthalene	low intermediate	low	moderate	low	low
	pentachloro phenol	intermediate	moderate	low	moderate	moderate
	phenanthrene	intermediate	moderate	very low	moderate	moderate
	pyrene	intermediate	high	high	moderate	high
Pathogens	entero viruses	mobile	present	high	high	high
	Shigella	low-intermediate	present	moderate	low-moderate	high
	P. aeruginosa	low-intermediate	very high	moderate	low-moderate	high
	protozoa	low-intermediate	present	moderate	low-moderate	high
Metals	nickel	low	high	low	low	high
	cadmium	low	low	moderate	low	low
	chromium	intermediate-low	moderate	very low	low-moderate	moderate
	lead	very low	moderate	very low	low	high
	zinc	low-very low	high	high	low	high
Salts	chloride	mobile	high	high	high	high

RECOMMENDATIONS

With a reasonable degree of site-specific design considerations to compensate for soil characteristics, infiltration may be very effective in controlling both urban runoff quality and quantity problems (EPA 1983). The following general guidelines for the infiltration of stormwater and other storm drainage effluent are recommended in the absence of comprehensive site-specific evaluations:

- Dry-weather storm drainage effluent should be diverted from infiltration devices because of their probable high concentrations of soluble metals, pesticides, and pathogenic microorganisms.
- Combined sewage overflows should be diverted from infiltration devices because of their poor water quality, especially their high pathogenic concentrations and high clogging potential.
- Snowmelt runoff should be diverted from infiltration devices because of its potential for having high concentrations of soluble salts.
- Runoff from manufacturing industrial areas should be diverted from infiltration devices because of its potential for having high concentrations of soluble toxicants.
- Construction site runoff must be diverted from stormwater infiltration devices (especially subsurface devices) because of its high suspended solids (sediment) concentrations, which would quickly clog infiltration devices.
- Runoff from other critical source areas (e.g., vehicle service facilities and large parking areas) should at least receive adequate pretreatment to eliminate their groundwater contamination potential before infiltration.

Runoff from residential areas (the largest component of urban runoff in most cities) is generally the least polluted urban runoff flow and should be considered for infiltration. Very little treatment of residential area stormwater runoff should be needed before infiltration, especially if surface infiltration is through the use of grass swales.

RECOMMENDED STORMWATER QUALITY MONITORING TO EVALUATE POTENTIAL GROUNDWATER CONTAMINATION

Most past stormwater quality monitoring efforts have not adequately evaluated stormwater's potential for contaminating groundwater. The following list shows the stormwater contaminants that are recommended for monitoring when stormwater contamination potential needs to be considered or when infiltration devices are to be used. Other analyses are appropriate for additional monitoring objectives (e.g., evaluating surface water problems). In addition, all phases of urban runoff should be sampled, including stormwater runoff, dry-weather flows, and snowmelts.

These are the urban runoff contaminates with the potential to adversely affect groundwater:

- Nutrients (especially nitrates)
- Salts (especially chloride)
- VOCs

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- Pathogens
- Bromide and total organic carbon
- Pesticides, in both filterable and total sample components
- Other organics, in both filterable and total sample components
- Metals, in both filterable and total sample components

The following urban runoff compounds with the potential to adversely affect infiltration and injection operations:

- Sodium, calcium, and magnesium (to calculate the sodium adsorption ratio to predict clogging of clay soils)
- Suspended solids (to determine the need for sedimentation pretreatment to prevent clogging)

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A MULTI-CHAMBERED STORMWATER TREATMENT TRAIN

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ABSTRACT

The Department of Civil and Environmental Engineering at the University of Alabama at Birmingham is engaged in a three year cooperative agreement with the Storm and Combined Sewer Program of the U.S. EPA. Part of this cooperative agreement includes the testing of a special treatment device (a multi-chambered treatment train, or MCTT) to treat runoff from critical source areas. This paper reviews the design of the MCTT and presents preliminary performance monitoring information. A pilot-scale MCTT has been constructed in Birmingham, AL and a six month monitoring period was started in May 1994. Two additional full-scale MCTT units will be constructed and monitored as part of Wisconsin's 319 grant from the EPA during the coming year. Complete organic and metallic toxicant analyses, in addition to conventional pollutants, are included in the analysis program. It is expected that the MCTT will be capable of cost-effectively removing at least 75% of the most critical toxicants near their source.

INTRODUCTION

Runoff from paved parking and storage areas, and especially gas station areas, has been observed to be heavily contaminated with concentrations of many pollutants being 3 to 600 times greater than typical receiving water criteria. These paved areas are usually found to contribute most of the toxicant pollutant loadings

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to the stormwater outfalls in residential and commercial areas. PAHs, the most commonly detected toxic organic compounds found in urban runoff, are mostly from fossil fuel combustion. These compounds are very hard to control by eliminating their use, and, unfortunately, their control by typical stormwater management practices is not well understood. The major benefit of this research project will be to better understand how these toxicants can be controlled at critical source areas, especially automobile service facilities.

METHODOLOGY

Earlier bench scale treatability studies of this U. S. Environmental Protection Agency (EPA) sponsored research found that the most beneficial treatment for the removal of stormwater toxicants (as measured using the Microtox™ test) included column settling for at least 24 hours (generally 40% to 90% reductions), screening through at least 40 micron (μm) screens (20% to 70% reductions), and aeration and/or photo-degradation for at least 24 hours (up to 80% reductions) (Pitt, *et al.* 1994). A pilot-scale MCTT has been constructed and is currently being tested in Birmingham, Alabama. Two full-scale MCTT units are scheduled to be constructed during the summer and fall in Wisconsin as part of their EPA 319 grant. The MCTT contains aeration, sedimentation, sorption, and sand/peat filtration and is expected to result in good toxicant removals. These devices will be suitable for subterranean use at gas stations and other automobile service facilities.

The MCTT includes a special catchbasin followed by a two chambered tank that is intended to reduce a broad range of toxicants (volatile, particulate, and dissolved). The runoff enters the catchbasin chamber by passing over a flash aerator (small column packing balls with counter-current air flow) to remove highly volatile components. This catchbasin also serves as a grit chamber to remove the largest (fastest settling) particles. The second chamber serves as an enhanced settling chamber to remove smaller particles and has inclined tube or plate settlers to enhance sedimentation. This chamber also contains fine bubble diffusers and sorbent pads to further enhance the removal of floatable hydrocarbons and additional volatile compounds. The water is then pumped to the final chamber at a slow rate to maximize pollutant reductions. The final chamber contains a mixed media (sand and peat) slow filter, with a filter fabric layer. The MCTT is typically sized to totally contain all of the runoff from a 12.7 mm (0.5 inch) rain from a typical 0.2 ha (0.5 acre) gas station. If the area is larger, then multiple, or larger, units will be needed. Figure 1 is a diagram of this device. Samples are being collected before and after each chamber of the device.

To better estimate fate and treatability of toxicants, samples are partitioned into filterable ("dissolved") and non-filterable ("particulate") components before being

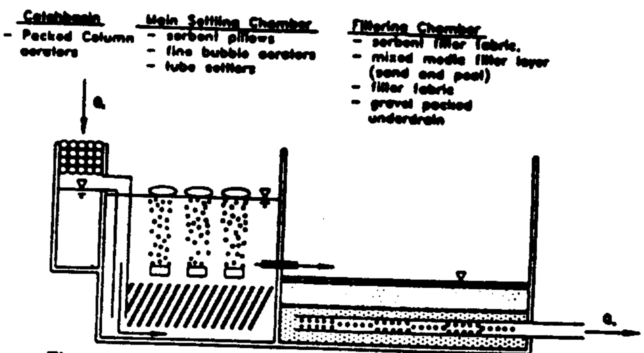

Figure 1. Multi-chambered treatment train (MCTT) schematic.

analyzed for a wide range of toxicants using detection limits from about 1 to 10 μg/L and conventional pollutants. Constituents being analyzed include heavy metals (copper, cadmium, lead, and zinc) and organics (phenols, PAHs, phthalate esters, herbicides, and pesticides). Particle size distributions, using a Coulter Multi-Sizer IIe, are also being made, in addition to conventional analyses for COD, major ions, nutrients, suspended and dissolved solids, turbidity, color, pH, and conductivity. Samples are also screened using the Microtox™ toxicity test to measure relative reductions in toxicity.

DISCUSSION: PRELIMINARY DESIGN OF THE MCTT AND EXPECTED PERFORMANCE

Catchbasin/Grit Chamber

Catchbasins have been found to be effective in removing pollutants associated with coarser runoff solids (Lager and Smith 1976, Pitt and Bissonnette 1985). High reductions in total and suspended solids (SS) (up to 44% reduction, depending on the inflowing water rate) were indicated by a number of prior studies. While relatively few pollutants are associated with these coarser solids, their removal will decrease maintenance of the other chambers.

The size of the MCTT catchbasin sump is controlled by three factors: the runoff flow rate, the suspended solids (SS) concentration in the runoff, and the desired frequency at which the catchbasin will be cleaned so as not to sacrifice efficiency. Figure 2 is a plot of the accumulation of SS versus accumulative rain. This plot provides an approximation for sizing the catchbasin.

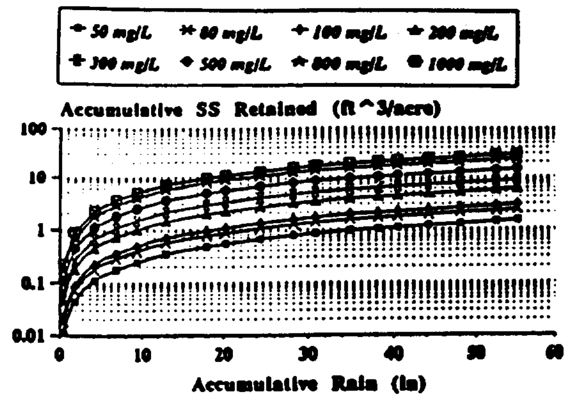

Figure 2. Accumulation of suspended solids in catchbasin sump.

Main Settling and Oil and Grease Trap Chamber

The main settling chamber mimics completely mixed settling column bench-scale tests and uses a treatment ratio of depth to time for removal estimates. In addition to housing plate or tube settlers, the main settling chamber contains floating sorbent "pillows" to trap floating grease and oil and contains a fine bubble diffuser. The settling time in the main settling chamber usually ranges from 20 to 70 hours.

Figure 3 shows the percentage of annual runoff treated, based on specific volumes of treatment provided. If runoff from 25 mm (1 inch) of rain is treated in the main settling chamber, about 70% of the annual Birmingham runoff volume would be directly treated. If this volume was increased to two inches, then about 90% of the annual runoff would be treated.

Figure 4 shows the percent toxicity reductions (compared to the initial toxicity levels) for all samples, plotted against the toxicity removal rate (depth/time), for plain settling alone. Toxicity removal rate is for the batch process which is equivalent to the surface overflow rate for continuous processes. The range of possible toxicant removal is expected to vary greatly, depending on sample characteristics. The settling chamber is supplemented by other processes including flash aeration, extended aeration, sorbent pillows, peat sorption, and sand filtration which will combine to reduce expected variations in treatment performance.

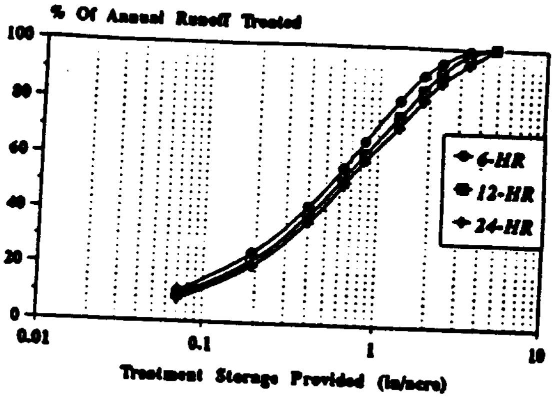

Figure 3. Effects of treatment volume on fraction of annual runoff treated.

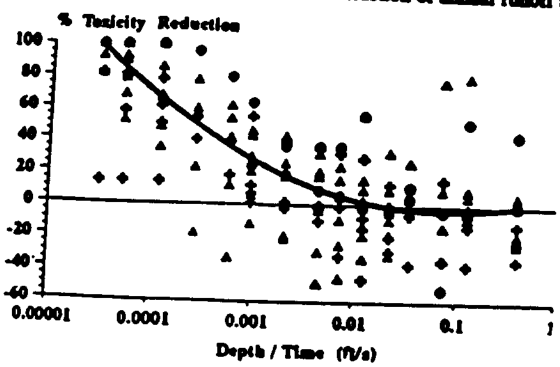

Figure 4. Percent toxicity reduction as a function of treatment rate (ft/s)

EXAMPLE DESIGN

A computer model was developed to determine the amount of annual rainfall treated, the toxicity reduction rate for each individual storm, and the overall toxicity reduction associated with the total annual rainfall for Birmingham, Alabama. Table I shows the treatment rates m/sec and median toxicity reductions for a 2.1m (7 ft) deep main settling chamber with the water held for various times (from Figure 4).

Table I. Median Toxicity Reductions for Different Treatment Holding Times

Holding Period (h)	Treatment Rate (m/s)	Median Toxicity Reduction (%) per Individual Rain
6	9.8×10^{-5}	46
12	4.9×10^{-5}	60
24	2.5×10^{-5}	75
36	1.6×10^{-5}	84
48	1.2×10^{-5}	92
72	8.2×10^{-6}	100

The same treatment rates and toxicity removals would occur if the main settling chamber was half as deep (1.1m or 3.5 ft in this example) and the water was held for half as long. For this shallower example, however, the treatment tank would have to be twice as large in surface area to provide the same volume. The computer simulation shows the significance of having an adequate volume. Table II illustrates the effects of different treatment volumes, expressed as inches of rain and runoff, using small storm hydrology concepts for paved areas (Pitt 1987), on the annual percentage of Birmingham rains captured and treated and on the annual total toxicity reduction. As an example, if the MCTT is full from a previous rain (because of the required holding period), the next storm would bypass the MCTT with no treatment. Birmingham rains occur about every 3 to 5 days, on the average, so it would be desirable to have the holding period significantly less than this value. Similarly, if the storage volume was small, only a fraction of a large rain would be captured and treated, requiring a partial bypass. The annual toxicity reductions are calculated by knowing the individual storm treatment reductions (from Table I) and the annual percentage of runoff treated. As an example, if the holding period was 24 hours for a 2.1 m (7 ft) deep settling chamber, the individual storm treatment would be about 75%. If the MCTT was large enough to contain the runoff from a 38.1 mm (1.5 inch) rain, then about 98% of the annual runoff would be treated, for an annual expected toxicity reduction of 73% (0.75 X 0.98 = 0.73).

Figure 5 is an extension of Table II for additional conditions. It shows plots for Birmingham for different annual control levels associated with holding periods from 6 to 72 hours and storage volumes from 2.5 to 64 mm (0.1 to 2.5 inches) of runoff for a 2.1 m (7 ft) deep MCTT. This figure can be used to determine the size of the main settling chamber and the minimum required detention time to obtain a certain level of control (toxicity reduction). As noted previously, if the tank is shallower than 2.1 m (7 ft), then the holding periods should be similarly decreased. If the tank is only 1 m (3.5 ft) deep, then the required holding periods would only be half as long, but the surface area would have to be twice as large to obtain the same storage volume.

Table II. Effects of Storage Volume and Holding Periods on Annual Runoff Treated and on Total Annual Toxicity Reduction

Holding Period (h)	12.7 mm rain with 10.2 mm runoff (0.50 in. rain with 0.40 in. runoff) % Annual Runoff Treated	% Annual Toxicity Reduction	38.1 mm rain with 33.5 mm runoff (1.50 in. rain with 1.32 in. runoff) % Annual Runoff Treated	% Annual Toxicity Reduction
6	84	39	100	46
12	62	37	100	60
24	52	39	98	73
36	48	41	91	77
48	46	42	88	81
72	44	44	84	84

An example design follows for a 0.2 ha (0.5 acre) paved drainage area and an overall annual toxicity reduction of about 75%. A combination of a 48 h holding time and 27 mm (1.05 in.) runoff storage volume would satisfy this goal. Figure 5 shows that this is the smallest MCTT that could achieve this annual reduction goal, without going to an unusually long treatment period. The marginal reduction in storage volume would be more than offset by problems associated with totally bypassing and not treating many of the storms that would occur with the 72 h treatment time (larger variations in runoff quality would result).

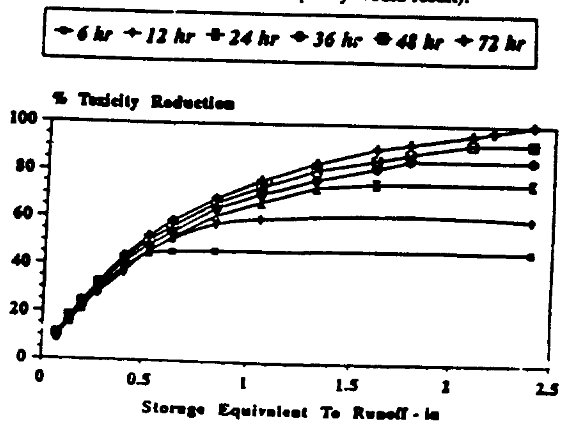

Figure 5. Effects of storage volume and treatment time on annual toxicity reduction

This 27 mm runoff volume corresponds to a rain depth of about 31 mm (1.22 in.). The 27 mm runoff storage volume corresponds to a chamber volume of 54 m^3 (1900 ft^3), a surface area of 25.5 m^2 (273 ft^2), and a depth of 2.1 m (7 ft). The toxicity reductions in the main settling chamber for captured runoff is about 92%. This device would capture and treat about 80% of the annual runoff at this 92% level, resulting in an annual toxicity reduction of about 74% (0.8 X 0.92).

Additional treatment would result from the filter. The pumped effluent from the main settling chamber would be directed towards a mixed peat and sand filter, which must provide a surface hydraulic loading rate of between 1.5 and 6 m per day (5 and 20 ft per day), and have a depth of at least 0.5 m (18 in.). In addition to the pumped effluent, any excess runoff after the main settling chamber is full would also be directed towards the filter.

Each of the treatment chambers would be vented, mosquito proofed, and be easily accessible for maintenance. The device should be inspected, the initial catchbasin should be cleaned, and the sorbent pillows should be exchanged, at least every six months.

PRELIMINARY OBSERVATIONS

A pilot-scale MCTT was set up to capture runoff from a parking and vehicle service area on the campus of the University of Alabama at Birmingham. The catchbasin/grit chamber is a 25 cm vertical PVC pipe containing about 6 L of 3 cm diameter packing column spheres. The main settling chamber is about 1.3 m^2 in area and 1 m deep which with a 48 h settling time should result in a median toxicity reduction of about 90%. The filter chamber is about 1.5 m^2 in area and contains 0.5 m of sand and peat directly on 0.15 m of sand over a fine plastic screen and coarse gravel that covers the underdrain. A Gunderboom™ filter fabric also covers the top of the filter media to distribute the water over the filter surface by reducing the water infiltration rate through the filter and to provide additional pollutant capture.

During a storm event, runoff from the parking lot is pumped into the catchbasin/grit chamber automatically. During filling, an air pump supplies air to aeration stones located in the main settling chamber. When the settling chamber is full, all pumps and samplers cease. After a quiescent settling period of up to 72 hours water is pumped through the filter media and discharged. Monitoring began in late May and five storms (of the 12 proposed) have been evaluated by the end of June 1994. Completion of the monitoring and laboratory analyses is expected by the end of September 1994. The following paragraphs briefly summarize the available data obtained to date.

The reduction in toxicity (as measured using the Microtox© test by Microbics) ranged from 70 to 100%, with a median reduction of 95% (slightly better than the 90% predicted). The toxicity of the filtered samples were also substantially reduced (50 to 100%, median of 76%). Almost all of the total sample toxicity reduction occurred in the sand and peat filter, but large reductions in the filtered sample toxicity (34 to 100%, median of 52%) occurred in the main settling chamber. The results from the specific metal and organic analyses are not yet available, but these toxicity data indicate excellent toxicant removals, as expected based on earlier bench-scale tests (Pitt, *et al.* 1994).

Overall COD reductions ranged from 36 to 100% (median of 64%) with influent concentrations ranging from 2 to 114 mg/L (median of 68 mg/L). Most of these reductions occurred in the filtering unit. Dissolved COD reductions showed substantial variations (0 to 100%, median of 50%), with concentration increases occurring in the filtering unit for some events and most of the dissolved COD reductions occurring in the main settling chamber.

Suspended solids reductions ranged from 25 to 60% overall, including large increases that occurred in the sand and peat filter due to limited media washout. The suspended solids reductions before the filter was much greater, being about 75 to 90%. Turbidity and color also experienced substantial increases during the filtration process (turbidity going from 2 to 16 NTU in the influent to the complete treatment unit to effluent values of 5 to 24 NTU, still relatively low, and color going from 24 to 58 HACH units in the influent to 44 to 100 HACH units in the effluent). The peat also apparently caused a reduction in pH, from 6.95 to 7.27 in the filter influent to 5.93 to 6.37 in the effluent.

CONCLUSIONS

This research examined the design of a multi-chambered tank to collect and treat stormwater runoff from critical urban source areas, including gas stations, oil change facilities, transmission repair shops, and other auto repair facilities. The collected runoff will first be treated in a catchbasin chamber where larger particles will be removed by settling. The water would then flow into a main settling chamber containing oil and grease sorbent material where it will undergo a much longer treatment period (20 to 70 hours) to remove finer particles and to remove oil residues.

These preliminary results show that the treatment unit is providing substantial reductions in stormwater toxicants (both in particulate and filtered phases), organics, and suspended solids. Slight increases in turbidity and color and about a unit in pH reduction also occurred during the filtration step. The filter unit appears to be responsible for most of the toxicity reductions. However, the main settling chamber also resulted in substantial reductions in the dissolved toxicity fraction, total and dissolved COD, suspended solids, turbidity, and color. The catchbasin/grit chamber also showed suspended solids reductions. The use of the MCTT is seen to be capable of reducing a broad range of stormwater pollutants that have been shown to cause substantial receiving water problems (Pitt 1994b).

ACKNOWLEDGMENTS

The Department of Civil and Environmental Engineering at the University of Alabama at Birmingham is engaged in a three year cooperative agreement (CR No. 819573) with the Storm and Combined Sewer Program of the U.S. EPA. This presentation is a preliminary description of one the activities of this agreement. Grateful acknowledgment is extended to the EPA staff for funding and directing this research.

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Stormwater Treatment: Inlet Devices and Filtration

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Abstract

The Department of Civil and Environmental Engineering at the University of Alabama at Birmingham is engaged in a three year cooperative agreement (CR No. 819573) with the Storm and Combined Sewer Pollution Control Program of the U.S. EPA to monitor the performance of three stormdrain inlet filters, an optimally designed catchbasin, and several filter fabrics and filtering media. Henderson & Breen Environmental Engineers of Forked River, New Jersey, are overseeing the field installations, sampling, and shipping of the samples to the University of Alabama at Birmingham (UAB) for analyses.

This summary reviews these devices and presents the field verification that has been conducted to date to confirm their performance. The test facilities for the inlet devices are located in a residential area and at the township public works yard in Stafford, NJ. The filter fabrics and filtering media are being evaluated in the laboratory using stormwater runoff from a large parking area on the campus of UAB. The monitoring program began in January 1994 and will include about 12 inlet and effluent samples from these devices over several different storms. Complete organic and metallic toxicant analyses, in addition to conventional pollutants, are included in the analytical program.

Introduction

Stormwater runoff from problem source areas needs to be treated to prevent harm either to the surface waters or the groundwaters. One approach is to treat the

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runoff from problem source areas before it mixes with the runoff from less polluted areas. The general features of critical source areas appear to be large paved areas, heavy vehicular traffic and outdoor use or storage of problem pollutants. The control of small critical area contributions to urban runoff may be the most cost-effective approach for treatment/reduction of stormwater toxicants. Single, small point source treatment devices are currently being marketed for runoff treatment. In order for a treatment device to be suitable for an industrial or commercial area, it must be inexpensive both to purchase and maintain. This research is designed to evaluate several commercially-available filtration devices and catchbasin units, as well as the common filtration media that can be incorporated into many stormwater treatment devices.

Monitoring Program

This research program is obtaining paired "before" and "after" samples from each device. About 12 pairs of samples will be obtained for each catchbasin device being tested in the field, creating about 48 samples (including both filtered and unfiltered before and after samples) that will be analyzed for each of the four catchbasin devices. Controlled laboratory tests are also being conducted on the filtration media and filter fabrics.

Samples will be partitioned into filterable and non-filterable components before analysis so that fate and treatability of pollutants may be better estimated. Samples will be analyzed for a wide range of toxicants using very low detection limit (1 to 10 μg/L) methods. The constituents being analyzed include conventional pollutants (COD, major ions, nutrients, suspended and dissolved solids, turbidity, color, pH and conductivity), heavy metals (copper, cadmium, lead, and zinc) and organics (PAHs, phenols, phthalate esters, and herbicides and pesticides). Samples will also be screened for relative reductions in toxicity across the treatment device using the Microtox™ toxicity test and for particle size distributions, using a Coulter Multi-Sizer IIe.

Preliminary Design and Expected Performance of Inlet Devices

Optimal Catchbasin. Catchbasins can be effective in removing the pollutants associated with coarser runoff solids, although relatively few pollutants are associated with these solids. High reductions in total and suspended solids (SS) (up to 45% reduction, depending on the influent flow rate) were indicated by a number of prior studies (Pitt 1979, Pitt 1984). The size of the catchbasin sump is controlled by three factors: the runoff flow rate, the runoff SS concentration, and the desired cleaning frequency (without sacrificing efficiency) for the catchbasin. Based on earlier EPA research, an optimal catchbasin design should have the following dimensions: If the outlet pipe is D inches in diameter, its bottom should be located about 2.5 D below the street level and 4D from the bottom of the catchbasin sump.

The overall height of the catchbasin should therefore be 6.5D, with a diameter of 4D. The optimal catchbasin is located in a residential area in Stafford, New Jersey.

Sages Filter. The Sages catchbasin filter was developed by John VanEgmond of Acton, Ontario. Figure 1 is a cross-section of the unit showing its placement in an existing catchbasin. It consists of subsurface gravel and sand prefilters and an activated carbon filter. After filtration, the stormwater is infiltrated into the local groundwater. The Sages unit is installed on a pole above ground in the Stafford Township public works year in New Jersey. This surface installation enables us to better control the stormwater flow into the unit and to better obtain representative inlet and outlet samples. The unit will be the last inlet device to be evaluated.

EMCON Catchbasin Filter. The EMCON filter unit was developed by Emcon North West in Bothell, Washington for use in existing catchbasins. Figure 2 shows a cross-section of the unit. It is a combination filtration/sedimentation device. When the filter fabric clogs, the stormwater overflows over small rectangular weirs, acting as a small sediment trap. In addition to the field tests, the EMCON filter fabric is also being tested in the laboratory.

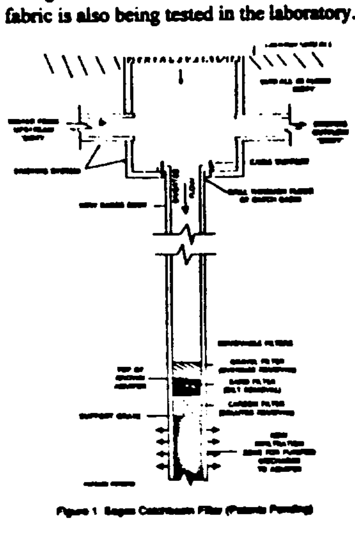

Figure 1 Sages Catchbasin Filter (Patents Pending)

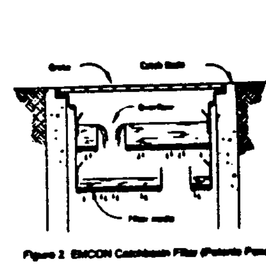

Figure 2 EMCON Catchbasin Filter (Patents Pending)

SoilSave. The SoilSave stormwater filter unit, developed by R.B.S. Enterprises, Paxinos, PA, uses a relatively coarse geofoam filtering media (900 µm cell side diameter) that is sandwiched between two pieces of galvanized screen. The SoilSave unit fits in a catchbasin and is sealed along the bottom and sides of the inlet box, forcing any water through the unit before it is discharged. It is designed to

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filter larger debris, including leaves and grass clippings, from the runoff. The SoilSave unit is installed in a residential area of Stafford, New Jersey.

Preliminary Design and Expected Performance of Filtering Media

Sand. Sand filtration for stormwater treatment began in earnest in Austin, Texas. The Austin sand filters are used for single sites and for drainage areas less than 20 ha. They are designed to hold and treat the first 12 mm of runoff with very good pollutant removal ability. If the City's design guidelines are followed, the assumed pollutant removal efficiencies, which are based upon preliminary results of the City of Austin's stormwater monitoring program, are as follows: fecal coliform bacteria (76%), total suspended solids (TSS) (70%), total nitrogen (21%), total Kjeldahl nitrogen (46%), total phosphorus (33%), BOD (70%), total organic carbon (48%), iron (45%), lead (45%), and zinc (45%) (City of Austin 1988).

In Washington, D.C., sand filters are used both to improve water quality and to delay the entrance of large slug inputs of runoff into the combined sewer system. Water quality filters are designed to retain and treat 8 to 12 mm of runoff with the exact design procedure based upon the amount of imperviousness in the watershed.

In the State of Delaware, the sand filter is an acceptable method for achieving the eighty percent reduction requirement of suspended solids, especially for sites with large impervious areas that drain directly to the filter. The purpose of the filter in many areas is to help prevent or postpone clogging of an infiltration device (Shaver). According to Delaware's specifications, the sand filter will adequately remove particulates (TSS removal efficiency 75 - 85%) but not soluble compounds. Studies of a six year old sand filter in Maryland show that the filter is just now becoming clogged after use in a heavily trafficked parking lot. Inspection below the surface of the sand filter shows that oil, grease, and finer sediments have migrated into the filter, but only to a depth of approximately 50 to 75 mm (Shaver).

Activated Carbon. Activated carbon filtration/separation has long been used in hazardous waste cleanup as an effective method for removing trace organics from a liquid. The activation process makes the charred carbon particles porous with a large internal surface area available for pollutant adsorption (Metcalf and Eddy 1991). Examples of compounds adsorbed by activated carbon include *n*-butyl phthalate, chlorobenzene, carbon tetrachloride, phenol, chloroform and nitrobenzene. Compounds that activated carbon does not adsorb include butylamine, cyclohexylamine, ethylenediamine and hexamethylenediamine (Bennett et al. 1982). Activated carbon filtration is limited by the number of adsorption sites in the media. Activated carbon has a very small net surface charge and is ineffective at removing free hydrated metal ions, unless they are complexed with easily-adsorbed organics prior to contact with the activated carbon filter (Rubin and Mercer 1981).

Composted Leaves. Composts made from yard waste, primarily leaves, have been found to have a very high capacity for adsorbing heavy metals, oils, greases, nutrients and organic toxins due to the humic content of the compost. The exact content of the composts and aging process for the composts used by W&H Pacific is not public knowledge. The composted leaf filter was developed by W&H Pacific for Washington County (Washington), the Unified Sewer Agency and the Metropolitan Service District of Washington County (W&H Pacific 1992). The filter consists of a bottom impermeable membrane with a drainage layer above. Above the drainage layer is a geotextile fabric above which is the compost material. The actual removal occurs in the compost layer by filtration, adsorption, ion exchange and/or biodegradation of organics. The composted leaf filter is proposed as an improvement over other stormwater treatment devices, such as detention ponds and grass swales, because of the smaller land area required for the filter. Testing of a prototype has shown the following pollutant removal rates: turbidity (84%), suspended solids (95%), total volatile solids (89%), COD (67%), settleable solids (96%), total phosphorus (40%), total Kjeldahl nitrogen (56%), copper (67%), zinc (88%), aluminum (87%), iron (89%), and petroleum hydrocarbons (87%) (W&H Pacific 1992).

Peat Moss. Peat is a partially decomposed organic material that is formed from dead plant remains in water and in the absence of air. Generally, the more decomposed the peat is, the lower its hydraulic conductivity. Peats are generally light-weight when dry and are highly adsorptive of water. It is highly colloidal and has a high cation-exchange capacity. Peat is also polar and has a high specific adsorption for dissolved solids such as transition metals and polar organic compounds. Peat naturally performs an ion exchange with copper, zinc, lead and mercury, especially at pH levels between 3.0 and 8.5. This capacity to bind and retain cations, though, is finite and reversible and is determined mostly by the pH of the solution. Peat is an excellent substrate for microbial growth and assimilation of nutrients and organic waste materials because of its high C:N:P ratio, which often approaches 100:10:1. Peat's ability to retain phosphorus in the long-term is related to its calcium, aluminum, iron and ash content with the higher the content of each of the above constituents, the higher the retention capability (Galli 1990).

For filtration devices, peat generally has been combined with sand to create a peat-sand filter (PSF). The Peat-Sand Filter System designed by the Metropolitan Washington Council on Governments (Washington, D.C.) has a grass cover on top underlain by twelve to eighteen inches of peat. The peat layer is supported by a four inch mixture of sand and peat which is supported by a twenty to twenty-four inch layer of fine to medium grain sand. Under the sand is gravel and the drainage pipe. The mixture layer is required because it provides the necessary continuous contact between the peat and the sand layers, ensuring a uniform water flow. Because this is a biological filtration system, it works best during the growing season when the grass cover can provide the additional nutrient removal that will not occur in the rest of the system (Galli 1990).

The PSF is usually an aerobic system. However, modifications to the original design by the Metropolitan Washington Council have been made to account for atypical site conditions or removal requirements. The estimated pollutant removal efficiency for the PSF for stormwater is as follows: suspended solids (90%), total phosphorus (70%), total nitrogen (50%), BOD (90%), trace metals (80%), and bacteria (90%) (Galli 1990).

Filter Fabrics. Little information is available in the literature concerning the performance of filter fabrics in removing stormwater pollutants. They have been used for years in controlling construction site runoff, but in filter fence arrangements where they act as small impoundments and not as true filters. This research project will be analyzing samples collected before and after filtering through several representative filter fabrics, including the fabrics used in the catchbasin filters described above.

Preliminary Project Findings

It was expected that the sand filter would retain any particles that it trapped. However, preliminary tests showed that sand by itself did not retain stormwater toxicants (which are mostly associated with very fine particles). This lack of ability to retain stormwater toxicants prompted the investigation of other filtration media during this research. Combinations of filtration media, especially those using organic materials (activated carbon, peat moss, composted leaves and ion exchange resins) along with sand, are currently being investigated for their ability to more permanently retain stormwater pollutants. Sand is mixed with most of these materials in order to maintain adequate hydraulic capacities (especially for peat) or to slow the flow rate of the stormwater passing through the media in order to increase the contact time and potentially improve pollutant sorption (such as for the activated carbon and the zeolite).

The following results are preliminary and are not intended to indicate the final project conclusions. The information does indicate how the performance of these special inlet devices and filtration media vary in their ability to remove common stormwater pollutants and that they have varying hydraulic capacities. Current tests are being conducted to measure their clogging potential and their ability to remove specific stormwater pollutants.

Inlet Performance. Table 1 shows the removal performance of three of the stormdrain inlet devices that were tested. The parameters listed for each inlet device are those where the change in concentration between the influent and effluent of the device was found to be significant ($\alpha < 0.05$) using a paired sample, one-tailed Student's T-test. The following is a complete list of analyses that have been performed to date on the paired samples from the inlet devices:

- Solids (total solids, dissolved solids, suspended solids, volatile total solids, volatile dissolved solids, volatile suspended solids)
- Physical parameters (turbidity, conductivity, pH and color)
- Toxicity (using a Microtox™ unit from Microbics)
- Anions and cations
- Particle Size (using a Coulter Multisizer IIe)

Table 1. Parameters Having Significantly Lower Effluent Concentrations than Influent Concentrations (Removal Percentages).

EMCON Unit.	Nitrate (Average removal efficiency for influents > 0.2 mg/L 6%).
SoilSave Unit.	Conductivity, bicarbonate, total solids, suspended solids, volatile total solids all had negative removals where the effluent > influent concentrations.
Optimum Catchbasin.	Turbidity (0 to 65%, average 38%). Color (0 to 50%, average 15%). Total Solids (0 to 50%, average 22%). Suspended Solids (0 to 55%, average 32%). Conductivity, carbonate, bicarbonate, nitrate, magnesium and calcium all had negative removals.

Those parameters not listed in Table 1 did not show any significant difference in influent and effluent concentrations. Other parameters currently being analyzed include PAHs, phenols, phthalate esters, herbicides and pesticides, and heavy metals. COD, toxicity, and the organic and metallic toxicants are all being analyzed on both filtered and unfiltered sample portions. Only the optimal catchbasin has shown significant (and important) pollutant reductions for major parameters. The SoilSave showed consistent scouring of downstream sediment, while both the SoilSave and the optimal catchbasin showed slight increases for several major ions, most likely associated with contact with concrete and other drainage system materials. The optimal catchbasin performance (32% removal for suspended solids) is within the range reported during earlier studies, as reported above.

Filter Fabric and Filter Media Performance. Initial testing of the filter fabrics was performed using particle size distribution comparisons. The test water was a composite of typical stormwater runoff samples currently being analyzed in our laboratory. The largest particle size found in the analyses was about 90 μm, indicating the typical predominance of smaller particles in runoff. These filter fabrics and media can be divided into four different performance classes, for the particle range 6 to 41 μm, as shown in Table 2. Our current research is testing these materials in much greater detail. The filters and media being selected for further study represent a wide range of performance (both in respect to removing particles and in hydraulic capacity).

Table 2. Filter Performance Classifications with Hydraulic Flow Rate Comments

A: High efficiency for all particles (6 to 41 μm)	Holchst 1125 (fast) Gunderboom (slow, requires several inches of head) Sand (18") (fast) Carbon (18") (very fast) Soil (18") (slow) Soil (9") (slow)
B: High efficiency for larger particles only (> 20 μm)	EMCON filter (fast) Exxon filter (very slow, requires 4" head) Peat (18") (slow) Peat (9") (slow)
C: Moderate efficiency for all particle sizes (6 to 41 μm)	Holchst 1120 filter (fast) Leaves (18") (very fast)
D: Poor efficiency for all particle sizes (6 to 41 μm)	Holchst 1135 filter (fast) ADS 4000 filter (fast) ADS 4420 filter (fast)

Testing newly constructed columns for hydraulic conductivity showed the following ranking of the media from fastest to slowest: sand > zeolite-sand >> composted leaves > carbon-sand > peat-sand. Initial clogging tests have shown that channeling occurred in the zeolite-sand combination media and that the clay solution flowed through these channels and bypassed passage through the areas of the filter where the fine particulates should have been trapped.

Nine filtering fabrics and filtration media are being tested for pollutant removal using stormwater runoff from a parking area on the UAB campus. Initial results from filtration of three (of 12 planned) separate runoff events are shown in Table 4. The activated carbon-sand combination media appears to be an excellent control for toxicity and for most other pollutants. The peat-sand media combination appears to be flushing out part of the media during the tests, resulting in increased sample color and turbidity, but also showed excellent toxicity reductions.

Table 4. Preliminary Results from Filtration of Stormwater Runoff

Toxicity: (two influent samples were "not toxic" and one was "toxic")

Good to excellent toxicity removal efficiency (>70%):	Activated carbon-sand
	Peat-sand
	Composted leaves
No noticeable removal:	EMCON filter fabric
	Gunderboom filter fabric
	ADS 4420 filter fabric
	Zeolite-sand (noticeable channels developed)
	Enretech (increased toxicity during first run; minimal removal in later runs).

Turbidity: (influent turbidity values were low: < 15 NTU)

Activated carbon-sand: initial flushing of fines which decreased in subsequent samples.
No media consistently and significantly reduced turbidity.

Conductivity: (influent conditions were between 50 and 175 µS/cm)

Negative Removal Efficiency (Effluent > Influent):	Activated carbon-sand
	Composted leaves
	Enretech
No noticeable removal:	Peat-sand
	Zeolite-sand
	Sand
	EMCON filter fabric
	Gunderboom filter fabric
	ADS 4420 filter fabric

pH: (influent values were between 6.7 and 7.7)

Peat-sand effluent approximately 0.5 - 1.0 pH units *lower* than influent.
Composted leaves effluent approximately 0.5 pH units *greater* than influent.

Color: (influent color was between 15 and 60 HACH color units)

Fair to good removal efficiency (30 - 80%):	Activated carbon-sand
Negative removal efficiency:	Peat-sand
	Enretech
	Composted leaves

Chemical Oxygen Demand: (influent COD values were between 80 and 100 mg/L)

Good to excellent removal efficiency (>70%):	Activated carbon-sand
Negative removal efficiency:	Peat-sand
	Enretech
	Composted leaves

Particle Size Distribution: (most influent particle sizes were between 1 and 50 µm)

Good removal efficiency:	Activated carbon-sand
	Sand
Fair removal efficiency:	EMCON filter fabric
	Gunderboom filter fabric
Poor (or negative) removal efficiency:	ADS 4420 filter fabric
	Peat-sand
	Zeolite-sand

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Deficiencies in Stormwater Quality Monitoring

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Abstract

Typical stormwater "quality" monitoring programs consist of measuring a suite of conventional pollutants in the runoff during selected storms where those concentrations are often compared to numeric water quality criteria and state standards. While such a strategy may conform to current minimum monitoring regulations, it provides essentially no useful data regarding water quality impacts of urban stormwater runoff. Stormwater monitoring programs need to properly evaluate the water quality impacts of the presence of chemical contaminants in concentrations above federal water quality criteria and state water quality standards. Site-specific water quality studies that properly incorporate aquatic chemistry and aquatic toxicology into the study design and data interpretation can provide the needed information to properly evaluate whether elevated concentrations of stormwater-associated contaminants which would lead to violations of water quality standards are, in fact, impairing the designated beneficial uses of the waterbodies receiving the stormwater runoff.

Introduction

A participant in a recent state of California Stormwater Quality Task Force meeting commented that he had been involved in monitoring stormwater runoff for the past few years but could find no useful way to use the data generated from the monitoring program. That finding would be expected based on the nature of typical stormwater runoff monitoring programs; it was predicted more than a decade ago (Lee and Jones, 1981), and key technical issues pointing to it were revisited more recently by Lee and Jones (1991a) and Lee (1992).

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Typical stormwater "quality" monitoring programs consist of measuring a suite of conventional pollutants in the runoff during selected storms. While such a strategy may conform to current minimum monitoring regulations, it provides essentially no useful data regarding water quality impacts of urban stormwater runoff beyond that which has been well-known since the work of Weibel *et al.* (1964). They found that urban stormwater runoff contains elevated concentrations of a variety of chemical contaminants and sanitary quality indicator organisms. The work of the senior author's graduate students in the 1960's and 1970's confirmed that finding and also showed that substantial portions of the chemical contaminants in urban stormwater runoff are in unavailable, non-toxic forms and thus would not adversely impact water quality as assessed by impairment of designated beneficial uses of the waterbody receiving the runoff.

The function of stormwater quality monitoring programs is to contribute to meeting the goal of urban stormwater quality management programs, which is to protect the quality of the receiving waters from degradation by stormwater-associated contaminants. In order to serve that function, monitoring programs must be designed and executed to provide meaningful information on water quality impacts of contaminants associated with stormwater runoff. It is therefore important to understand the technical deficiencies in the current stormwater quality monitoring approaches and effect appropriate modifications so that technically valid, cost-effective evaluation and management programs can be instituted.

Inadequacies of Current Stormwater Quality Monitoring Programs

Current stormwater quality monitoring programs focus on measuring total concentrations of a selected group of chemical contaminants in stormwater runoff where the concentrations found are often compared to the US EPA numeric water quality criteria and state water quality standards. Not properly considered in this approach are the nature/availability of chemical contaminants in urban stormwater runoff; the environmental chemistry, fate, and toxicity/availability of the chemical contaminants in the receiving water; and the foundations and assumptions of the water quality criteria and standards relative to the characteristics of urban stormwater runoff to receiving waters.

The tone for the current stormwater monitoring and management programs was set by the US EPA National Urban Runoff Program (NURP) conducted in the 1980's. NURP confirmed on a national basis that urban stormwater runoff contains high concentrations of a wide variety of contaminants. Table 1 presents median concentrations of chemical contaminants from the NURP stormwater runoff studies reported by Pitt and Field (1990). It shows that the concentrations of a number of commonly measured constituents in urban stormwater runoff (such as chromium, copper, cyanide, lead, zinc, and chlordane) typically exceed the US EPA freshwater water quality criteria. However, the NURP studies provided no information upon which to evaluate the water quality significance of those elevated

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Table 1. "Estimated Contaminant Concentrations in US Municipal Stormwater Outfalls"*

	Median (µg/L)	US EPA Water Quality Criteria** (Fresh Water) (µg/L)	Drinking Water MCL (µg/L)
Arsenic	7	190 (As III)	50 ***
Chromium	30	11 (Cr VI)	50
Copper	35	6.5	1000
Cyanide	40	5.2	200
Lead	150	1.3	15
Zinc	150	59	5000
Bis(2-ethylhexyl) phthalate	6	15,000	—
Chlordane	1.5	0.0043	0.00046
Chrysene	1.5	—	—
Fluoranthene	3	3,980	42
Pentachloro-phenol	15	13	0.28
Phenanthrene	1.5	—	—
Pyrene	2	—	—

* Table Information and Table Title from Pitt and Field (1990)

** From US EPA *Quality Criteria for Water* (1987); 4-day average values for a hardness of 50 mg/L as $CaCO_3$.

*** In the process of being decreased.

— Means no values available.

concentrations of contaminants in urban stormwater runoff.

As discussed by Lee and Jones (1991b) and Lee and Jones-Lee (1994b), for numerous reasons, a mechanical comparison of concentrations of chemical contaminants in urban stormwater runoff with US EPA numeric water quality criteria and state standards does not provide a reliable assessment of the impact of stormwater-associated contaminants on water quality/beneficial uses of receiving waters. First, the US EPA criteria and state standards equivalent were generally developed for available forms of contaminants; many contaminants in urban stormwater runoff are present in unavailable/non-toxic forms. Second, it would indeed be rare that fish and aquatic life would be expected to reproduce and live in 100% stormwater runoff. The finding of even toxic levels of available forms of contaminants in urban stormwater runoff does not indicate that there would be toxicity or adverse impacts in the receiving waters. Typically there is appreciable dilution of urban stormwater runoff with the receiving waters at the point of mixing. If adequate dilution were not available, it would be likely that the aquatic life habitat associated with stormwater runoff would be severely limited by other factors, such as available water.

Third, the duration of exposure that aquatic organisms can receive from a runoff event should be considered in the interpretation of stormwater quality data and in the application of existing water quality criteria. The impact of a chemical contaminant on an aquatic organism depends on the duration of the organism's exposure to the given level of available forms of the contaminant. The US EPA water quality criteria were developed for protection of highly sensitive species under worst-case exposure conditions. The aquatic life criteria values listed in Table 1 to which the concentrations of contaminants in urban runoff were compared are what the US EPA considers to be chronic exposure criteria values, specified as 4-day average concentrations. The 4-day average was somewhat arbitrarily selected by the US EPA to represent a worst-case exposure situation so the criteria would be protective under chronic exposure conditions (lifetime or critical lifestage exposure). With few exceptions, many types of aquatic organisms could be exposed to the criterion concentrations of available forms of many types of contaminants for somewhat longer than 4 days without adverse impact. Urban stormwater runoff events are typically short-term and episodic in nature; receiving water organisms would not be expected to be exposed to the available forms of contaminants in urban stormwater runoff for critical chronic exposure durations. Thus, the chronic exposure criteria are over-protective for most urban stormwater runoff situations and for most contaminants.

The US EPA also lists 1-hr criteria values to represent worst-case shorter-term exposure situations and the associated concern for acute toxicity to aquatic life. Application of such criteria values to urban stormwater runoff would also be over-protective for most contaminants in urban stormwater runoff and most aquatic life forms. Many forms of aquatic life can readily survive exposure to available forms of chemical contaminants at the acute criterion concentration for several-day periods without adverse impacts. Generally, the concentration of a toxic contaminant that would kill 50% of test organisms in a 4-day exposure period is 50 to 100 times the chronic safe (no impact) concentration of that contaminant. Even a much larger factor would be expected to apply to typical stormwater runoff situations where the exposure of receiving water organisms would be expected to be on the order of a few hours to a day or so. There are no reliable chemical criteria by which to evaluate the potential adverse impacts on aquatic life-related beneficial uses of receiving waters that could be caused by the short-duration exposures to contaminants in the vicinity of a stormwater runoff discharge.

In addition to the over-protective aspects of the criteria discussed above, the US EPA water quality criteria specify that the 1-hr criteria values not be exceeded more than once in three years, to allow for "recovery" of the perturbed system.

It is well-known that even considering toxic forms of contaminants, exceedance of a 1-hr criterion value more than once in three years does not necessarily adversely affect the aquatic ecosystem - the designated beneficial uses of the waterbodies. To specify that any exceedance, independent of magnitude of the water quality criterion or standard, can occur no more than once in three years is grossly over-protective of the beneficial uses of waterbodies.

The US EPA recognizes the highly over-protective nature of its current water quality criteria and the associated implementation approach; it is, under the current administration, working toward correcting this problem. While the chronic exposure criteria have been in effect for many years, they were not being enforced by many states because of their highly over-protective nature. With its beginning to focus on chronic toxicity to aquatic life, the US EPA is increasing its efforts to require that states enforce chronic exposure aquatic life criteria. This, in turn, necessitates that the Agency adopt more appropriate approaches for development and implementation of its water quality criteria into state standards and NPDES discharge limits. This is especially important for regulating stormwater runoff in order to avoid spending billions of dollars of public funds in the unjustified over-regulation of stormwater-associated contaminants.

The data being generated by current stormwater quality monitoring programs and the approaches used for their interpretation are providing misleading information regarding the impacts of urban stormwater runoff on receiving water quality. These technically unreliable approaches are being used by "environmental" groups and other interest-activists to claim that "the data" show that urban stormwater runoff discharges are having a significant adverse impact on water quality. It is likely that citizens' suits arising out of the implementation of the provisions of the Clean Water Act will become common in the future. In order to defend itself against inappropriate claims, dischargers need reliable data describing the real impacts of urban stormwater runoff based on evaluation of the water quality characteristics of the waters receiving the stormwater discharge. In order to do this and protect the interests of the public, stormwater dischargers will need to do considerably more than the minimum required monitoring of their discharges (e.g., only measuring total concentrations of selected chemical contaminants in stormwater discharges).

Factors to Consider in Establishing a
Stormwater Quality Monitoring Program

A report entitled, "*Guidance for Conducting Water Quality Studies for Developing Control Programs for Toxic Contaminants in Wastewaters and Stormwater Runoff*," was developed by the authors to discuss major issues in the development of technically reliable, cost-effective evaluation and control programs for chemical contaminants in discharges (Lee and Jones-Lee, 1992). Key factors that need to be considered in establishing monitoring programs for urban

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stormwater runoff-associated contaminants are synopsized below.

- Clearly establish the objectives of the monitoring program.
- Understand the nature and assessment of "water quality," the beneficial uses of the receiving water, and water quality concerns.
- Select the parameters to be measured, justify the selection of each, and understand appropriate approaches for the interpretation of data for each parameter selected.
- Examine the results of previous studies to gain information on the expected concentration ranges and the expected variability (spacial and temporal) of the concentrations of contaminants in stormwater runoff and in the waterbody that is receiving the runoff.
- If no reliable data are available from previous studies, or if existing data are inadequate to define the variability of contaminant concentrations and other characteristics needed to establish a reliable monitoring program, conduct a pilot study for similar types of land use to make these determinations.
- List factors that can influence results of the study and how they may influence the results. For those factors that cannot be controlled, develop a plan to incorporate that information in the interpretation of the study results.
- Determine the statistical level of confidence at which the objective of the monitoring program is to be achieved and understand its relevance to assessing "water quality significance."
- If the purpose of the monitoring program is to determine changes in water quality characteristics that could be influenced by the stormwater runoff, select the magnitude of change that is to be detected and design the monitoring program for the runoff and receiving waters accordingly.
- Determine what factors control or influence the designated beneficial uses of the waterbody of concern, e.g., habitat, hydrodynamics, pollutants, etc.
- For each stormwater discharge point, determine the number and location of discharge/runoff and receiving-water samples to be collected in order to achieve the desired statistical confidence level and to determine water quality significance of the parameters of concern.
- Select sampling techniques and methods of analysis to meet the study objectives and level of confidence desired, being careful to avoid the "standard methods syndrome."
- Verify that sample collection and analytical methods are appropriate for each discharge and for the waterbody receiving the discharge for various seasons of the year.
- Conduct studies to evaluate the precision of sampling and analytical procedures and technique, the reliability of sample preservation, and the spacial and temporal variability of the system under investigation.
- Critically examine the relationship between the results of present and past studies.
- Review data for reliability and sufficiency as they are collected.
- Analyze and interpret data as sufficient information is collected. Consider modifications in the program that may be indicated by the data as they are

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collected.

The guidance provided by Lee and Jones-Lee (1992) for establishing a monitoring program for assessing the impacts of stormwater-associated contaminants on receiving water quality is significantly different from the approaches typically followed in establishing stormwater quality monitoring programs. The recommended approach requires a fairly sophisticated understanding of aquatic chemistry and aquatic toxicology as they are pertinent to evaluating impacts on "water quality," i.e., impacts on the designated beneficial uses of a specific waterbody receiving a particular stormwater runoff. For aquatic life-related beneficial uses it is the changes in numbers, types, and characteristics of the desirable aquatic organisms in the waterbody receiving the stormwater discharge of concern to the public that define water quality impact.

Assessing Impacts of Stormwater Runoff on Receiving Waters

Impacts of stormwater runoff-associated contaminants must be assessed on water quality in the vicinity of the discharge (near-field) and in the waterbody overall. For assessing the near-field impacts, the primary points of focus are the concentrations of available forms of contaminants and the duration of exposure that aquatic organisms in the near field can receive during the runoff event, as well as zones of passage by which organisms can traverse the area without exposure. The points of focus are fundamentally the same for assessing the water quality impacts on the waterbody overall, but consider the longer-term dilution and transformations that affect the concentrations and contaminant availability, as well as the aquatic life or other designated beneficial uses of the waterbody overall as they may be impacted by factors other than stormwater discharge.

As discussed above it is technically unreliable to presume that water quality impact is evidenced by the presence of chemical contaminants in runoff or receiving water in total concentrations in excess of US EPA water quality criteria or state water quality standards. The US EPA water quality criteria and state standards equivalent to them were not designed to regulate stormwater-associated contaminants. Because of the episodic nature of stormwater runoff events and the diminished availability/toxicity of many stormwater-associated chemical contaminants, a mechanical comparison between concentrations of total chemical contaminants in stormwater runoff with water quality criteria and standards typically greatly overestimates the potential water quality impacts of the stormwater-associated contaminants.

A reliable stormwater quality monitoring program includes appropriate consideration of the water quality/beneficial-use characteristics of waters receiving the stormwater runoff and how those characteristics may be affected by the discharged contaminants. Water quality impact studies must be highly directed toward addressing the key issues of concern. For example, if the concentration of

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a contaminant that is regulated because of its potential to bioaccumulate in fish tissue and render the tissue to be judged unsuitable for human consumption (e.g., mercury) exceeds water quality criteria-standards designed to prevent excessive bioaccumulation, the studies of the impacts of that runoff on receiving water quality should include measurement of the mercury concentration in the edible tissue of appropriately selected fish types or other edible aquatic life. If the concentration of mercury in the edible tissue is less than the FDA Action Limit or other appropriate standard, it may be concluded that whatever the past discharges of mercury have been from all sources, and despite the measured concentrations in runoff, those discharges are not resulting in excessive mercury in fish tissue, i.e., are not adversely affecting that aspect of the beneficial use. The finding of what are determined to be "excessive" concentrations of mercury in water without a concomitant finding of "excessive" concentration of mercury in fish tissue (the reason for concern about mercury) is not uncommon. This is because the US EPA criterion for mercury does not consider the fact that mercury exists in a wide variety of chemical forms, only some of which are available to be taken up by fish tissue. If, however, excessive levels of mercury were found in the edible tissue of fish in the waters receiving the stormwater discharge, additional studies would need to be conducted to determine whether the stormwater runoff-associated mercury was the cause or a significant contributor to the excessive mercury in the fish tissue. Such an assessment would require the conduct of specific studies designed to address that issue by qualified individuals.

For many contaminants in stormwater runoff that occur at elevated concentrations, the concern is the potential for toxicity to aquatic life. Since such assessments cannot generally be made on the basis of measured concentrations of contaminants in runoff or receiving water, it is important that the stormwater quality monitoring program include direct assessment of aquatic life toxicity of the discharge at carefully selected locations in the receiving waters. Some urban stormwater discharges will cause toxicity to test organisms in the commonly run standard toxicity tests. However, such toxicity tests tend to greatly overestimate the toxicity that would be expected in the waters receiving the discharges. That is because the duration of exposure and the exposure conditions in the test system are far worse (adverse) than those normally received by aquatic organisms in the receiving waters. Therefore, finding toxicity in toxicity tests of a stormwater runoff sample or of a sample of receiving water containing the discharge should not be interpreted to mean that the stormwater is having a significant adverse impact on the designated beneficial uses of the receiving waters. The toxicity tests conducted should be site-specific studies of the type described by Lee and Jones (1991b) which properly mimic the exposure conditions that organisms would likely encounter in the receiving waters for the stormwater discharge.

Before entering into comprehensive site-specific studies of the impacts of stormwater runoff-associated potentially toxic contaminants in receiving waters, however, it is important to determine whether the receiving waters are, in fact, causing toxicity to sensitive forms of aquatic life in the receiving water. If the receiving water watercolumn waters are not causing toxicity, it is obvious that neither stormwater-associated contaminants nor contaminants contributed from other sources are causing toxicity-related impairment of designated beneficial uses of the waterbody. The importance of making this fundamental assessment, and potential ramifications of overlooking the obvious were illustrated by recent regulatory actions for San Francisco Bay. Studies have shown that even though domestic wastewater discharges and stormwater runoff to San Francisco Bay contain copper and several other contaminants in concentrations above US EPA water quality criteria and state water quality objectives (standards) and the concentrations of copper in the waters of the Bay exceed the US EPA criterion at times by two- to three-fold, the Bay water containing that copper (and for that matter all other contaminants) was non-toxic to several forms of copper-sensitive aquatic organisms. As a result, there is no justification to require that the managers of stormwater discharges to San Francisco Bay spend public funds to treat the stormwater runoff to control contaminants that were of concern because of their potential to cause toxicity to aquatic life in the San Francisco Bay watercolumn.

Another area of expressed concern about the chemical contaminants in stormwater runoff is the potential for particulate contaminant forms in the runoff to accumulate in receiving water sediments where they could cause toxicity to aquatic life living in or on the sediments. While it is conceivable that this might occur, the potential for it to occur cannot be assessed based on the total concentrations of contaminants in the runoff or in the receiving water sediments. Lee and Jones (1992) and Lee and Jones-Lee (1993, 1994a) have reviewed approaches for assessing the significance of chemical contaminants in aquatic sediments that have evolved over the past two decades. As they discussed, biological effects-based evaluations are recommended for that purpose; chemical concentration-based evaluations have proven to be highly unreliable for making such assessments.

It is also important to consider in this regard that many aquatic sediments cause toxicity to aquatic life due to natural or other conditions that have nothing to do with stormwater runoff-associated contaminants. The finding of aquatic life toxicity in tests of sediments from downstream of a stormwater discharge cannot be presumed to indict stormwater runoff even if the runoff contained high concentrations of the same type of total contaminant. Many of the contaminants in stormwater runoff are in particulate forms that do not equilibrate with other forms of the same contaminants in the receiving waters or sediments.

Contrary to the statements made by Paulson and Amy (1993), it is not possible to reliably predict potentially toxic forms of stormwater-associated contaminants that will be present in the receiving waters from equilibrium-based chemical models. The use of those models requires that thermodynamic equilibrium be quickly achieved in the receiving waters. This will rarely be the case. Further, those models require information on complexation and sorption reactions that may occur in receiving waters but for which there are no reliable thermodynamic data available. Chemical measurements, *per se*, of the stormwater runoff or of the receiving waters will not provide reliable information on the potential biological effects of chemical contaminants in the stormwater runoff. Direct measurements of biological effects such as toxicity and bioaccumulation must be made.

Lee and Jones-Lee (1994c) have recently discussed a very significant problem associated with the approach being used by the US EPA in regulating chemical contaminants in aquatic systems that will become of particular significance in regulating stormwater-associated contaminants. This problem evolves out of the Agency's Independent Applicability Policy in which chemical-specific water quality criteria and state standards are presumed to be independently applicable to contaminants in point and non-point source discharge-runoff. This Policy means that in those situations where excessive concentrations of chemical contaminants above the US EPA water quality criteria are found where the exceedance is of concern because of potential aquatic life toxicity, yet measurements of the receiving waters for the discharge show no aquatic life toxicity to several sensitive forms of aquatic life, still requires the control of chemical contaminants causing the exceedance. This is the situation that has developed for copper in San Francisco Bay. The US EPA's Independent Applicability Policy is obviously technically invalid and should be abandoned. Biological effects-based criteria should take precedence over chemical-specific criteria in regulating chemical contaminants.

Monitoring of Performance of BMP's

Jones-Lee and Lee (1994) and Lee and Jones-Lee (1994b) discussed approaches to evaluate the efficacy of structural BMP's for the control of stormwater runoff-associated contaminants. They emphasized the importance of not following the conventional approach of judging the efficacy based on changes in the total concentrations of contaminants across the BMP (upstream vs. downstream). If the purpose of constructing a BMP for an existing discharge is to improve the designated water quality/beneficial uses of waters receiving the stormwater discharge, it is important to select, judge and monitor the performance of the BMP based on changes in the receiving water quality. This will necessitate the conduct of site-specific studies of the receiving water as discussed above.

Conclusions

The stormwater quality monitoring programs typically conducted today are significantly deficient in providing information to properly assess the impact of stormwater runoff-associated chemical contaminants on the designated beneficial uses of the waters receiving the runoff. The data generated by these stormwater monitoring programs provide an exaggerated impression of the potential water quality impacts that can readily be used by environmental activists and others against stormwater dischargers in an attempt to force compliance with measures that have nothing to do with protection of the water quality/designated beneficial uses of waters receiving stormwater runoff. Stormwater dischargers need to expand the scope of their monitoring programs to properly evaluate the water quality impacts of the presence of chemical contaminants in concentrations above federal water quality criteria and state water quality standards. Site-specific water quality studies that properly incorporate aquatic chemistry and aquatic toxicology into the study design and data interpretation can provide the needed information to properly evaluate whether elevated concentrations of stormwater-associated contaminants which lead to violations of water quality standards are, in fact, impairing the designated beneficial uses of the waterbodies receiving the stormwater runoff.

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APPENDIX B

OTHER ISSUES

Conference participants were asked, at the beginning of the conference, to write down issues that they considered important. The following are the responses received.

1. Our discussions this week have focused on monitoring related to applications for an NPDES permit, and have emphasized that there is fuzziness in the results, and that to get statistically significant results, you need many samples. The real problem, however, lies in the fact that there are two phases of regulatory activity.

   - Permit Writing - during this phase, the regulatory personnel see things in shades of grey, and one can negotiate with them. These people set the monitoring required for permit compliance.

   - Permit Compliance and Enforcement - These regulatory personnel see things only in black and white. One is either in compliance or not. Furthermore, the performance of these personnel is judged based upon orders and findings, and the dollars assessed in fines.

   We thus need to define monitoring for compliance. Monitoring done for assessment of BMPs or for studies does not work - as evidenced by the discussions this week. Monitoring for compliance must address the black/white mentality.

2. Unrealistic expectations have been placed on our current monitoring. What we really need is classes of monitoring.

   - Event-based chemical monitoring to establish the effectiveness of individual BMPs. This type of monitoring cannot be used to establish aggregated BMP impact on receiving waters.

   - Biological monitoring to establish long-term trends in habitat quality (one must recognize that we will never know the direct impact of BMP implementation on habitat quality).

- Integration of receiving water quality modeling with monitoring to establish probable short-term or projected impacts of BMPs.

3. The municipal permit monitoring requirement should be re-assessed on an annual basis. Changes to the monitoring plan should be negotiated between the permittee and the regulators. Recognize that the monitoring plan needs to evolve over time.

4. We must include the contribution of agricultural activities in an overall monitoring plan, not just the characterization of stormwater from urban areas and industrial sites.

5. The following are two important research needs:

   - Define relationships (descriptively and quantitatively if possible) among watershed conditions, aquatic ecosystem conditions, and biological response. These data should be used to define conditions that need to be maintained for ecosystem stability and productivity, and to determine the effectiveness of various mitigation and management strategies at the biological population, community, and ecosystem levels.

   - Get documentary evidence of the effectiveness of various preventive source controls.

6. As a consultant, in order to give better advice to my firm's clients, I need to be aware of a variety of BMPs, both source and treatment controls, and, most importantly, the effectiveness of these BMPs.

   At this point in time, little is known about the effectiveness of the vast majority of these BMPs. Data are available on some of the more common treatment control (structural) BMPs, such as several types of detention basins and swales. However, these data yield a wide range of BMP effectiveness.

   Thus, a well though out and funded research program is needed to more accurately predict the effectiveness of many BMPs under a wide variety of conditions (climatic, geographic, construction controls, maintenance frequency).

   There was some emphasis on structural (treatment) controls at this conference, however the CWA emphasizes the reduction of pollutants in storm water. This leads us to source controls, and the need for research to define these source controls and their effectiveness. The use of unleaded gasoline is a good example of reduction of a pollutant due to source control.

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APPENDIX C

SUMMARY: AD-HOC SESSION

Stormwater and Aquatic Ecosystem Health

John R. Maxted
(with review by Earl Shaver and Rich Horner)

Attendees:

John Maxted - Delaware Department of Natural Resources
Robert Wilson - Arizona Department of Environmental Quality
Derek Mack-Mumford - City of Scarborough, Canada
Rich Horner - University of Washington
Betty Rushton - SW Florida Water Management District
Bill Snodgrass - Ministry Ontario Transport, Canada
Mike Thomas - Atlanta Regional Commission
Rob McCleary - Delaware Department of Transportation
Ed Herricks - University of Illinois
Randy Greer - Delaware Department of Natural Resources
Earl Shaver - Delaware Department of Natural Resources
Marshall Jennings - USGS
Ron Rossmiller - HDR Engineering
Tom Waller - University of North Texas
Roger Bannerman - Wisconsin Department of Natural Resources
Bill Tate - USEPA; NPDES Stormwater

Introduction:

An ad-hoc session was held during the 1994 Engineering Foundation Conference at Crested Butte, Colorado, on the subject of freshwater aquatic ecosystem health, specifically streams and wetlands. This was a follow-up to the morning session on "Monitoring Receiving Water Trends" in which a holistic approach to stream health was emphasized. This approach involves the assessment of physical habitat and biological integrity (aquatic invertebrates and fish) to complement the more traditional assessments of Stormwater impacts based upon hydrology and water quality. There was general recognition by many Conference Attendees that monitoring programs designed to assess the impacts of Stormwater and the effectiveness of controls should include measures that address all of the primary attributes of stream health including hydrology, water quality, physical structure (habitat) and biological integrity.

It should be made clear that this session on aquatic ecosystem health was focused on ecological health. Therefore, issues related to human health (e.g., bacterial/viral contamination) were not discussed.

Summary:

The discussions can be divided into three areas:

- A review of some of the impediments to expanding monitoring beyond traditional measures (water quality).
- A listing of projects that the group was aware of that focus on physical habitat and biological measures.
- A list of actions that would help to communicate and summarize data and information on the affects of urbanization on aquatic ecosystem health.

The primary impediment to the inclusion of physical habitat and biological measures in stormwater monitoring was identified as the lack of personnel and expertise. Put simply, local governments do not have biologists on staff nor have States directed their biologists to address stormwater impacts or to work with Stormwater regulatory programs. Stormwater regulatory programs are currently an extension of the traditional control philosophy of the NPDES program focused on chemical criteria and water quality. In the area of habitat and biology, methods are available (e.g., EPA, "Rapid Bioassessment Protocols", 1989, EPA444/4-89/001), but have not been widely applied to Stormwater. The lack of public education was also identified as an impediment to incorporating these measures into a Stormwater control program.

The discussion quickly moved on to a review of how biological monitoring was being applied in different parts of the country. In general, it was felt that the tone for focusing more attention on biology in the assessment of aquatic ecosystem health should be set by EPA through the development of biological criteria. While EPA has been successful in promoting a greater awareness of the need to use biological criteria on a national scale, the sense of the group was that the program is not well funded and requirements are lacking that would lead to meaningful progress over the next several years. Accomplishments have been made in selected States where individuals have taken particular interest in biological criteria. A wide variety of activities were presented by the attendees including those of Federal agencies, States, local governments, and academia. No attempt is made here to summarize these activities. The following people may be contacted for information: Jennings, Bannerman, Shaver, Waller, Herricks, Maxted, and Snodgrass.

Action Items:

One of the most interesting and productive discussions focused on the actions that could be taken to summarize data and information on various subjects related to urbanization, stormwater, and aquatic ecosystem health and to consider the need for additional research. The group identified the following three subject areas where information was known to be available but was not summarized or in a form that could effectively be utilized by engineers and scientist in the stormwater field. Summaries of the "State of the Science" in these areas would also help to identify data gaps and promote additional research.

- Effect of Urbanization on Aquatic Ecosystem Hydrology. A report would summarize both empirical studies and modeling estimates of the affect of urbanization on the hydrology of various types of non-tidal streams and freshwater wetlands. The types of systems might be separated by geographic location, gradient, and stream order. Data would be presented on the changes in both the frequency and severity of flooding events after urbanization.

- Factors Affecting the Erosion of Streambanks after Urbanization. A report would present and explain the concept of "shear stress" and the factors that lead to streambank instability due to changes in hydrology after urbanization. The first and second order streams of forested watersheds are often stable and vegetated while the banks of streams in urban watersheds are often unstable and unvegetated. What are the mechanisms that cause defoliation and bank failure and what factors are most important in predicting the affect of urbanization on stream banks; e.g., percent imperviousness, frequency of inundation, velocity, soil type, forest cover, integrity of the riparian zone, etc. Research would also be summarized on the proportion of sediment delivered to stream channels from bank erosion in urbanized and non-urbanized watersheds. Sediment has been identified as one of the primary mechanisms affecting the biological integrity of urban streams.

- Effect of Urbanization on Biological Integrity. Data were presented at the conference on the relationship between percent imperviousness and the macroinvertebrate community of non-tidal streams in Delaware (Shaver and Maxted). Additional work on streams and wetlands was also discussed regarding the effects of various land use changes on the resident biota (Horner). The group was interested in a summary of the literature on these subjects. Biological endpoints might include fish, amphibians, aquatic plants as well as macroinvertebrates.

Marshall Jennings (USGS) indicated some interest in being involved in the first item, while John Maxted (Delaware DNREC) was interested in being involved in the third. The group was very much interested in seeing the topic of aquatic ecosystem health addressed in future Engineering Foundation conferences.

APPENDIX D

LIST OF ATTENDEES

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Stormwater NPDES Related Monitoring Needs presents various perspectives and expertise from industry, as well as state and local governments, on the monitoring requirements of the current U.S. Environmental Protection Agency NPDES regulations, and particularly those governing discharges of stormwater to the environment. Twenty-five invited papers review methods of locating inappropriate discharges to storm drains, system runoff characterization, monitoring receiving trends, and policy and institutional issues of NPDES monitoring. BMP monitoring for data transferability, and protocols for monitoring BMP for effectiveness are also addressed.

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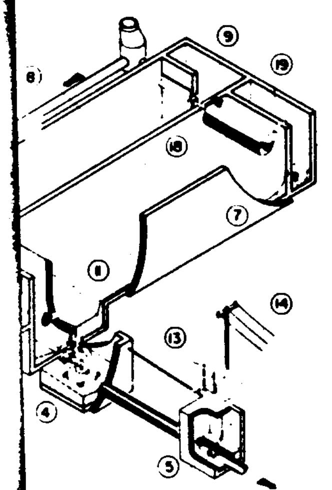

1 interceptor
2 backwater prevention with air-regulated siphons
3 diversion chamber with three overflows
4 electrically operated knife-valve
5 flume, parabola shaped orifice plate
1, 6 tube-type in-line storage
7 off-line first flush tank
8 off-line clarifier tank
9 clarifier overflow with scum board
10 clarifier overflow control
11 soft rubber check flap
12 backflow prevention from high receiving water levels
13 electronic control
14 remote control from WWTP
15 "Sewer Spy"
16 receiving waters
17 storm outlet

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Urban Stormwater Quality Enhancement–
Source Control, Retrofitting, and Combined Sewer Technology

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ABSTRACT

This proceedings contains the papers presented at the Engineering Foundation Conference on "Urban Stormwater Quality Enhancement—Source Control, Retrofitting and Combined Sewer Technology," held October 22-27, 1989, in Davos Platz, Switzerland. Session topics include institutional issues; stormwater regulations and standards; on-site detention, infiltration and percolation; inlet controls; planning; real-time control; in-systems control; treatment; rehabilitation; and research needs. One supplemental paper not presented at the Conference is included.

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FOREWORD

The Urban Water Resources Research Council (UWRRC) of the American Society of Civil Engineers has for more than 20 years been a leader in the transfer of urban runoff technology among researchers, practitioners and administrators. A series of Engineering Foundation Conferences, held in the United States and abroad, has been one of the major vehicles for this transfer. This proceedings reports on the latest Conference in the series.

At the preceding such conference on "Current Practice and Design Criteria for Runoff Water Quality Control," held in 1988 in Potosi, Missouri, it was clear that there was a great deal of technology, developed in Europe specifically for first flush control and combined sewers, that would probably be applicable to the solution of storm and combined sewer pollution problems in North America. Of particular interest were presentations on retrofitting of existing urban systems and comprehensive detention facility design. As a result, the UWRRC, together with European colleagues, decided that the best way to exploit the potential of this European technology was to hold an Engineering Foundation Conference in Europe, involving both European and North American engineers.

All papers at the conference were by invitation, and were presented by well-known scientists and engineers. Each was reviewed prior to acceptance by the appropriate session chairman, and by the editor of the proceedings. Each paper was presented by the author, and subjected to discussion and review by the conference participants. The papers are grouped by session, and the session chairman is listed in the table of contents. One supplemental paper, submitted after the conference, has also been included. All papers are eligible for discussion in the appropriate ASCE journal, and all papers are eligible for ASCE awards.

The Conference organizers express their sincere appreciation to the Engineering Foundation for providing financial and administrative support, and particularly to Herman Bieber and Jack Donaldson, for providing outstanding assistance in the day-to-day on-site management of the Conference and related activities. Finally, we would like to thank Mr. James Elder and Mr. Dennis Athayde, of the U. S. Environmental Protection Agency, and Mr. Peter Stahre, Gatukontoret Malmo, for arranging funding support for the conference.

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WATER SCIENCE AND TECHNOLOGY: GLOBAL ORIGINS

by Stuart G. Walesh, M. ASCE[1]

Background

This conference was arranged by an international committee. U.S. representatives included members of the Urban Water Resources Research Council (UWRRC) of the American Society of Civil Engineers (ASCE) and staff of the Engineering Foundation (EF), an organization providing support to U.S. engineering societies. Since 1965, the UWRRC and the EF have sponsored 11 EF conferences. All of them, with the exception of this one, were held in the United States.

In spite of the location of the previous UWRRC-EF conferences, at least a small number of water experts from other countries have usually participated. These conferences were characterized by a bond among the water resource engineers and scientists. Regardless of geographic origins, ethnic and cultural backgrounds, and political persuasions, the participants shared a strong interest in their chosen water-related disciplines.

The obvious bond among water engineers and scientists probably reflects the strong and pervasive effect of water on human life. Most communities are concerned with providing drinking water, disposing of wastewater, irrigating crops, and mitigating flooding. Most people appreciate the aesthetic, recreational and other benefits of water -- especially in urban areas.

During the last UWRRC-EF conference, which was held in the State of Missouri in the U.S. during July, 1988, many con-

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versations were held between representatives of the UWRRC and conference participants from other countries. As a result of these fruitful discussions, the idea of holding the next EF conference in Europe quickly developed.

The primary purpose for placing the next conference -- this conference -- in Europe was to provide increased opportunities for U.S. participants to hear papers by and learn from water experts who are active in other countries. The international organizing committee for this conference arranged a program in which over two-thirds of the papers are being presented and sessions are being chaired by experts from outside of the U.S.

Purpose

The author is privileged to be invited to address this group as the keynote speaker. Given the international motivation for and international participation in the conference, a global theme seems appropriate. Accordingly, this paper addresses the historic, international basis for the science and technology used in the water resources field.

The preparation of this paper provided an opportunity for some systematic study into the origins of the science and technology used in the water resources field. The author strongly suspected, at the beginning of the project, that modern water resources efforts are built on a foundation of science and technology drawn from around the world and going back to at least the beginning of recorded history. The subsequent study confirmed this initial impression.

Approach and Scope

Presentation of the historic record of the development of the science and technology used in water resources would require volumes of writing or days of speaking. At best, a paper can present only snapshots of the historic and global development of the water resources field. These glimpses will hopefully form a montage of images which, in at least a modest way, enhances understanding of and appreciation for the global origins of our work.

The global origins of science and technology used in the water resources field are presented by selected subject areas drawn from hydrology and hydraulics. Water quality science and technology was excluded in order to provide a manageable scope of coverage. However, analysis and design of water quality systems is highly dependent on hydrology and hydraulics, which are the foundation of the water resources field. Hydrologic-hydraulic subjects were chosen to be of expected broad interest. Topics selected are: the hydrologic cycle, discharge measurement, hydrostatics, dams, collection-transportation-distribution works, the Manning equation, the Lloyd-Davies or rational formula, Darcy's Law, and computer models.

Within each of the selected subject areas, material is presented chronologically and in snapshot fashion. The focus is on the individuals who made scientific discoveries or created new technology. Where feasible, the contemporary environment is framed in terms of existing science and technology and the motivation for discovery and creativity.

The Hydrologic Cycle

Biblical writers referred to and apparently wondered about what is now referred to as the hydrologic cycle. For example, the Old Testament Book of Ecclesiastes says "all streams run to the sea, but the sea is not full; to the place where the streams flow, there they flow again." (Revised Standard Version, Chap. 1, Verse 7).

Curiosity about the hydrologic cycle, particularly the origin of streamflow, can be traced to the earliest of recorded history. In the third century B.C., the Chinese scientist Lu Shihh Chhun Chhiu contributed to the understanding of the evaporation component of the hydrologic cycle by writing (Brutsaert, 1934, p. 19):

> The waters flow eastwards from their sources, resting neither by day nor by night. Down they come inexhaustibly, yet the deeps are never full. The small (streams) become large and heavy (waters in the sea) become light (and mount to the clouds). This is (part of) the Rotation of the Tao.

Thus, the seas never fill because some of the sea becomes "light", that is, evaporates.

One of the Greek philosopher Plato's explanations of the origin of flow in springs, rivers, and lakes, was his concept of a huge subterranean reservoir. The subterranean reservoir, which he called Tartarus, was

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located in the center of the earth. The water in Tartarus surged back and forth -- a sort of internal seiche. This reciprocating action pumped water out of Tartarus at high locations on the earth surface, such as hills and mountains, from where the water flowed down slope continuously forming or replenishing springs, rivers, and lakes. The oscillating action of Tartarus also drew inflow from streams, rivers, and lakes at low locations on the earth's surface, thus helping to conserve the amount of water in Tartarus (Biswas, 1970, p. 58).

Aristotle, Plato's student, rejected the Tartarus idea proposed by his teacher. One of Aristotle's arguments against the Tartarus mechanism was that there would be evaporative loss of water during the surface water phase. Plato's theory did not explain how this continuous loss of water from the system would be replenished. Aristotle's critique suggested that he possessed at least a rudimentary understanding of the important roles of evaporation and precipitation in the hydrologic cycle.

Perhaps Aristotle should have stopped with his criticism of Plato's Tartarus. Instead, he went on to theorize a continuous conversion of air into water (condensation) within the earth with water appearing as springs which combined to form rivers and lakes (Biswas, 1970, pp. 66-68).

As inquiring early hydrologists trying to understand the hydrologic cycle, neither Plato nor Aristotle apparently ever made measurements. They knew of length measuring, time measuring (water clock), and weighing (balance) devices. "Why" was their interest, not "how much". Their approach to science, which was casual and undisciplined by modern standards, might be understood by considering the words of Aristotle (Biswas, 1970, p.69):

> Search for truth is one way hard and in other way easy, for it is evident that no one can master it fully nor miss it wholly, but each adds a little to our knowledge of nature, and from all the facts assembled there arises a certain grandeur.

That is, all that really mattered is contributing a little bit of new knowledge, or at least trying.

In contrast with the Greeks, whose hydrologic - hydraulic contributions relied on philosophying and theorizing, other nations focused on observation and measurement. Practical concerns often motivated these efforts. Rain gauges are mentioned in the Mishnah, a book of religious writings which describes four centuries of Jewish religious and cultural activities in Palestine (now Israel and Jordan) from about two centuries B.C. to two centuries A.D. Precipitation was measured because of its importance to agriculture (Biswas, 1970, pp. 99-100).

The writings of the Roman Lucretius, who lived during the last century before Christ, illustrate the Roman's pragmatic, observational approach. In his work, On Nature, he suggests a rudimentary understanding of the evaporation component of the hydrologic cycle -- an understanding apparently based on thoughtful observation of common phenomena. Lucretius writes (Brutsaert, 1934, p.17):

> For certainly we do see that clothes soaking with wet are dried up by the sun with his burning rays. But we see that seas are many and stretching wide beneath; therefore although the sun may sip but a small portion from the surface of any given place, yet over so great an expanse he will take away from the waves in abundance. Then further the winds also can lift a goodly portion of moisture by sweeping the surface, since under the winds we see very often the roads grow dry in one night, and the soft mud massing together in crusts.

In other words, observation of common occurrences reveals the evaporation process -- a process that must be operative in a massive way over the ocean. Lucretius correctly deduced that evaporation was influenced by solar energy and the wind.

Rain gauges were used in China at least as early as 1247 A.D. The conical or barrel-shaped collection containers were systematically placed in every provincial and district capital. The Chinese are thought to be the first to use snow gauges. Placed in mountainous areas, these gauges were in the form of large bamboo cages. One Chinese writer, Chhin Chiu-Shao, described a method for estimating area wide rainfall from point observations

(Biswas, 1970, p. 127).

The Koreans prayed for precipitation from ancient times because of its importance to rice farming and their government began measuring precipitation as early as the fourteenth century A.D. The Korean gauges were cylindrical and apparently made of metal. These gauges were imported from China or copied from the Chinese gauges. They were about 30 cm (12 inches) high and 15 cm (6 inches) in diameter and were mounted on top of a stone block cr pillar. The block or pillar was usually inscribed with the date of installation and with some deferential comment about the king or other high official (Biswas, 1970, pp. 127-132).

In the 17th century, the Frenchman Sedileau was charged with investigating the precipitation that would be available around Versailles to supply artificial fountains and water jets in the Parc of Versailles. He carried out three years of precipitation and evaporation experiments.

Although he obviously judged the experiments to be necessary, he apparently didn't like to do them as suggested by his words (Brutsaert, 1934, p.27):

> There are certain fundamental experiments on which all of physics is based, and which one must necessarily make, however annoying they may be, if one wants to reason correctly in this science: otherwise all the reasonings which are made on natural things are speculations in the air.

Sedileau observed that the annual evaporation rate from a water surface was twice the annual precipitation rate. He correctly explained the watershed implications of this apparent discrepancy by noting that much of the precipitation infiltrates into the ground thus being protected from immediate and rapid evaporation. In other words, regional evaporation would be approximately in balance with regional precipitation (Brutsaert, 1934, p. 28).

Edme Mariotte (1620, approximately, to 1684 A.D.) was one of the first to demonstrate by rainfall-runoff measurements that annual rainfall on a watershed was more than sufficient to account for annual runoff from the

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watershed. (Biswas, 1970, pp.213-219) Mariotte's rainfall - runoff studies were carried out on the Seine River watershed which terminated in Paris at the confluence of the Seine and Marne rivers. Interestingly, Mariotte's place of birth, Dijon in east central France, was on the headwater divide of the watershed and the source of the three years of rainfall data used in his rainfall - runoff investigation.

He used the annual precipitation at Dijon to estimate the annual rainfall volume on the Seine River watershed. Streamflow measurements on the Seine at Paris yielded the annual runoff volume for the watershed. Runoff volume was found to be about one-sixth of the rainfall volume clearly indicating the sufficiency of rainfall to account for runoff. Mariotte performed a similar rainfall - discharge study on a large spring.

Edme Mariotte also prepared a manuscript for a book on the motion of water and other fluids (Traite du mouvement des eaux et des autres corps fluides). Apparently knowing that death was imminent, Mariotte gave the manuscript to a friend and scholar who carried the project through to publication in 1686. Titles of the five parts of the book suggest that it was a predecessor of current fluid mechanics textbooks.

As a result of inquiries going back at least 23 centuries, the hydrologic cycle is now understood to be the continuous, unsteady circulation of the water resource from the atmosphere to and under the land surface and, by various processes, back to the atmosphere. The hydrologic cycle is dynamic in that the quantity and quality of water at a particular location may vary greatly with time. Within the hydrologic cycle, water may appear in all three of its states: solid, liquid, and gas. And water engineers and scientists continue to seek further understanding of the hydrologic cycle and of its response to cultural changes.

Discharge Measurement

Measurement or prediction of volumetric discharge in pipes and channels, over dams, through orifices, and at other control structures is basic to water management. From the earliest times, volumetric discharge was thought to be determined solely by cross-sectional area. The Greeks were the first to record the recognition that volumetric discharge of water is a function of cross-sectional area and velocity. The Greek historian, Hero, said (Rouse and Ince, 1963, pp. 21-22):

> It is to be noted that in order to know how much water the spring supplies it does not suffice to find the area of the cross-sectional flow....It is necessary also to find the speed of the flow...

Although the Romans subsequently developed water transportation technologies, such as aqueducts, they apparently did not fully understand or appreciate the discharge principles exposed centuries earlier by the Greeks. A case in point is Sextus Julius Frontinus, water commissioner for the city of Rome. His writings strongly suggest that he understood the dependence of discharge on cross-sectional area but did not comprehend the equally important role of velocity (Rouse and Ince, 1963, p. 25, pp. 30-32).

Leonardo da Vinci (1452-1519 A.D.), the illegitimate child of a Florentine lawyer, was born in Vinci, Italy. Generally considered to have been a genius, his observational and analytic powers contributed to many fields, including hydrology and hydraulics, as documented by Biswas (1970, pp. 136-147).

Leonardo was one of the first to clearly express the continuity principle as it applied to open channel flow. He used the following analogy to explain the principle:

> Let us imagine an avenue formed of three consecutive sections, each of a different width; the first section, the narrowest is four times less wide than the second, and this one (the second) is twice narrower than the third; people, closely pressed against each other, fill these avenues; they must march together in a continuous manner; when the people in the large avenue take one step forward, those in the middle one must make two and those in the smallest, eight; a proportion which you will find in all motions passing through sections of width.

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Leonardo contributed to discharge measurement by determining river velocity profiles in vertical and horizontal planes. He used special floats and walked along the river pushing an odometer for distance while he measured time by singing up and down the musical scales.

Incidentally, Leonardo planned to write a book on water and identified 15 chapters. Based on the chapter titles (e.g., rivers, repairing the banks of rivers, conduits, canals, machines turned by water, raising water) his book could have been titled "Water Resources Engineering". Unfortunately, he never had time to complete the project.

Hydrostatics

Hydrostatic principles are frequently and routinely used in urban water management to calculate the pressures and forces exerted by water. For example, hydrostatics enters into the structural design of earthen berms and concrete outlet works and floodwalls. Hydrostatics is also applied in floodproofing of existing and new residential, commercial, and other structures and in calculating the stability of tanks and other vessels totally or partially submerged in saturated soil.

Modern hydrostatic principles were largely developed by Archimedes (287-212 B.C.), the Greek theoretician and mathematician. The son of an astronomer, Archimedes was born in Syracuse, Sicily and devoted his career to advancing mathematics and inventing or refining mechanical devices such as the water screw and war machines or engines. Interestingly, Archimedes died when Syracuse fell to the Romans. The Greeks used some war machines developed by Archimedes in their defense of the city (Rouse and Ince, 1963, pp. 15-19).

According to legend, Archimedes discovered the buoyancy principle while bathing nude in a public bath. A very excited Archimedes is supposed to have left the bath and run through the streets naked shouting "Eureka (I have found it!)" (Rouse and Ince, 1963, p. 16). If he was in fact that exuberant about this discovery of the buoyancy principle, his actions would certainly be excused given the usefulness of his work in modern water management.

Dams

One of the oldest major dams was constructed by King Menes on the Nile River in what was already Egypt in about 3000 B.C. (Biswas, 1970, pp. 2-5). He dammed the Nile just upstream of Memphis, an ancient city and one-time capital of Egypt, about 200 Kilometers (125 miles) from the Mediterranean Sea near what is now Cairo.

King Menes apparently constructed the 450 meter (1470 foot) long, 15 meter (50 foot) high dam on the Nile for two reasons. First, the dam facilitated building Memphis on the fertile, former river bed and floodplain of the Nile. Second, the dam was part of a protective moat around Memphis consisting of the diverted river, a lake, and a canal. The dam functioned for at least 2500 years.

Another of the oldest known dams is the Sadd el Kafara Dam about 18 miles south of Cairo, Egypt. Although the dam was apparently short-lived, according to Biswas (1970, pp. 5-7) the remnants were not discovered until 1855 and remain to this day.

Constructed approximately between 2950 and 2750 B.C., the dam was probably intended to provide drinking water for workers and animals at a nearby quarry. The 106 meter (348 foot) long, 11 meter (37 foot) high dam was constructed of rubble masonry. There was no spillway and mortar was not used in construction. Furthermore, although the dam was to intercept runoff from a 186 square kilometer (72 square mile) tributary area, the resulting reservoir had a capacity of only 568,000 cubic meters (460 acre-feet). This was equivalent to 0.3 centimeters (0.12 inches) of runoff from the watershed.

Because of the absence of a spillway and the very small storage capacity, this first dam was doomed to early failure. Lack of sediment deposits at the site suggest that the dam failed in the first flood season.

The Egyptian engineers probably benefitted from the failed Sadd el Kafara effort. Lessons learned may have included the need for a spillway, a stable and cohesive structure, and a storage capacity commensurate with the tributary watershed. For example, the Egyptians subsequently constructed a 2000 meter (6560 feet) long, 6 meter (20 feet) high, rock-filled dam in Syria in the 14 century B.C. This 34 century old dam is still in use (Biswas, 1970, pp.5-8).

The valley of the Tigris and Euphrates rivers, in what is now called Iraq, is one of the cradles of civilization. According to Biswas (1970, pp. 19-22), the advantages of being in a valley enriched by two rivers was partly offset by the ever-present danger of flooding. Therefore, the careful design and proper maintenance of water control works, such is dams, irrigation channels, levees, and canals, was critical to survival.

King Hammurabi conquered the valley around 1760 B.C. He codified laws into what is now called the Code of Hammurabi (discovered in 1901 and maintained in the Louvre Museum in Paris.) The crucial nature of dams and other water control facilities is clearly evident in the code. Consider, for example, this provision:

> If any one be too lazy to keep his dam in proper condition, and does not keep it so; if then the dam breaks and all the fields are flooded, then shall he whose dam the break occurred be sold for money and the money shall replace the corn which he has caused to be ruined.

A dam owner in the Tigris and Euphrates valley certainly understood the nature of his responsibility. In the area of off-site and downstream responsibility of water managers, the almost 4000 year old Code of Hammurabi is consistent in intent (although not penalties) with modern laws and legal decisions.

Collection - Transportation - Distribution Works

Wherever people have gathered into communities, the provision of water for drinking, bathing, irrigation, and other uses has required the construction of systems to collect, transport, and distribute water. Two of these, the qanat system used in arid areas and the Roman aqueduct systems are of particular interest.

The people of Armenia (now Iran, Turkey, and the Soviet Union) and Persia (now Iran), were among the first to use the ingenious and difficult to construct qanat systems. Qanats existed in Armenia at least as early as the seventh century B.C. They were used extensively in Persia and also later in Egypt, as far west as Spain, and as far east as India. Biswas (1970, pp. 26-29) provides an informative account of the form, function, and historic

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development of qanat systems.

A qanat is an excavated, gently sloping tunnel having an egg-shaped cross section and lined with rock if needed. The qanat intercepted ground water and conveyed it to populated areas to meet drinking water, irrigation, and other needs. The vertical or largest dimension of the tunnel cross section was about the height of the workers who excavated the tunnel.

Individual qanats had average lengths of about 40 kilometers (25 miles) with some thought to be over 160 kilometers (100 miles) long. Longitudinal slopes were in the one to three percent range and at some places the qanats were 400 feet below the ground surface.

Vertical shafts positioned every 20 to 140 meters (65 to 460 feet) along the entire length of the qanat supplied air to laborers who dug the tunnel in an upstream direction to permit continuous release of ground water that entered the tunnel. The vertical shafts also provided access for reflected light, which was used to guide the workers, and for removal of excavated material which was placed in goat-skin bags and lifted through the vertical shafts.

Why did the Armenians, Persians, and others develop the elaborate, underground qanat technology as opposed, for example to the seemingly simpler surface and near surface aqueduct used later by the Romans? Several factors apparently lead to the use of qanats.

First, qanats were used in hot and arid areas having limited surface water supplies, which would favor groundwater sources, and having high evaporation rates which would also favor sub-surface or at least covered conveyance works. Second, construction of aqueduct type systems would have required maintaining relatively uniform slopes in hilly country. Although the Romans met this challenge centuries later, they also had to develop the ability to construct massive bridges to convey the aqueducts across river valleys. Finally, the deep, sub-surface route of the qanats would tend to keep the water cool and relatively free of potential pollutants.

In summary, qanat systems were an ingenious solution to a challenging water supply problem--a solution tailored to a particular set of circumstances. Similarly, the Romans subsequently developed aqueduct systems to transport water

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in response to their physical and social environment.

Partly because of their extensive public baths, Roman cities required an essentially continuous, large flow of clean water. As the Roman city of Nemausus (now Nimes, in extreme southern France) grew to a population of about 50,000 during the last century B.C., an adequate water supply was required. As researched and described by Hauck (1989), Roman engineers decided to transport water by gravity from springs near the small town of Ucetia (now Uzes), France.

The entire aqueduct system is thought to have been designed by Marcus Agrippa, a friend of Caesar Augustus. Besides being an accomplished military officer, Marcus Agrippa was the chief designer of public works throughout the Roman Empire. He specialized in water supply systems.

Although the springs were located 20 kilometers (12 miles) to the north, the aqueduct which was designed and constructed by the Romans was 50 kilometers (31 miles) long. The much longer route was dictated by the need to maintain gravity flow, the inability to accommodate pressure flow, and the need to minimize crossings of valleys and other low areas.

Because the source spring was only 17 meters (56 feet) higher than the intended distribution point in the Nemausus, the aqueduct had an average slope of only 0.034 percent. The Romans were apparently able to construct the aqueduct within this severe constraint without causing flat or reverse sloped reaches where water stagnated.

Even though the chosen route avoided most obstacles, the aqueduct did have to cross the deep valley of the Gard River (a tributary to what is now called the Rhone River which flows into the Mediterranean Sea on the southern coast of France). This crossing was achieved by designing and constructing in about 19 B.C. the 16 story (49 meter or 160 foot) high, 275 meter (902 feet) long Pont du Gard (Bridge of the Gard). This beautiful, three-tired masonry structure still stands as do some other portions of the 2000 year old aqueduct system. The Pont du Gard is the tallest bridge ever constructed by the Romans.

The two large lower tiers of the bridge are composed of a series of masonry arches -- each 24.5 meters (80 feet) wide. The third tier consists of smaller arches supporting the concrete water channel which conveyed an

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average flow of about 350 liters per second (12 cubic feet per second or eight million gallons per day).

To minimize flow resistance, the channel along the entire length of the aqueduct was lined with a pinkish cement composed of lime, pork fat, and the latex-like milk of unripe figs and called maltha. In keeping with Roman custom, most of the channel was constructed just below the ground surface and covered. The typical channel section consisted of a concrete foundation, sidewalls of stone masonry built on the foundation and a semi-circular stone arch over the top. The structure was then back filled. Over the Pont du Gard, the channel was covered by stone plates. Aqueducts were covered to prevent the water from being warmed by the sun and to minimize the entry of dust, dirt, and other materials (Rouse and Ince, 1963, p. 26).

The aqueduct ended at the circular castellum (distribution reservoir). This 6 meter (20 foot) in diameter, 1.4 meters (4.6 feet) deep masonry structure served to distribute flow to lower areas in the city by gravity through ten 0.3 meter (1 foot) diameter pipes. The pressure conduits that distributed the water in Roman cities were usually constructed of lead and clay but sometimes bronze, copper and bored stone were used (Rouse and Ince, 1963, pp. 27-28).

The Uzes-to-Nimes aqueduct conveyed water for about four centuries. The Pont du Gard stands today as a testimony to the creativity and persistence of the Roman engineers.

A system of nine aqueducts, having a total length of 422 kilometers (262 miles) were built to supply water to Rome. Construction dates for these aqueducts, which drew on springs, rivers, and a lake, ranged from 312 B.C. to 52 A.D. The Roman aqueduct system was under the jurisdiction of Sextus Julius Frontinus (35 A.D., approximately, to 104 A.D.). After a military career, he was appointed to serve as commissioner of the Roman waterworks in about 97 A.D., when he was about 62 years old. Frontinus was obviously very proud of his water system as indicated by his statement (Biswas, 1970, p. 89, pp. 92-94):

> Will anybody compare the idle Pyramids, or those other useless though much renowned works of the Greeks, with these aqueducts, with these many indispensable structures?

The Manning Equation

The Chezy formula, experimentally developed about 1770 by the French engineer Antoine Chezy, is the basis for most formulas used for turbulent flow in open channels. Chow (1959, pp. 93-101) and Williams (1970) trace the approximately 120 year evolution of development in open channel flow analysis from the Chezy equation into the now widely-used Manning equation. Chezy verified the formula with measures on the Courpalet Canal and Seine River in late 1969. The Chezy formula is:

$$V = C(RS)^{1/2}$$

Where V = mean velocity with dimensions of length divided by time

C = a flow resistance factor called Chezy's C

R = hydraulic radius of the channel or conduit with dimensions of length

S = dimensionless slope of the hydraulic grade line

Although Antoine Chezy originally developed and verified the formula using experimental data for open channel flow, it may be mathematically derived for both open channel flow and pipe flow.

From the time of its introduction, the principal problem associated with practical application of the Chezy formula was determination of the Chezy flow resistance factor C. As a result, many investigators developed and reported on experimentally-derived formulas including one by Ganguillet and Kutter, two Swiss engineers, which was published in 1869. They expressed Chezy's C as a complicated (i.e., in pre-electronic calculator/computer times) function of S, $R^{1/2}$ and a coefficient of channel roughness called Kutter's n.

Another formula for C was that proposed in 1897 by the French engineer H. Bazin which expressed C as a function of only $R^{1/2}$ and Bazin's m, the latter being a coefficient of channel roughness. In 1867 P. G. Gauckler, a French engineer, proposed an experimentally-derived equation for open channel flow that was equivalent to expressing Chezy's C as being directly proportional to $R^{1/6}$.

Subsequently, many other investigators, including the

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Irish engineer Robert Manning in 1889, proposed the same dependence of Chezy's C on $R^{1/6}$. The proportionality constant was later determined to be 1/n, in metric units, or 1.49/n, in English units. The coefficient of channel roughness (i.e., n) has been incorrectly attributed to Manning, inasmuch as it is now referred to as Manning's n. Manning's n may be considered numerically identical to Kutter's n.

Thus, based on the work of several investiagators, Chezy's C is expressed as: $C = (1/n)\ R^{1/6}$ in metric units and $C = (1.49/n)\ R^{1/6}$ in English units. This expression, combined with the Chezy formula, yields the familiar open channel formula in, respectively, metric and English units: $V = (1/n)\ AR^{2/3}\ S^{1/2}$ and $V = (1.49/n)\ AR^{2/3}\ S^{1/2}$. This equation was misnamed the Manning Equation--misnamed in the sense that although Manning made a confirming contribution, he was not involved in a major way.

The Ganguillet and Kutter formula, the Bazin formula, and other available formulas were generally not as suitable for practical application as the Manning formula because they are either based on limited experimental data, as is the Bazin formula, or were cumbersome to use without computational aids, as is the Ganguillet-Kutter formula. The Manning formula produced results equal to or better than all other formulas and lent itself to rapid calculation, primarily because of its relatively simple form and the availability of a variety of nomographs and other computational aids prior to the development of electronic calculators and computers.

Because of this combination of accuracy and ease of use, the Manning formula is internationally the most widely used of all open channel flow formulas. It was recommended for international use in 1936 by the Third World Power Conference.

The Lloyd-Davies Formula or Rational Formula

During the period 1842 to 1847, Irish engineers made what is thought to be one of the first attempts to predict flood flows as a function of rainfall. According to Biswas (1970, pp. 301-305), who documents the Irish contributions, their motivation was the design of drainage channels having sufficient capacity to convey the peak discharge generated by the recorded maximum daily rainfall.

The Irish engineers assumed, in essentially correct fashion, that rainfall evaporated, infiltrated, or

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appeared as streamflow. Initially, they incorrectly assumed that evaporation and infiltration for a given watershed occurred at a constant rate throughout the year, that is, were independent of factors such as precipitation rates and duration and antecedent moisture conditions. Given their flawed hypothesis, they concluded that annual stream flow volume as a percent of annual rain flow volume could be applied to individual rainfalls, or more precisely, to daily rainfalls. Thus if annual streamflow was X percent of annual rainfall, then X percent of any given daily rainfall would appear as daily streamflow.

The desire to convert rainfall to runoff gave rise to the idea of a runoff factor or coefficient. The Irish engineers soon realized that the factor or coefficient for daily or other rainfall depended on more than the ratio of annual runoff to annual streamflow. More specifically, runoff was gradually seen to be influenced by factors such as watershed slope, soil characteristics, and vegetation.

By 1847, the following flood-flow computation formula was being used in Ireland:

$$Q = 2.52\ CIA$$

Where Q = peak discharge in cubic feet per minute

C = dimensionless runoff coefficient

I = maximum daily rainfall in inches (they used 1.5 to 2.0 inches)

A = tributary area in acres

Irish engineer Thomas J. Mulvaney (1822-1892), in his 1851 paper in the Proceedings of the Institute of Civil Engineers of Ireland, set forth the basic idea of what is now called the Lloyd-Davies method in some countries (e.g., Great Britain) and the rational method in others (e.g., the U.S.). Mulvaney's understanding of the rainfall-runoff process and his influence on the Lloyd-Davies/rational method is suggested by his statement about what is now called the time of concentration (Biswas, 1970, p. 303):

> The first matter of importance to be ascertained in the case of the small or mountain catchment, is the time which a flood requires to attain its maximum height, during the

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> continuance of a uniform rate of fall of rain. This may be assumed to be the time necessary for the rain which falls on the most remote portion of the catchment, to travel to the outlet, for it appears to me that the discharge must be greatest when the supply from every portion of the catchment arrives simultaneously at the point of discharge, supposing, as above promised, the rate of supply to continue constant, in this length of time being ascertained, we may assume that the discharge will be the greatest possible, under the circumstance of a fall of rain occurring, of the maximum uniform rate of fall for that time...so that, having ascertained the extent, form and average inclination of any catchment, we may be able to determine, in the first place, the duration of constant rain required to produce a maximum discharge, and consequently to fix upon the maximum rate of rainfall applicable to the case.

Mulvaney should probably be honored for his seminal work by having the method named after him. However, the method is called the Lloyd-Davies formula in Great Britain because D. E. Lloyd-Davies published the paper on the subject in the Proceedings of the Institution of Civil Engineers in 1906.

For the origin of the word "rational" in the rational method and for early field measurements on the urban rainfall-runoff process, one must go to the U.S. in the late 19th century. Emil Kuichling, City Engineer of Rochester, New York, carried out some important experiments in the course of his work (Kuichling, 1889; McPherson, 1969). Kuichling was concerned with commonly used methods based on rainfall periods of one hour or more. He hypothesized that shorter periods of more intense rainfall may cause larger flows and, accordingly, perhaps storm sewers were being undersized.

Therefore, Kuichling performed rainfall-runoff measurements on five sub-basins in Rochester, ranging in size from 10 to 145 hectares (25 to 357 acres). Based on his measurements, he concluded the following:

1) Runoff volume is proportional to imperviousness. This effect is accounted for in the Lloyd-Davies/rational method by the runoff coefficient.

2) Maximum discharge occurs when the rainfall lasts long enough for the entire tributary area to contribute flow. This is the basis for defining the time of concentration and is used to determine the average rainfall intensity in the Lloyd-Davies/rational method.

3) Peak discharge is proportional to rainfall intensity. This is the basis for including intensity in the Lloyd-Davies/rational method equation.

4) Antecedent moisture levels are likely to have a significant effect on peak flows. However, Kuichling was not able to provide a means of accounting for antecedent moisture conditions.

Kuichling published the results of his Rochester research to establish a basis for additional investigations that might be done by engineers. He states in his paper (Kuichling, 1889):

> ...and hence is obvious that a more rational method of sewer computation is urgently demanded...it is sincerely hoped that the efforts of the writer will be amply supplemented by many valuable suggestions and experiments each other member of the Society (American Society of Civil Engineers) may generously contribute.

Now known as the rational method in the U.S., apparently because of Kuichling's use of the word "rational", the technique developed by Kuichling is used extensively throughout the U.S. However, in spite of the request for additional investigations as stated in his 1889 paper, few studies have been conducted (e.g., Schaake et al., 1967) and the Lloyd-Davies/rational method has changed little since Kuichling introduced it into U.S. engineering practice a century ago.

The formula is:

$$Q = CIA$$

Where Q = peak discharge for the recurrence interval

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T in cubic feet per second

C = dimensionless runoff coefficient

I = average rainfall intensity during a period of time equal to the time of concentration for the selected recurrence interval in inches per hour

A = tributary area in acres

Although the Lloyd-Davies/rational method appears simple, it is apparently often misused. Consider, for example, the results of the survey of 32 U.S. communities (Ardis et al., 1969) in which the staffs were asked to apply the rational method. Only six of the communities used the method correctly, the most common errors being the following:

1) Failing to consider rainfall as being variable, that is, as being dependent on the time of concentration.

2) Calculating flows for individual sub-basins and simply summing them to get total flow for the watershed rather than determining a rainfall intensity and weighted runoff coefficient for each successive downstream point in the drainage system.

3) Failing to account for flow time in storm sewers in computing the time of concentration.

Another widely held misconception about the Lloyd-Davies/rational method is that the time of concentration corresponds to the duration of the storm. The time of concentration is simply the critical time period used to determine average rainfall intensity from intensity-direction-frequency curves. Inasmuch as rainfall is a random event, it is possible that a rainfall event could have a duration equal to the time of concentration of a sub-basin. However, it is much more likely that the total duration of a storm will be longer than the time of concentration used in the rational method. Furthermore, the critical duration of interest could occur anywhere within the storm. Misuse of the rational method in calculating peak discharges and volumes is discussed by Walesh (1989, pp. 100-111).

Darcy's Law

In 1716, the French formed a corps of civilian engineers (Corp des Ingenieurs des Ponts et Chaussees, that is,

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corps of engineers for bridges and streets). This civilian corps was formed to distinguish the public works responsibilities of these engineers from the responsibilities of the long standing corps of military engineers (Corps des Ingenieurs du Genie militaire).

The Ecole des Ponts et Chaussees was founded in 1747 to educate the young and growing core of what we would now call civil engineers. As a result, the word ingenieur, which traditionally meant craftsman-builder, now began to take on the meaning of a scientifically-educated professional (Florman, 1987, pp. 48-49).

Henry Philibert Gaspard Darcy (1803-1858) was a member of the French civil engineering corps. Born in Dijon, France, he returned there after his education in Paris and was given responsibility for designing and constructing the municipal water supply system. Because the completed system functioned so well, Darcy was later retained as a consultant on a similar project by the city of Brussels, Belgium.

To gain further insight into the behavior of sand filters, which were one component of the Dijon water supply system, Darcy conducted experiments on flow through porous media. Prior to his research, mechanical energy loss through a porous medium was thought to be proportional to the square root of velocity or the rate of flow. However, his experiments demonstrated that energy loss is proportional to velocity as stated in what is now called Darcy's Law:

$$v = k\ (dh/dl)$$

Where k = coefficient of permeability with dimensions of velocity

h = mechanical energy or total head per unit weight of liquid with dimensions of length

l = distance in the direction of flow with dimensions of length

Darcy published the results of his experiments and the equation he developed as part of his 1856 report (Les fontaines publiques de la ville de Dijon) on the Dijon water supply (Rouse and Ince, 1963, pp. 169-171).

Darcy appears to have been motivated to experiment with flow through porous media--which led to a fundamental discovery--in order to more conscientiously carry out his water filtration responsibilities in Dijon. His results met the needs of that project but also spawned additional significant analytic work in well hydraulics.

Using Darcy's work as a foundation, others developed formulas now commonly used in groundwater work. Examples are Dupuit's and Thiem's analytically-derived equations for axially symmetric, steady flow to well and Theis's methodology for axially symmetric, unsteady flow to a well.

Incidently, Darcy also conducted experiments, with the results published in 1857, on flow of water through conduits of various size and material. He demonstrated that resistance to flow depended, in part, on the type and condition of the inner walls of the conduit. His experiments also suggested that as conduit flow shifted from a laminar condition to a turbulent condition, energy loss changed from being directly proportional to velocity to being proportional to velocity squared. As a result of his work with pipe experiment, Darcy's name is attached, along with that of Julius Weisbach (1806-1871), to what is now known as Darcy-Weisbach pipeflow equation and methodology (Rouse and Ince, 1963, p. 161, pp. 170-171).

Computer Models

Digital computer modeling techniques developed within the water resources field during the last few decades. When used by experienced engineers, these models facilitate greatly improved watershed analysis and design. As stated anonymously:

> The computer is incredibly fast, accurate, and stupid. Man is unbelievably slow, inaccurate, and brilliant. The marriage of the two is a challenge and opportunity beyond imagination.

Computer models enable engineers to answer two fundamental questions typically addressed in all but the most trivial water resource projects. First, how does the existing system function, that is, what are the causes of the water-related problems? Second, how could the watershed system be modified or altered to mitigate existing problems and to prevent similar and new problems from occurring?

Most of the algorithms in watershed models are not new. For example, and as already noted, the basis for the Manning open channel flow equation goes back to at least

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1770. Rational method concepts, such as the time of concentration, and similar time parameters used in computer models can be traced at least as far back to the work of Thomas J. Mulvaney in the 1850's. Unit hydrograph theory, which is used in many watershed computer models, was well established as early as 1932 (Sherman, 1932). Therefore, the algorithms used within computer models, and more specifically, the theories and techniques on which they are based, are generally not new. Their origins can typically be traced back decades and even centuries.

The most important feature of the development of watershed digital computer models is that they provided the ability to link the algorithms representing many hydrologic-hydraulic-water quality processes and to make the necessary voluminous computations at a reasonable cost. The practical application of hydrologic and hydraulic knowledge was not fully realized until the development of the digital computer and digital computer models.

One way to classify computer models is event versus continuous. The principal distinction between event and continuous models is the type and amount of meteorologic data used as input and the manner in which the data are processed within the computer program. Event models typically require as input one or a few design storms in the form of a synthetic hyetograph or one or a few historic storm hyetographs. These few hyetographs are entered into the model and output consists of an equal number of hydrographs. If a recurrence interval is attached to an input hyetograph, the usual assumption is that the resulting output hydrograph has the same recurrence interval.

A fundamentally different approach is used with continuous models, as exemplified by the Stanford Watershed model (Crawford and Linsley, 1966), which was apparently the first continuous hydrologic-hydraulic model. The entire meteorologic record, usually consisting of decades of available precipitation, temperature, and other similar data, is used as input. The computer processes all the continuous meteorologic input and produces, as output, a continuous hydrograph. The usual procedure is to statistically analyze the continuous output in the same fashion as one would statistically analyze a long stream-flow record.

Next to the creation of computer models, the subsequent development of continuous simulation was probably the most significant technologic development within modeling. Although the first continuous simulation model was developed in the U.S. by Crawford and Linsley, who were seeking an improved way to more fully incorporate all aspects of the hydrologic cycle, they were influenced by the contributions of the Japanese researcher Sugawara (Crawford, 1989; Sugawara, 1961). Working at the University of Kyoto, he published a paper in 1961 describing the use of idealized storage structures -- conceptualized as containers of various sizes, shapes and configurations -- that he defined and combined to build rainfall-runoff models. Using manual calculations, Sugawara operated the idealized storages on a continuous basis. The computation method was not very sophisticated. However, Sugawara's approach was new in that it included a continuous accounting of various components of the hydrologic cycle -- many factore influencing the overall rainfall - runoff process were included.

Crawford and Linsley were influenced by the work of Sugawara and used some of his concepts in combination with digital computation to produce the Stanford Watershed model in 1966. Other continuous simulation models or models that could be used in a continuous simulation mode were subsequently developed in the U.S. including STORM (Storage, Treatment, Overflow, Runoff Model), HSPF (Hydrocomp or Hydrologic Simulation Program - Fortran), and SWMM (Storm Water Management Model) (Bedient and Huber, 1988), which were developed in the U.S., and a model developed by Dorsch Consult in Germany. The Dorsch model, which was completed in 1972, was developed independent of the Stanford Watershed model (Geiger, 1989).

The principal advantage of the important development of continuous simulation is that it eliminates the design storm dilemma. Instead, continuous simulation produces a result similar to a long-term streamflow record on which a variety of useful statistical analyses may be performed.

Because continuous simulation is such a recent development in the overall chronological history of hydrology and hydraulics, its relative significance is difficult to determine. However, with the passage of time, the development of continuous simulation will probably be increasingly viewed as a very significant milestone in the water resources field.

Concluding Observations

The roots of the science and technology used today in the water resource field encircle the globe and reach back to the beginnings of recorded history. Contributions to water resource engineering science and technology have emerged from all parts of the world. Wherever people have gathered to form a community there has been concern with very basic water-related needs such as providing drinking water, disposing of wastewater, irrigating crops, and mitigating flooding. Paralleling this pragmatic concern, there apparently has been widespread curiosity about water -- rainfall, streamflow, springs, and evaporation. Need and curiosity have been strong motivators in the water resources field.

Many of the scientific discoveries and technologic developments in the water resources field have not been motivated so much by simple desire to better understand the physical world, but rather by a need to "get the job done." Recall, for example, Armenian and Persian developments of qanat systems centuries before Christ to collect and transport water in arid climates; Sedileau's 17th century precipitation and evaporation experiments in support of his assignment to supply water for fountains at Versailles; Kuichling's 19th century rainfall-runoff studies to facilitate improved storm sewer design in Rochester, New York; and Darcy's 19th century porous media and pipe flow experiments which enabled him to design the water supply system for Dijon, France. In their desire to create effective water facilities and systems, engineers from all over the world have contributed much to water resources science and technology.

Acknowledgements

Two books, one by Biswas (1970) and one by Rouse and Ince (1963), were major sources of material used in this paper. The water resources community owes much to these authors for their research and writing. Besides providing enlightenment, perhaps their works will inspire ongoing research into the origins of the water resources science and technology, particularly by non-western nations and cultures.

The engineering profession needs an enlarged understanding of its global roots. By so doing, the profession gives credit where credit is due. Furthermore, knowledge of roots helps in understanding how "small" the world is.

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STORMWATER QUALITY INSTITUTIONAL CONSIDERATIONS

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ABSTRACT

This paper explores stormwater quality institutional issues and uncertainties in two ways:

1. Characteristics of the four different parties (legislators, regulators, consultants and project proponents) typically involved with the resolution of water quality issues are presented. Understanding the motivating factors behind each of these parties is essential if constructive, cost-effective mitigation strategies are to evolve.

2. For a variety of public and private clients, an eight step evaluation/mitigation strategy has proven effective, assuming that study goals, objectives, principles, and policies are clearly articulated and agreed upon. Despite the effectiveness of the procedure however, important aspects of each of the eight steps will be viewed differently by each of the four parties associated with the process.

The paper concludes with the assertion that our technical capability to mitigate the urban runoff quality problem exceeds our understanding of the problem and current institutional policies that regulate problem responses.

INTRODUCTION

Urban stormwater quality management is presently dominated by institutional considerations. True, a fortune is being poured into assessing impacts on receiving waters; evaluating the effectiveness of artificial wetlands at immobilizing pollutants; establishing the extent to which infiltration practices will contaminate groundwater and other such technical questions; but at the "grass roots" level, institutional questions are the paramount concern.

The four interest groups that interact on this subject are: (1) legislators/politicians, (2) regulators, (3) consultants, and (4) "users" or project advocates (generally private developers). Typical questions that each of these parties asks are as follows.

[1] Member, ASCE; Vice President, Wright Water Engineers, Inc., Denver, Colorado, USA.
[2] Fellow, ASCE; Senior Advisor, Wright Water Engineers, Inc., Denver, Colorado, USA.

Legislators/Politicians

- Is my constituency (the electorate) sincerely interested in controlling pollution from stormwater runoff?
- How much mileage can my political action group get out of attacking some aspect of the stormwater quality management framework?
- Should we have a runoff quality ordinance?

Regulators

- How am I going to regulate urban nonpoint source polluters when I don't even have the budget or staff to regulate point sources?
- From a practical standpoint, how will the U.S. Environmental Protection Agency's (US EPA) NPDES regulations for stormwater discharges affect our regulatory policies?
- How am I going to be able to hold a land developer's feet to the fire to induce him to implement reasonable runoff quality mitigation measures when I don't have the legal authority to do so and when I am not even convinced that the measures will tangibly improve water quality?

Engineering Consultant

- My client has asked me to develop a runoff quality strategy for his proposed development; what am I going to tell him?
- Why can't regulators provide me with good guidance and direction on this subject since they normally have so many specific requirements on water quality issues?
- Where is the reference or manual that tells me how I can solve my client's problem in ten steps and where do I purchase the associated software?

Project Advocates (Usually, Land Developers)

- Tell me, again, how these pollutants that you say are in urban runoff hurt anything or anyone.
- Why can't you tell me, as my consultant, more specifically what I need to do? And why can't you tell me, as the designated regulatory reviewer, what performance standard I need to meet and why I should be expected to accommodate to a rapidly evolving regulatory basis?
- What is the benefit to me? Why must the expense be mine? Is there any way to reduce the cost?

Notwithstanding the fact that there is undeniably linkage between technical and nontechnical considerations in urban stormwater management, the answers to these questions will not come from the technical arena. Yet the importance of these questions is striking. Consequently, we must begin to devote at least as much attention to the institutional elements of the

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water quality equation as to the technical elements. The question of how an overworked state health department staff member with no budget and no supporting staff and a lifetime of experience with trickling filter design is suddenly going to properly evaluate stormwater management plans for a 500-acre commercial/residential development is just as important as is the question of how complex mixtures typically found in urban runoff affect benthic organisms.

THE FOUR GROUPS INVOLVED WITH THE DECISIONMAKING PROCESS

Institutional problems tend to be "people" problems, problems with differing viewpoints among the various parties involved in the resolution of water quality issues. Consistency among intents of parties involved is elusive. Four principal interest groups are involved routinely in water quality decisionmaking and the scatter among their viewpoints is significant. These interest groups are termed: (1) legislative; (2) regulatory; (4) consulting professionals; and (4) users (developers, clients). Within each group, there are disparate viewpoints, described as follows:

Legislative - This group includes persons with authority to enact statutes and ordinances. They are swayed by various value judgments regarding public and private responsibilities and the significance and reliability of environmental projections. They may be strongly influenced by their constituencies' viewpoints. They may be pro- or anti-development. Most importantly, they often as individuals hold differing views about the intent of enacted statutes and ordinances. Unfortunately, without a clear understanding of legislative intent, regulations and design standards are difficult to formulate.

Regulatory - This group has responsibility for evolving, implementing, applying, interpreting and enforcing statutes and ordinances, which are usually rephrased as regulations in greater detail than the statutes or ordinances themselves. The group includes: (1) zealots, who tend to reflect extreme pro- or anti-development viewpoints; (2) ambitious public employees, who would avoid controversy and generally tend to reflect expediently the viewpoints of their political leadership; (3) objective, practical professionals with centrist viewpoints who seek the most practical technically and economically correct problem solutions and in doing so may alienate those with extreme viewpoints; (4) "enforcers," those who indiscriminately implement the letter of regulations as a matter of worship without regard for specific situation variables; and (5) those who do as they may be instructed without apparent concern, conviction, perception, initiative, eagerness or reluctance. Thus, regulatory policies tend to reflect the personal viewpoints of the persons in charge of the regulatory process.

Consulting Professionals - As individuals they may range in competency from highly developed to incapable. They may have the same individual viewpoints as may regulators, and sometimes appear to lack keen perception of the public interests they are licensed to protect. Some consultants subordinate their own views and respond in accordance with the directions of regulators, to avoid confrontations, delayed acceptance of their client's projects, and the risk of alienating regulators with whom they must interface regularly. Other consultants are easily manipulated by their clients and will doggedly combat regulators if they believe that this will impress their clients. Many consultants are distinctly uneasy without explicit guidance and criteria standards. A final complicating factor is that there

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continues to be little interaction among the very disciplines that should work together to maximize benefits, including planners, landscape architects, lawyers, economists, environmental scientists and engineers.

Users - These also should be thought of as individuals rather than institutions. Some are motivated economically and will do only what they are forced to do by regulators. Some perceive good environmental relationships as good business and strive to do what seems best for the public interest, but their perceptions of the latter may vary. They generally seek project approval "yesterday" and will often agree to comply with excessive regulatory demands to avoid project delay. Their consulting professionals often are instructed to do whatever may be necessary to avoid project delays. They may work "behind the scene" to influence project acceptance outcomes.

These are the primary "people variables" which shape and otherwise influence institutional water quality decisionmaking. They explain the diversity or lack of consistency among water quality policies of the many involved institutions. Any of the participants also may jealously seek to preserve authority for unilateral decisionmaking, often causing multijurisdictional decisionmaking or agreement to be impossible or inconsequential.

Interestingly, one technically strong, articulate person in any phase of the procedural hierarchy can have great influence upon institutional policy outcomes. Conversely, one indecisive, technically deficient, inarticulate person in a key decisionmaking position can pose inordinate difficulties for all parties.

The role of the regulatory administrator is viewed as the primary key to the nature of institutional processes. The administrator may have little or no technical ability but he has authority to interpret the intent of statutes or ordinances. These interpretations require rationales that may involve many non-technical considerations, and may be syllogistic rather than logical. With such interpretations, the character of the regulatory process can be distorted to contrast with the intent of the enabling legislation. Consequently, replacing a regulatory administrator may be the quickest and most effective way to influence the functioning of a regulatory institution.

RUNOFF QUALITY EVALUATION/MITIGATION STRATEGY

The authors have found the following runoff quality evaluation/mitigation strategy to be effective, provided that study goals, objectives, policies and principles are clearly articulated and agreed upon:

1. Define pollutant sources,
2. Estimate probable pollutant concentrations based on technical and non-technical factors,
3. Evaluate -- at least qualitatively -- impacts on receiving waters,
4. Establish applicable regulatory requirements and have them confirmed in writing,
5. Examine an array of mitigation measures and select a preferred alternative,
6. Interface water quality management schemes with traditional drainage considerations,
7. Pay special attention to institutional issues such as financing, public safety, maintenance, appearance, etc.

8. Objectively judge the preferred management strategy in the context of goals, objectives; policies and principles defined at the outset of the project.

The four interest groups described above will view each of these eight steps differently and may have widely divergent opinions on the following important kinds of questions:

<u>Define Pollutant Sources</u>

- What "sources" will need to be evaluated for the proposed project?
- Will it be feasible to eliminate certain categories of sources due to land use and/or development requirements? For example, if a privately maintained resort is willing to commit to no use of road salt, should road salt be considered a potential source?
- At what degree of risk do potential sources become consequential?
- How are the source characteristics likely to change over time? This is particularly important in the context of urban runoff because the runoff quantity/quality aspects of a basin vary dramatically as it transitions from undeveloped to active development to early building to maturity.
- What is the behavior/process whereby pollutants may enter or not enter receiving waters through runoff?
- Is pollutant entry into the water environment a function of the rate of runoff, amount of runoff, or time of runoff?
- Is it most appropriate for individual pollutants or classes of pollutants to be regulated by public agencies for the subject setting?

<u>Estimate Probable Pollutant Concentrations</u>

- In the environment or in runoff?
- At what time during runoff; that is, initial runoff, peak runoff, or after discharge into receiving waters?
- Given statistical summaries of the US EPA national urban runoff program (NURP) data, do the unique characteristics of the study area in question argue for projected pollutant concentrations that are low, high or average, and why?
- To what extent do site specific data need to be collected? Phrased in another way, how reliably can data be extrapolated to the specific setting?
- What are the natural "background" levels of pollutants?
- Are "illicit discharges" likely to be a problem?
- What is the pollutant's minimum detection level? What is the practical detection level? If the practical detection level is subject to a 40 percent error under the best of laboratory conditions, what is the significance for regulatory standards?

<u>Evaluate Impacts on Receiving Waters</u>

- Are existing water quality classifications and standards reasonable for the receiving stream? If the receiving stream has not yet been classified, what discharge standards are appropriate?
- Are anticipated impacts actual or hypothetical?
- For the specific setting, can impacts be categorized as: (1) very likely to occur, regardless of site specific considerations, (2) likely to occur given a certain set of site specific conditions,

or (3) nearly impossible to project with any accuracy given our basic lack of understanding of impacts on receiving waters?

- Because the regulating entity will almost certainly have only chronic and acute stream standards, in what context can these standards be utilized? Might other standards be more appropriate?
- Is an occasional "spike" really harmful or will it rapidly disperse without significant lingering affects?
- Do the target pollutants pass through or are they concentrated by each of the various biologic systems?
- One of the great unknowns regarding receiving water impacts is the role that "complex mixtures" play. Is it at all feasible for the subject setting to project the mixture of contaminants likely to be found in the runoff along with the associated implications of such a mixture?

Establish Regulatory Requirements in Writing

- Is the regulator prepared to commit to specific requirements in writing? If not, what will be required to obtain such a commitment?
- Will the regulatory strategy be: (1) technology-based, (2) best management practice-based, (3) receiving stream standard-based, or (4) hydrology-based? What are the implications of each of these regulatory schemes in the context of the US EPA's forthcoming NPDES regulations for stormwater discharges?
- If the regulatory review process requires the consultant to make one conservative assumption after another (such that caution is heaped upon caution), what is the probability of the scenario that is developed? Is this a proper regulatory approach? Is it prudent? Is it equitable?
- Should correction of a problem be the sole responsibility of a project proponent or should the community have concurrent responsibility to manage the introduction of pollutants to minimize the problem? Such as by prohibiting use of certain compounds?
- What actual risks, in terms of probability, are involved with each pollutant? How do such risks compare with other common risks in the human environment? Isn't it incongruous to focus upon elimination of very low risks while routinely accepting much greater risks in our daily lives? Shouldn't we be considering definitions of "acceptable risk" in terms of probable consequences?
- What is a reasonable consensus among regulatory fears, political concerns, arbitrary standards, prudence, potential liability, public health and safety, technical facts, economic soundness and proponents interests? How can unbiased objectivity be achieved?

Examine Mitigation Alternatives and Select Preferred Alternative

- Is the underlying basis (need) for the mitigation measures rational and demonstrable or poorly substantiated? In our view, there should be considerably more latitude in the design process if the underlying need cannot be clearly demonstrated.
- What measures are potentially applicable for the subject setting?
- What are the full array of consequences -- both quantifiable and non-quantifiable -- of a given measure or combination of measures?
- How do various alternatives fare in the context of such considerations as: appearance; safety; maintainability; replacement frequency; groundwater recharge; water rights and other factors?

- How reasonably can design specifications and observed performance be extrapolated from one setting to another? Do pollutant removal efficiencies from an artificial wetland in a hot, humid environment portend removal rates in a cold, high mountain setting?
- What are the comparative risks of the different mitigation strategies being evaluated? Who decides how large these risks can be?
- What constitute significant and insignificant constraints in the subject setting?

Interface Water Quality Management Schemes with Traditional Drainage Considerations

- Are proposed water quality mitigation strategies consistent with existing or proposed drainage and flood control facilities? How can the technologies best be "married"?
- Is one group of regulators involved with drainage and flood control issues while another group is responsible for water quality enhancement? How can the land developer and his consultant best resolve conflicting regulatory desires and requirements?
- Do existing drainage policies focus on getting rid of the water at all costs, or do they look broadly at each of the interfaces between water and all urban activities and interests?
- Do existing drainage policies need reevaluation and modification? Who is to judge? How to influence such change and gain its acceptance?
- Can multiple political subdivisions agree upon and implement a coordinated regional plan and design standards? What value have design standards if there is no coordinated regional drainage master plan?
- Is there a sufficient information/data base available to project comparative benefits and costs of quantity mitigation versus quality mitigation? If, for example, it is clear that flood hazard reduction is far more economically justifiable than water quality enhancement, where does this leave water quality enhancement?

Focus Special Attention on "Institutional" Issues

- Can water quality management be assuredly funded through some mechanism, such as a utility district or other permanent means?
- Can existing inapplicable and burdensome laws or regulations be modified?
- How much special attention should be focused upon: financing; design reviews; multiple interest consensus; performance evaluation; public health and public safety; compliance with drainage master plan objectives; maintenance needs and assurance; public recreation; property value protection and enhancement; short-term versus long-term objectives implementation and comparative benefits of alternative actions?

Judge the Preferred Management Strategy Objectively

- Objectively as viewed by whom?
  - The cautious public servant who feels he must protect himself by being conservative?
  - The more highly placed public servant who is sensitive to the desires of influentials?
  - The public counsel who strives for low liability solutions?

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- The consultant who is constantly cognizant of the need to exhibit "standard engineering practice" to reduce liability (this is frequently a real hindrance to innovation)?
- The project proponent who will ultimately pay for the strategy?
- Special interest social (sometimes environmental) groups who may thoughtfully evaluate the available alternatives, but who also may use the proposed project as a smoke screen to further their objectives?

o What criteria should be used to evaluate alternative water quality mitigation strategies?

o How reasonably can dollar benefits be assigned to water quality enhancement of urban streams -- many of which will never be capable of supporting desirable aquatic life forms?

CONCLUSION

A compelling argument can be made that we know more about the technical aspects of urban stormwater management than we do the institutional considerations. Hundreds of millions of dollars have been spent to: (1) collect and analyze urban runoff quality data, (2) assess impacts to receiving streams (although admittedly, much work still needs to be done in this area) and (3) design, install, maintain and monitor mitigation measures. By contrast, relatively little attention to date has been focused upon the legal, social, economic and other institutional factors that have been proven time and time again to be the determining factors in whether or not a stormwater management system will be success or a failure. The probable role that the "people factors" described herein will play in stormwater quality management decisions cries out for greater recognition.

Although many of the institutional questions raised within this paper will only be answered with time, the various parties involved with the stormwater quality decisionmaking process can at least thoughtfully evaluate: (1) perspectives, attitudes and methods of operation commonly associated with legislators, regulators, consultants and project proponents and (2) important provocative and oftentimes unanswerable questions that will be raised during the eight step problem evaluation/mitigation design procedure (or some variation thereof) described herein.

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UK URBAN STORMWATER CONTROL - INSTITUTIONAL ISSUES

by David Fiddes[1]

Introduction

Increasingly within the UK sewerage field attention is being focused on performance deficiencies of existing networks and the development of cost effective methodologies for achieving targeted levels of service. The emphasis initially was on structural problems but this broadened to cover flooding and is now embracing also the environmental impact of discharges to receiving waters. This logical progression has allowed much progress to be made but many problems have still to be resolved. Some of these are due to deficiencies in understanding of the underlying processes, others because of deficiencies in available technology. Both are being tackled by research and development, but major impediments to progress are provided by institutional difficulties. The paper concentrates on these institutional issues with the author expressing some highly personal views in the hope of stimulating debate.

Historical background

The UK has probably the oldest and most complete sewerage system in the world. The earliest sewers were built primarily for surface water drainage. Combined sewer building had a great impetus from the death by cholera in 1848 of 53,000 people. The early sewers protected wells and the areas immediately adjacent to the houses but many urban rivers became little better than open sewers. Interceptor sewers and treatment works were installed later in the century. These 19th Century sewers form the backbone of our present system.

As early as the Royal Commission Report of 1865, the benefit of having a single authority responsible for complete drainage systems was recognised but this did not come about for over a century. In 1973 responsibility for the complete water cycle was vested in 10 regional water authorities for England and Wales instead of the previous 1,600 local authorities. This happy situation provided the right climate for very solid advances in sewerage rehabilitation planning during the late 1970s and early 1980s. Unfortunately there has not been the same rationalisation of the wider

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planning area and conflicts and impediments to integrated planning are all too frequent as will be discussed later. This frequently results in having to settle for sub-optimal solutions.

Current problems

In the past it was difficult to measure the performance of the sewerage system as it was largely out of sight and out of mind. For several years a national register of sewer collapses was kept but the figures were found to be extremely uncertain and difficult to interpret. Flooding statistics are even more suspect as all surveys have shown that under-reporting is endemic. The reporting of defective storm overflows is also thought to be very much under-estimated. However, on the basis of the best available data, the author made an estimate some years ago of the likely required future expenditure on rehabilitation. This is given in Table 1.

Table 1 - UK sewer future funding - known problems (Fiddes 1986)

PROBLEM	COST (£ million)
Structural backlog	1,000
Short life sewers	1,500
Existing flooding	2,000
Failing overflows	1,500
TOTAL	6,000

These figures justify the high priority put on sewerage rehabilitation activity in the UK.

The performance of the receiving waters is more easy to assess, albeit against some rather arbitrary standards.

Water quality surveys are done at 5 yearly intervals, Table 2 showing the latest results. River and estuary reaches are put into one of four classes - good, fair, poor and bad. From the table it will be seen that 10% of river reaches in England and Wales are in the poor or bad classes. That is, they are not good enough to support reasonably good fisheries or to be economically treatable for drinking water supply. Using a similar classification, 8% of estuary reaches are of poor or bad quality.

Table 2 - Summarised results of 1985 river quality survey (DoE 1986)

WATER AUTHORITY	CLASSIFICATION OF RIVER REACHES			CLASSIFICATION OF ESTUARY REACHES		
	GOOD/ FAIR (%)	POOR/ BAD (%)	TOTAL (km)	GOOD/ FAIR (%)	POOR/ BAD (%)	TOTAL (km)
Anglian	91	9	4328	98	2	547
Northumbrian	97	3	2784	70	30	135
North West	78	22	5323	72	28	451
Severn-Trent	87	14	5150	100	0	61
Southern	97	3	1992	97	3	380
South West	94	6	2941	100	0	355
Thames	93	7	3546	100	0	138
Welsh	94	6	4600	98	2	44
Wessex	95	7	2467	97	3	145
Yorkshire	88	12	5767	74	26	70
England and Wales	90	10	38,896	92	8	2730

Not all rivers, of course, would be expected to support viable fisheries. In 1978 the European Community required all member states to designate waters suitable for fisheries so that a report for the whole community could be produced. The UK's response of over 50,000km, of which 97% were already complying, was far ahead of any other member state.

This relatively good position with respect to other European states is confirmed in Table 3 where results from a number of countries are compared on the same basis. It will be noted in the bottom line that over one quarter of all community river reaches are of poor quality or are grossly polluted.

Table 3 - River quality in Europe

	PERCENTAGE OF RIVER LENGTHS IN UK QUALITY CLASSES			
	UNPOL-LUTED	SATIS-FACTORY	POOR	GROSSLY POLLUTED
UK: England and Wales	67	24	9	2
Scotland	95	4	0.5	0.5
Northern Ireland	84	11	5	0
Belgium	56	17	16	11
West Germany	45	40	14	1
Luxembourg	72	13	11	4
Netherlands	77	18	4	1
EC Overall	39	35	22	5

The UK results give no grounds for being complacent.

In 1985, for the first time since these surveys were undertaken, more river reaches deteriorated than improved. This is thought to be due to non-point pollution but has also been accepted as justification for the need for more money to upgrade sewage treatment works. At present some 22% of major works are failing their discharge consent standards and the Government has agreed to an extra £700 million to ensure compliance within 4 years.

There are a number of further areas of concern. The first is very relevant to this conference - pollutant loadings from storm overflows and surface water outfalls in urban areas. A major research programme, the subject of another paper to this conference (Crabtree and Clifforde 1989), is under way in the UK to collect the data and develop the understanding to be able to set relevant standards and design effective control schemes.

As will be seen in Table 4, there has been a steady increase in pollution incidents over the last few years. These are cases where pollution of rivers has been

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reported to the Water Authority and, on investigation, the report was proved.

Table 4 - Water pollution incidents (England and Wales) (WAA 1987)

YEAR	TOTAL INCIDENTS
1980/1981	12,500
1981/1982	12,500
1982/1983	12,300
1983/1984	15,250
1984/1985	18,648
1985/1986	19,892
1986/1987	21,095

The majority of these are industrial spills, washoff from mining areas or failures of the urban drainage system, but a disturbing number are a growing area of concern - agricultural incidents. These are generally failures of the farm internal drainage systems allowing silage liquors or cattle slurry to wash directly, untreated, into a river. Such runoff is far stronger than urban runoff or storm sewage so that when it happens, fish kills are almost inevitable. A recent survey shows that about half of all cattle farms are at risk.

One of the biggest concerns is the quality of bathing waters. The waters around the UK are relatively cold so sea bathing is not as common as, for example, in the Mediterranean. There are, however, 400 Eurobeaches which are required to comply with the Bathing Water Directive. At present only about two-thirds do, but the success rate is steadily improving. The principal remedial measure being adopted is to upgrade the coastal sewers and install long sea outfalls designed with the benefit of comprehensive computer flow and water quality models of the sewer system and coastal waters. All beaches will comply by 1995, but the cost of the outfalls will be £800 million with quite a lot more for the associated sewerage.

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Table 5 - Bathing water quality 1987 (WAA 1988)
(Compliance with Directive; Coliform Standards)

AUTHORITY	NUMBER OF BEACHES	
	PASS	FAIL
Anglian	18	10
Northumbrian	9	10
North West	10	20
Southern	38	27
South West	96	13
Thames	0	2
Welsh	28	19
Wessex	32	6
Yorkshire	20	2
TOTAL	251	109

UK approach to sewerage rehabilitation

When the Water Authorities were formed in the early 1970s it was possible for the first time to take stock of the inherited problems. The situation regarding sewers looked pretty bleak (NWC/DoE 1977), but following an extensive research effort by the Industry a cost effective strategy emerged which was set out in the Sewerage Rehabilitation Manual (WAA/WRc 1984). The approach advocated was to retain, where practicable, the existing pipework by optimising network performance and hence avoiding wholesale sewer replacement. Detailed investigations would be confined to the core of the system where the consequences of structural failure were most expensive and where the major flooding problems were concentrated. The strategy for the remainder - the bulk of the system - could safely remain one of reaction to failure as in the past. The planning procedure is set out as a flow diagram in Figure 1.

The Manual also brought together advice on the tools and techniques that had been evolving in parallel to the development of the strategic thinking and which formed the building blocks for the implementation of the planning procedures. These included:

- undertaking structural inspections using CCTV (for the smaller sewer systems);
- systematic recording of defects using the Manual of Sewer Condition Classification (WWC/DoE 1980);
- guidance on application of available renovation techniques and lining design to preserve, for the foreseeable future, the structural integrity of unsound sewer lengths;
- building and verifying network analysis models of sewer systems using the Wallingford Procedure simulation program WASSP-SIM and flow surveys;
- optimal use of flow reduction and attenuation techniques to eliminate unacceptable levels of surface and property flooding and discharge of storm sewage to receiving streams;
- integration of all of the above techniques to produce plans for short and medium term implementation of the optimal, cost effective upgrading works.

The approach adopted is to undertake studies of complete sewerage systems (Drainage Area Studies) and to consider concurrently the three aspects of performance: sewer collapse, flooding and environmental impact of discharges. The selection of rehabilitation options is illustrated diagramatically in Figure 2. It should be noted that sewer separation is not considered a viable option and that, because of their high cost, the traditional solutions of replacement and reinforcement are only retained as the final options to be considered when all else fails. This ranking may change in the near future when pipe bursting and other trenchless pipelaying techniques become established.

PERFORMANCE ASPECTS		STRUCTURAL INTEGRITY	SURFACE & PROPERTY FLOODING	POLLUTION OF RECEIVING WATERS
FAILURE DIAGNOSIS		CRITICAL SEWER SURVEY	WASSP-SIM ANALYSIS WITH DESIGN AND TIME SERIES STORMS	
UPGRADING OPTION MATRIX	ASPECT	DEFECTIVE SEWER LENGTHS	FLOOD PRONE AREAS	UNACCEPTABLE STORM SEWAGE OVERFLOWS
OPTION (in order of consideraton)				
FLOW ATTENUATION (M)		x	xxx	xx
REPAIR (L)		xxx	-	-
RENOVATION (M)		xxx	x	x
OVERFLOW RATIONALISATION (L)		-	xx	xxx
FLOW REDUCTION (M)		x	xx	xx
MAINTENANCE (L)		-	x	x
REINFORCEMENT (H)		-	xxx	xx
REPLACEMENT (H)		xxx	xxx	xxx

NOTES: (1) Engineering relevance of option indicated by crosses (xxx = high, x = low).
(2) Relative cost of options indicated by (H) = high, (M) = medium and (L) = low.

Figure 2 - The integrated approach to sewerage rehabilitation (Clegg et al 1989)

Drainage Area Studies are being systematically undertaken by the UK water utilities with two Authorities, North West Water and Severn-Trent Water, having made the greatest progress. By early 1988 each had completed studies for about one-sixth of their drainage areas and reported the results as shown in Table 6.

Table 6 - Comparison of Drainage Area Studies (Clegg et al 1989)

	SEVERN-TRENT WATER	NORTH WEST WATER
Number of study areas	200	91
Population served	8 million	6.9 million
Number of completed and fully reported studies	32	17
Identified required investment	£67 million	£327 million
Estimated overall need	£400 million	£1,320 million
Investigation costs	£2 million/annum	£5 million/annum

The two studies support the following general conclusions:

(1) Investment need varies enormously between study areas and cannot be assessed accurately without a detailed study and good records.

(2) Investment is rarely for a single reason.

(3) System problems can be split into structural, flooding and pollution aspects but solutions are essentially inter-related and any split here is arbitrary, subjective and likely to be misleading.

(4) The Drainage Area Studies identified significantly more problems than had been anticipated. This has the effect of depressing level of service estimates.

Requirement for total catchment planning

The intensive investigation activity related to sewerage networks is providing for the first time the opportunity to undertake comprehensive studies of the impact of drainage discharge on receiving waters. This allows discharge consents to be expressed in terms of permissible pollutant level related to "fitness for use" standards for the receiving water body and the levels of dilution and dispersion of the discharge plumes. The

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sewerage authority is then free to consider all of the options open to upgrade the performance of the network and so optimise the capital works involved, minimising the cost without putting the water quality objectives at risk.

The principal drawbacks are greater monitoring and investigative costs and the need for a comprehensive modelling capability within the receiving water networks. If the potential benefits are to be realised, a complementary set of procedures to those for sewerage Drainage Area Studies need to be developed. Such an approach is set out in Figure 3.

Four phases are involved. In the first phase, the region is divided up into catchments and the Uses defined for the individual river reaches and other water bodies. Appropriate standards are defined for these Uses and the current performance monitored against these standards to identify where adequate performance is not being achieved.

In the second phase, flow and water quality computer models are built for the urban drainage, river and marine systems. The urban drainage system will discharge pollutant loads into the river. These will be both continuous, from treatment works, and intermittent discharges of storm sewage. The river model is used to check on the impact of the urban drainage and agricultural discharges and to quantify the pollutant loads passing out to sea. The marine model can then be used to check on the impact for marine Uses (such as bathing and shellfisheries) of the river flows and direct sewage discharges from long sea outfalls, storm overflows and surface water outfalls.

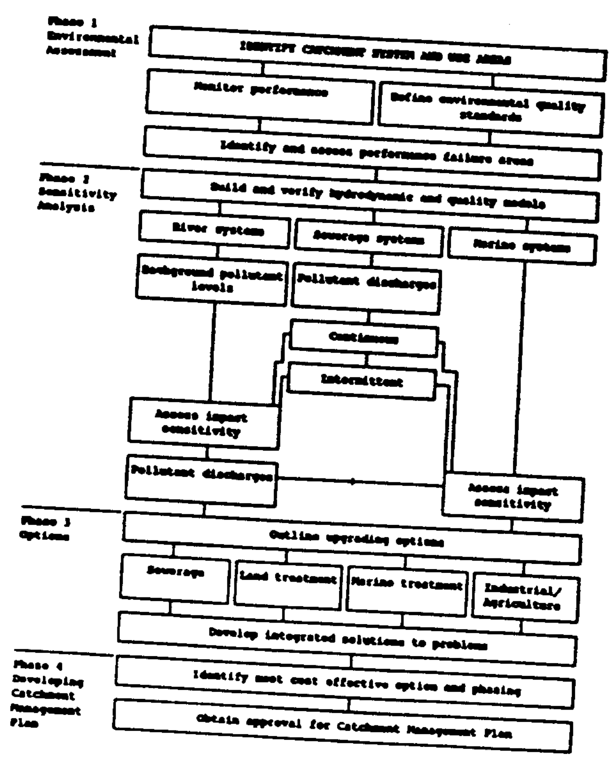
In the third phase, the various options that are open to solve the problems identified can be tested, again using the computer models. These include:

- o improving the sewerage network;
- o upgrading the treatment works;
- o building new long sea outfalls; or
- o requiring on-site pre-treatment by industrialists and farmers.

The important point to note is that we are looking for integrated solutions that will ensure the achievement of the required Environmental Quality Standards for the foreseeable future.

The final phase is producing the plan, including details of how the works will be phased.

Figure 3 - Catchment management plan flow diagram



Move towards integrated planning

Concurrent with the operational side of the Industry developing these new procedures the financial side was also questioning previous practice.

Traditionally the value of assets owned by the Authorities had been assessed either in terms of their historic cost or current replacement value. These asset values were then written off over their assumed effective "life". About 4 years ago, this practice began to be questioned for assets which are long lived and are parts of systems which themselves have virtually infinite life. Sewerage networks certainly qualify. It was argued that these "renewals assets" will be maintained indefinitely and their total replacement value is of little significance. The important cost is the present value of the anticipated maintenance works expected to be needed in the foreseeable future. To make such estimates and audit them it is necessary to undertake Drainage Area Studies as described above to generate what has become known as Asset Management Plans.

The idea of Asset Management Plans was just beginning to catch on when privatisation entered the scene. Information on the outstanding liabilities of an Authority is required to put into the Prospectus to inform potential shareholders. Subsequent to flotation the Government Regulator will also need the same information, regularly updated, in order to be satisfied that sufficient monies are being set aside for long term maintenance and that a national asset is not being allowed to deteriorate.

Institutional impediments

In the paper so far a picture has been painted of an industry which, from knowing virtually nothing about its assets and operating a policy of crisis maintenance, in a matter of 12 years, turned itself round to one committed to a very high level of planned maintenance and performance monitoring.

It might therefore be thought that the UK Water Industry is now able to apply optimally all of the new technology which is being reviewed at this conference. Unfortunately the true picture is very different and the impediments are almost totally institutional.

These institutional impediments can be considered as historical, informational or political, although in practice the boundaries can get a bit blurred.

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Historical impediments

Historically, planning responsibility has become very fragmented. To illustrate the problems it is instructive to take the viewpoint of the two bodies with a financial interest in having cost effective solutions to urban drainage problems - the developer and the sewerage authority.

The developer planning a major new housing estate has to get planning permission from the planning authority (the District Council) who, when considering how urban drainage will be handled, will take advice from other authorities likely to be affected. These will be the Highway Authority for road drainage, the Drainage Authority (National Rivers Authority [NRA]) for surface drainage. For both the sewerage authority (Water Services plc) will need to be involved if the new surface water sewers are to be adopted as part of the public network and will have direct involvement for any foul or sanitary sewers. The interests of these bodies may be in conflict.

The Highway Authority will wish to minimise maintenance costs and get surface flows below ground as quickly as possible to avoid hazards to traffic. Thus above ground flow attenuation or flow reduction through infiltration will not appeal. The NRA may wish to favour the opposite approach to reduce flood flows in rivers and streams and maximise groundwater recharge to maintain dry weather flows. The Sewerage Authority will wish to encourage above ground flow control measures as this reduces the storm loading on the existing sewerage system into which the new sewers may be coupled while leaving maintenance responsibility with others. It will however, be less happy to take on responsibility for flow control structures within sewers it is required to adopt. Thus with future financial responsibility split, sub-optimal solutions (from a national point of view) are very likely and the developer frequently gets frustrated.

The Sewerage Authority trying to find cost effective solutions to current system performance deficiencies can get equally frustrated. Here the problem stems from fragmented ownership. Public sewers have linked into them house drains which are owned by the householder and highway drains owned by the Highway Authority. From a hydraulic viewpoint these are a single, integrated system. Many upgrading options are available and some are listed in Table 7.

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Table 7 - Methods of hydraulic upgrading

FLOW ATTENUATION	FLOW REDUCTION	INCREASED SYSTEM CAPACITY
Detention tanks Controlled surcharge/flooding Surface detention Storage of road runoff Gully pot storage	Disconnection of roof areas Permeable pavements Infiltration control CSO rationalisation Separation	Replacement Reinforcement Renovation Polymer injection Maintenance operations

It is simple to demonstrate with network analysis models that the most effective methods are the above ground options of disconnection or attenuation of roof runoff, followed by surface detention. However, these are the ones that are institutionally currently impossible to apply.

In March 1986 a Government discussion document introduced the idea of changes to sewerage law which would have made house drains public sewers. Unfortunately it was considered unwise to make this radical change at the same time as privatising the service and the proposal was dropped.

A major study of the scope for control of urban runoff is in progress at the Construction Industry Research and Information Association (CIRIA). This is concentrating mainly on promoting runoff control associated with new development but hopefully it will also provide a strong case to put to Government to re-introduce the changes to the law proposed in 1986.

The fragmentation of responsibility discussed above is about to be made worse. Prior to privatisation the Water Authorities had a large measure of autonomy being controlled only by restrictions on borrowing and charging. They are not going to be privatised in their present form as it was considered unacceptable for a private company, in a monopoly situation, inheriting massive public assets and having such environmental and public health responsibilities, to regulate itself particularly when it would have responsibility for the regulation of others. Two new regulatory bodies have been set up with some responsibility transferred to an existing third.

The NRA will be responsible for setting discharge consents for sewage treatment works, storm overflows, surface water outfalls and sea outfalls. That is unless toxic, persistent (Red List) substances are present when Her Majesty's Inspectorate of Pollution (HMIP) get involved to specify the required treatment process. The logic for HMIP taking an interest is to enable pollution by dangerous substances to be controlled across the three elements of air, land and water. The third regulator is the Director General (DG) of the Office of Water Services who is responsible for ensuring that specified levels of service to the public are being achieved, that the long term assets are being adequately maintained and that any costs being passed through to the consumer for asset maintenance and achievement of environmental standards are fair after making allowance for efficiency improvements to be expected from a well run business. The danger in split responsibility is evident here as in the previous example of housing development. Will the best interests of the community be served when several Government departments have powers to restrict the options of a utility but are not accountable for the consequences?

Information impediments

When crisis maintenance was the only available management option solutions tended to be of high cost and uncertain benefit. This is no longer necessary with the wealth of information on system performance and very much improved appreciation of the true causes of system failure. However, the volume of information required to be collected and interpreted should not be underestimated. It is relatively easy to justify the cost of Drainage Area Studies and Catchment Management Plans when the evidence of flooding and pollution are self-evident. To maintain the models and monitoring systems on a long term basis so as to be able to have regular Plan updates is a very different and more taxing exercise. The challenge of the Information Technology (IT) age is one the Water Industry has started to face up to but history is not too encouraging when, after its first 150 years, the basic information about pipe location is still too frequently lacking.

It will be a tragedy for the Industry, the Government and the country, if the first real opportunity to undertake integrated catchment planning were to be missed and the approach discredited due to the difficulties of collecting, maintaining, updating and auditing basic data which in other process industries is taken for granted.

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Political impediments

"Green" issues are no longer the province of only the experts and small pressure groups. All political parties have seen the need to appear to be environmentally concerned and the search is on for "sustainable development". The danger with political enthusiasm is that the accompanying publicity builds up hopes that cannot be fulfilled in politically acceptable timescales. There is a need to be seen to be doing something positive. In the UK, with the advantage of large regional water utilities and a National Rivers Authority, it should be possible to progress steadily, as outlined earlier, towards Catchment Management Planning. Environmental Quality Objectives (EQOs) are set for the component parts of the receiving water system, based on the planned uses. "Fitness for use" standards (EQSs) can then be defined against which discharge consents can be tested by monitoring and modelling. A typical Use Area Chart is shown in Figure 4.

This approach gives the utility a free hand to optimise its engineering solutions while giving the regulatory authority the means of satisfying itself that the proposed solution will not inhibit the achievement of the EQOs.

The alternative approach of the regulatory authority specifying the technology to be used is not only sub-optimal from a national viewpoint, as it must be applied conservatively, but it stifles initiative in the utility to look for ways of improving process performance which could have environmental as well as internal efficiency benefits.

An example giving concern is marine treatment. The UK is under pressure from some other European states, who have local eutrophication problems, to install secondary treatment before discharging sewage to sea from long sea outfalls. Apart from the cost - another £2,400 million and no significant environmental benefit - this would result, if implemented, in large additional quantities of sludge, the disposal of which has environmental hazards. Sludge disposal is already a major problem. It is possible to show that the best practicable environmental option for sludge disposal in many cases is disposal at sea. But there is a lot of pressure from other North Sea states to reduce this practice (in the North Sea at least) and the UK has bowed to this pressure and agreed to make 10% cuts for each of the next 5 years.

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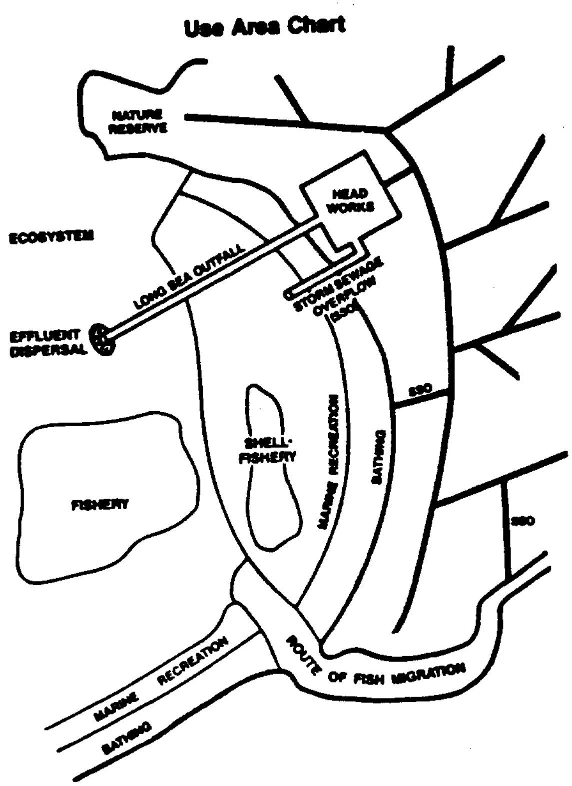
Figure 4 - Use area chart (Dempsey and Lack 1988)



A political argument sometimes put forward against the EQO/EQS approach is that all dischargers are not equally disadvantaged. It can therefore influence demographic shifts. It is the author's view that such a claim would not bear up under detailed investigation.

Conclusions and general observations

(1) Pressures to improve efficiency and quantify, in an auditable way, future capital funding needs have encouraged and allowed the UK Water Industry to set up the procedures and information systems to be able to undertake comprehensive catchment management planning.

(2) The performance of urban drainage systems still leaves much to be desired, largely due to historic restrictions on capital spending. All current Environmental Quality Objectives are achievable. The timescale by following the EQO/EQS approach will be shorter than by the regulatory authorities specifying Best Available Technology due to the logistics of completing the massive capital programme the latter would require.

(3) The optimal use of evolving stormwater control technology is seriously inhibited by the fragmentation of planning responsibility for new urban development and the split in drain/sewer ownership for the upgrading of existing systems. Better guidance to developers and cooperation between local authority departments will assist the cost effective drainage of new development but a change in sewerage law, as proposed in 1986, will be required before the most effective control technologies can be used for upgrading.

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STORMWATER REGULATIONS AND STANDARDS, INTRODUCTION

by Poul Harremoës[1]

Introduction

The pollution derived from rain runoff from urban areas is receiving increasing attention from the public, the press, and politically. That applies in particular to Scandinavia due to increasing demands for better sewage purification. In Denmark, all treatment for towns bigger than 5000 inhabitants must include nutrient removal before the end of 1992. That requirement is based on observations since 1981 of algae and oxygen problems in the coastal waters of Scandinavia. The attention is focused not only on the treatment of the regular daily flow, but also on the diffuse sources of pollution, of which rain runoff is one of the most significant.

The relative contribution of nutrients from rain runoff is not very significant on an integrated scale (Harremoës, 1988c), but may be important in relation to the local recipient. However, the attention has brought to the surface the other problems of urban runoff: bacterial pollution, organic matter and oxygen depletion plus toxicity from ammonia, hydrogen sulfide, metals and specific organic compounds.

The difficulty of the problem is the irregularity of the discharge. It is not possible to apply the well known rules and standards for the discharge from treatment plants. Until today the rules have been crude in relation to the scale and the extent of the problem and in relation to the cost of the engineering structures required for the

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abatement of the problems. There is a demand for an analysis of principles and for recommendations with respect to the regulation of design and operation of urban runoff.

Upon request from the Danish Environmental Protection Agency an analysis of principles and possibilities was undertaken by PH-Consult ApS. This introduction is essentially an extract of the the report to DEPA (PH-Consult ApS, 1989).

Current practice

Around the turn of the century the sewer system of the city of Copenhagen was changed. Big interceptors were constructed along the harbour. It is interesting to read the reasoning for the rules applied. All reasoning was related to the cost of construction. It was a very costly enterprise for the city. The design criterion was a required dilution of 1:2, corresponding to a frequency of approximately 40 overflows pr. year. That led to reasonable pipe diameters and pump stations. No doubt, it was a significant improvement.

Until recently, the rule was the same, except that the dilution was gradually increased to 1:5, based on daily peak flow.

In recent years we have seen changes: like a maximum overflow frequency of 10 times per year, or a required 95% decrease compared to overflow volume without detention basins. Only seldom have the rules been motivated with a rationale, based on a desired objective for the receiving water.

It is noteworthy that rules in other countries are but variations on the same theme.

Sweden decided to change all combined systems to separate systems. This happened for all but the big cities, where the cost was overwhelming. When the investigations during the 70'es and 80'es revealed the extent of pollution discharged from separate systems, the requirement for change to separate system was abolished.

In Germany they developed rules for the critical flow at which the overflow goes into operation (Abwassertechnische Vereinigung e. V., 1977). They are based on an empirical relationship with the ratio between the flow in the receiving river and the flow in the sewer. The critical flow essentially varies between 7 and 15 l/(s*ha). Detention basins are derived from simple relationships

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based on the critical flow and the permissible flow to the treatment plant. The rules are under revision (Göttle, 1988).

The rule in England was also based on dilution, essentially 1:6 based on average dry weather flow (Cliffords et. al., 1986). The whole approach is now under revision, but the ultimate approach is still to be seen.

In Switzerland the rules are based on a combination of required dilution and a specific flow, 15 l/(s*ha), above which the overflow can be untreated. The rules are under revision (Krejci, 1987; Gujer and Krejci, 1987).

The Netherlands have very different rules. These are based on the fact that the interceptors are essentially horizontal and act as basins and sedimentation tanks (TNO, 1985 and 1986).

The most comprehensive investigations of the problems associated with urban runoff have been made in USA (Lager et. al. 1974; Field and Turkeltaub, 1981; Field and Weisman, 1982; U.S. Environmental Protection Agency, 1983). The first models were developed in the USA (SWMM) (U.S. Environmental Protection Agency, 1971). However, the ultimate policy is still under revision (U.S. Environmental Protection Agency, 1988).

It is clear from an analysis of the different national rules that they are essentially based on the same tradition and that they are all under revision. It is a good time for international communication on the issue; in order to learn from each other, while the rules are still being shaped and before they harden into fixed approaches, not to be altered for quite some time due to inertia in the legislative and administrative systems.

Fundamental principles

The tradition has been to formulate the rules essentially based on cost of construction. The new wave of concern is based on the demand for pollution abatement. The cost will be significant, but society appears to be willing to pay the cost required to achieve the objective.

Which objective? There is only one rational approach to a solution: That is to reason backwards from a required water quality in the environment to a permissible discharge.

This concept has been the policy in Denmark for two decades. It gave rise to comprehensive receiving water investigations and a lot of planning procedures. There was political division with respect to the merits of the system. Some considered the action to be too slow. The algae and oxygen problems of the Danish waters demanded limits on all discharges with respect to nutrients from treatment plants: 8 mg/l total N and 1.5 mg/l total P. The scheme is being implemented rapidly.

The proposed policy with respect to pollution from runoff is:

(a) The rules should be based on water quality criteria for the local and downstream receiving waters.

(b) The rules should be operationally sound, without giving rise to too many local investigations and possible delaying actions.

It is essential to distinguish between basic features of the pollutants. The most basic categorization is the time scale. It is essential to distinguish between acute and accumalative pollution.

Acute pollution is characterized by a here and now effect. This applies to oxygen depletion and toxicity. These problems have to be judged on the basis of extreme statistics (Harremoës, 1986, 1988a and 1988c).

Accumulative pollution is characterized by the accumulation in the receiving water. The individual discharge is of little concern, apart from its contribution to the accumulation in the water or the sediments. Typically it is important for nutrients, metals and persistent organics.

The real problem is to identify the most basic phenomena and the most essential parameters, that are manageable as a design basis -and forget about all the inferior phenomena. A compromise has to be reached between the oversimplification of the past and the potentially confusing comprehensiveness of computer models. It is a traditional skill of the engineer to make such choices, but it is not an easy task.

The proposal is to standardize the water quality criteria and to standardize the approaches for the calculations to be used for the determination of the permissible discharge to the receiving water. The water quality criteria have to be formulated on a statistical basis. The calculation methods require information about the receiving water, e.g. flow, reaeration, residence time, etc. Where these are not

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available default values are recommended on the basis of simpler input (slope, depth, etc.).

Approaches to regulation

The rules can be formulated with respect to design at different locations in the system, which is best characterized by following the water flow:

- rain
- surfaces
- gully pot
- wastewater flow
- pipes
- overflows
- basins
- local purification
- sewage treatment
- receiving water

As explained above the rules should always be motivated on the basis of reasoning from water quality objectives to operational rules. In practice such rules cannot be formulated so ideally, but they must nevertheless be precise to be enforcible. One example might be rules forbidding the use of lead in gasoline in order to decrease the lead pollution of surface water due to rain runoff. Another example is to require scumboards as an enforcible rule. It has turned out that it is very diffucult to set standards for floatables and to reason backwards to purification at the individual overflow structure.

Pollution abatement can be achieved through differant approaches:

- affecting the behavior of the public by education
- improving the professional practice in planning, design, construction and maintenance.
- provide guidelines for the profession
- setting norms for the profession
- setting standards for the profession
- making laws through parliament

There has been a tendency in Denmark to pass too many laws. This development has been due to political pressure to achieve abatement fast. This is under revision, because it is being realised that environmental protection is becoming very bureaucratic. "Reading and interpreting laws has become more important than understanding the problem."

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Due to the staggering cost of water pollution abatement it is essential to reach solutions which achieve the desired goals under the local circumstances. Such flexible solutions are not reached through the simplicity of the traditional rules. Where possible, the first three items of the list above should be the approach (behavior, professional practice, guidelines). That is possible, because of the very improved and widespread knowledge and skill of the professional today - as compared to two decades ago.

Pollutant runoff

Pollutants are carried with the rain and with the runoff. Numerous investigations have been made of the magnitude, interrelationships, time variation and stochastic properties of the pollutant transport - too numerous to be fully described and evaluated here.

In the literature there are essentially three approaches to the interpretation of the data from such investigations:

- Determination of a characteristic concentration, and its statistical variation.
- Determination of empirical relations between characteristic properties and the concentration in the runoff, and the statistical variation.
- Deterministic description of the runoff processes, involving the important physical, chemical and biological phenomena.

the development of deterministic descriptions of the hydraulic phenomena, e.g. in available computer programmes like SWMM, WASP and MOUSE, has been very successful. They can accurately simulate the runoff processes. Flow and stage can be adequately simulated compared to reality, if the models are adequately calibrated for the systems under investigation.

Typical figures for the uncertainty of simulation are, (Paulsen, 1987):

Runoff volume in mm:

For the calibrated volume runoff data the standard deviation is 4-7% for the mean flow; 20-40% for the individual event. For the non-calibrated events the same figures are: 3-10% and 20-40%.

Pollutant runoff in kg/ha:

> For the calibrated mass transport of pollutant the standard deviation is 10-30% for the mean mass; 50-140% for the individual event. For the non-calibrated events the same figures are: 20-60% and 50-180%.

These data are just examples of the general trend in the literature. It is postulated that it has not been possible to simulate the pollutant runoff without a very significant residual statistical variation. If deterministic description of pollutant transport is to be applied in practice, the significant statistical variation has to be accounted for. The stochastic variation is so big that there is reason to question the need to develop elaborate deterministic simulation tools.

Data from several investigations have been analyzed in order to determine empirical relations between parameters like rain intensity, rain depth, duration, mean and max. flow, etc. Essentially, they have been unsuccessful. An investigation of all available, quality controlled data from Scandinavia did not produce relationships which could stand the test of statistical significance.

One exception is the results from The Netherlands (Uunk, 1985; Onderdelinden and Timmer, 1986). Due to excessive sedimentation in virtually horizontal interceptors the concentration becomes dependent on the flow.

Where such investigations have not revealed empirical relationships the best approach is to use a simple characteristic concentration: the event mean concentration, and to account for its statistical variation (U.S. Environmental Protection Agency, 1983; Harremoës, 1988a).

$$P = Q_w C_w + Q_r(C_r + C_e) = (Q_w + Q_r)C_m$$

P is the total transport
Q_w is the wastewater flow
Q_r is the runoff
C_w is the concentration in the wastewater
C_r is the concentration in the surface runoff
C_e is the concentration from erosion in the pipe
C_m is the mean concentration

Indications are that the statistical variation is log normally distributed, at least good enough for practical application. The standard deviation is in the order of 0.6-0.9 on the natural logarithm, corresponding to a factor of uncertainty of 1.8-2.5.

Water Quality Impact

Overflow from combined systems and outflow from separate systems occur less than 5% of the time and the effect is a statistical phenomenon. The water quality criteria known from continuous loads on receiving waters cannot be applied. The phenomena of transport and conversion of the pollutants in the receiving water are more complicated. There is still a significant lack of knowledge.

The state of the art will be reviewed in brief:

Acute pollution must be evaluated on the basis of the frequency of the rare events with massive loading of the recipient. The accumulative pollution has to be evaluated on the basis of the total discharge over a period. The individual event is important only by its contribution to accumulation, not as an individual event.

Acute pollution:

Bacterial pollution

The bacterial content of outflow from separate sewers is low relative to the well established criteria and is seldom an issue.

The bacterial content in raw sewage is in the order of 10^7 E. Coli/100 ml. That is 10^4 bigger than the traditional criteria, demanding less than 10^3 E. Coli/100 ml., 5% of the time. The effect is reduced by dilution and bacterial disappearance (Harremoës, 1970). One of the difficulties is that overflow occurs less than 5% of the time.

The solution proposed is to expand the established criteria as follows, assuming a log normal distribution:

Probability %	E.Coli conc./ 100 ml.
20	10^2
5	10^3
0.7	10^4

These probabilities are difficult to detect in practice, because they require many samples in the season. However, the criteria for rare events can be used as design criteria.

It is not possible to perform a receiving water investigation in detail for each overflow structure. The idea is to get a general knowledge of the properties of the receiving water and to supplement with default values based on general knowledge as required. Flow data for rivers are mostly available. Currents along coasts can be estimated. However, the rate of bacterial disappearance is like a research project to determine (Harremoës, 1970). In practice, default values have to be made available.

By running historical rain series through a model of the urban runoff system, e.g. the SAMBA model within the MOUSE-package, the statistics for the overflow can be produced. It is the mass of bacteria discharged in each event that counts. The loading series can then be applied to a receiving water model of the transport, dilution and disappearance of the bacteria. At a given point at a beach the statistical distribution of the bacterial contamination can be calculated. The result is evaluated for compliance. Abatement may be achieved by decreasing the overflow frequency by introduction of storage in the runoff system or by relocating the discharge point for the overflow.

Oxygen depletion

Oxygen depletion is seldom a problem for outflows from separate sewer systems due to low BOD in the runoff.

Oxygen depletion from combined sewer overflows can involve three phenomena:

- Immediate depletion due to BOD-degradation in the water phase. The traditional oxygen sag from discharge of dissolved BOD.
- Delayed depletion due to BOD-extraction from the water phase and accumulation in the sediments, from where oxygen demand is exerted on the water phase. This is significant because the extractable part of BOD dominates domestic sewage and because the extraction is very rapid, (Harremoës, 1982).
- Scour of accumulated BOD in the sediments due to increased flow. The BOD may have accumulated in the sediments due to to extraction from a daily discharge if inadequately purified.

These phenomena are well established and can be adequately modelled.

The proposed approach is to run a historical rain series through the runoff system to produce a series of BOD-discharges. An example is given in Figure 1. It is the total mass of BOD per event that counts. That series is then loaded on to a model for oxygen depletion in a river, from which is produced a series of oxygen concentrations to be compared with statistical criteria for oxygen in rivers, (Harremoës, Hvitved-Jacobsen and Johansen, 1986). An example is given in Figure 2.

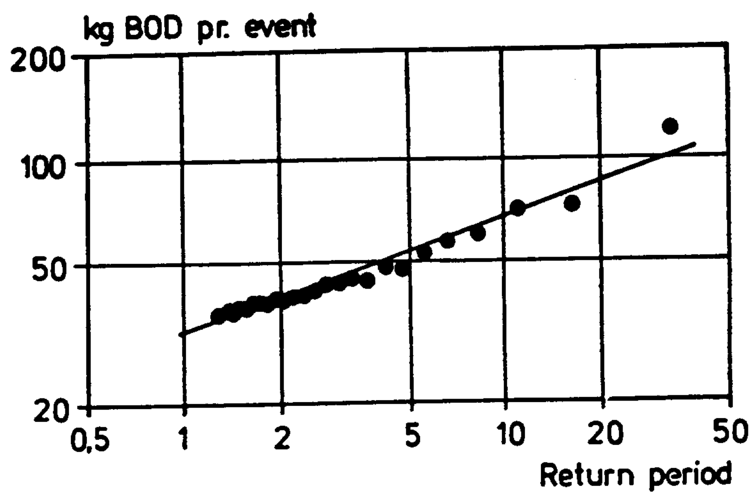

Figure 1: Extreme statistics for the discharge of total BOD from individual overflow events, derived from calculation of overflow from a long historical rain series. Calculation by the SAMBA-model of the MOUSE-program package. The statistical variation between individual overflow events are of significance (Harremoës, 1988a).

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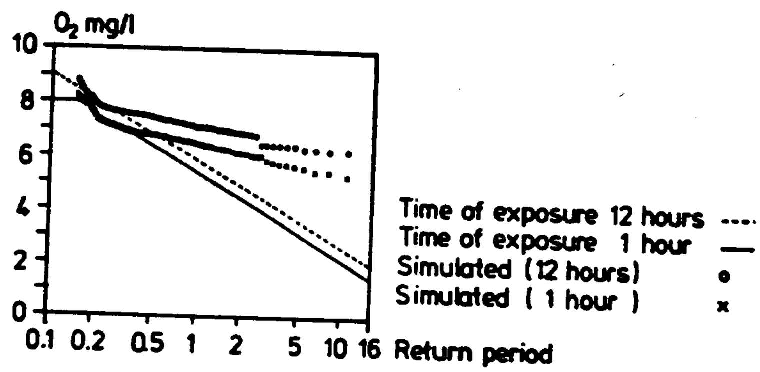

Figure 2: Extreme statistics for the oxygen concentration in a river exposed to combined sewer overflows with extreme loading statistics as shown in Figure 1. The distribution is based on calculation with a simple river model based on immediate and delayed oxygen depletion. The statistics is compared with the distribution of required oxygen in rivers in Denmark.

Overflows are often discharged into small tributaries upstream in the system. These small rivers are sensitive to these shock loads. It is the experience in Denmark, that such overflows will not comply with the criteria unless very costly storage tanks are installed in the system. This is often considered extravagant by practitioners, because the rule is much more stringent compared to the traditional rules. However, there are only three logical reactions to the situation:

- Build the required storage tanks, which may be expensive.
- Relocate the overflow structure, which may be expensive too.
- Declassify the river to a lower standard, which of course is cheap.

Ideally, that choice of pollution abatement versus cost should not be made by the professionals, but by the politicians.

In order to save the investment the river may even be classified as part of the sewer system. The trend in Denmark goes in the opposite direction.

Specific pollutants

There has been concern for the effect of the discharge of potentially toxic substances with the runoff. This is a very complicted issue, but research tends to show that the potential pollutants are toxic only in soluble form. The total concentrations in the runoff tend to be lower than the criteria for acute toxicity. Furthermore the distribution between the soluble form and the adsorbed or complexed form is such that the toxic soluble concentration is but a fraction of the total concentration.

Acute toxicity due to metals and refractory organics is not considered to be a serious problem in connection with rain runoff.

Accumulative pollution:

Nutrients

Nutrients cause eutrophication. It is the accumuleted load on the receiving water that counts, e.g. over the year or the season. It is meaningless to look at the discharge of nutrients from runoff alone. The contribution from urban runoff is just one of many contributions. Frequently, it is a small contribution (Harremoës, 1988c). However, the contribution can be significant when the daily flow of wastewater has been intercepted.

The best approach to the calculation of the load on the lake from combined sewer overflows is to run a historical rain series through a calibrated model of the sewer system. The accumulated discharge can be calculated for each year covered by the series. An example is given in Figure 3. The statistical uncertainty of the concentration of the individual event is damped by the accumulation. It is an interesting fact that the discharge varies significantly from one year to the other due to meteorological variations.

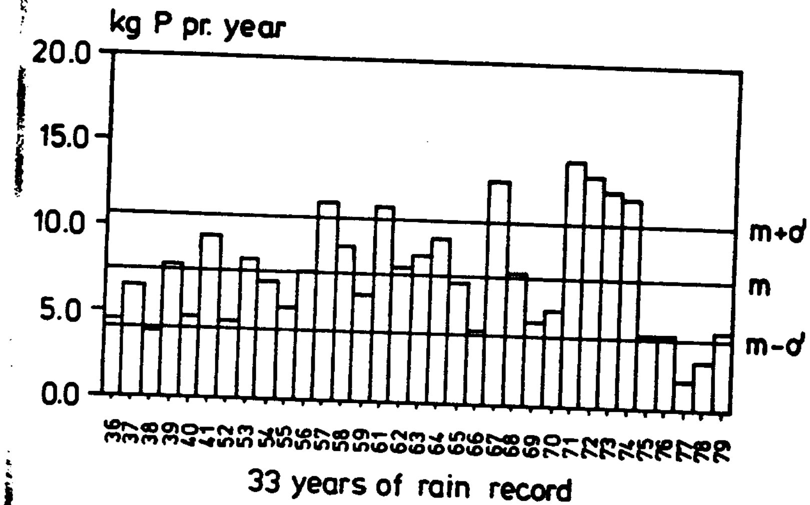

Figure 3: Annual accumulated phosphorus load from a combined sewer overflow to a lake. Calculation by the SAMBA-model of the MOUSE-program package. Notice the significant variation from year to year. The statistical variation between the individual overflow events is without significance.

Priority pollutants

It appears, from U. S. literature in particular, (U.S. Environmental Protection Agency, 1983), that persistent organics in urban runoff do not pose a problem under normal circumstances.

The total annual discharge of metals per unit of paved urban area is not very different for the separate versus the combined sewer system. To many practitioners that fact has come as a surprise.

Indications are that the metals discharged with the urban runoff can accumulate in the sediments downstream from the discharge point to concentrations which may give rise to toxic reactions to the biota living in the sediment or at the surface (Ellis, 1988; Benoist et. al., 1989; Visser and Lijklema, 1989).

This is a very difficult issue. Not only does the scientific evidence for detrimental effects leave much to be desired, but the implications are noteworthy. The separate sewer system was introduced on the assumption, that the discharge from the system was "clean". The separate sewer system is costly by comparison. The cost becomes excessive if the runoff from separate systems has to be purified before discharge to the ocean, estuaries, lakes and rivers.

Treatment plant performance

The traditional focus on pollution during rain runoff is at the overflows. The tradition is to design treatment plants for a fixed maximum permissible flow through the plant. Discharges greater than that are simply diverted to overflows. That is still current practice.

It is the final clarifiers of the treatments plants which are the determining factors for the pollution from the treatment plant during rain. The diffuculty is that the performance of final clarifiers vary from plant to plant, from time to time and during the event. This is a dynamic phenomenon.

It is an essential feature that the clarifier can tolerate high flow for a short time, but only low flows for a long time. The increased storage in the catchment in order to protect the upstream recipients from the pollution from overflows will increase the period of high flow after rain at the treatment plant. The traditional design can no longer be accepted.

The whole systems must be looked at as one entity. The design has to be based on systems analysis in order to reach reasonably optimal design and operation. We are beyond the time when these mattars could be dealt with by simple rules of thumb.

Conclusions

The traditional rules for the regulation of outflow from separate systems and the regulation of overflow from

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combined systems no longer serve the needs of the society in the balance between protection of the environment and the cost of achieving that goal. In the past that balance was tilted in favour of the economical aspects.

The demand for improved water quality will be so costly, that traditional rules are too simple. There is need for more differentiated rules, that will justify the high cost where it is needed for water quality abatement, and allow cheaper solutions, where it is not required for achieving water quality standards.

There are available today adequate models, with which to simulate the relation between discharge and resulting water quality for the most essential problems: Bacterial pollution, oxygen depletion and effect of loads of nutrients. There is an inadequate knowledge of the potential for water quality deterioration due to discharge and accumulation of metals. It appears that priority pollutants do not give rise to an acute toxicity problem under normal conditions.

New rules can be formulated on the basis of a combination of limitation of pollution sources (e.g. lead), practical requirement with respect to structure (e.g. scumboards) and guidelines for practical application of models for calculation of permissible discharge quantity per event vs. frequency for acute pollution and quantity per year for accumulative pollutants.

The whole system - the sewer system, the treatment plant and the receiving waters - must be looked upon as a whole. It will not be possible to establish strict rules for design of the individual component in this system in such a way that the result will be even close to an optimal solution for the system under design or operation.

The increased knowledge about the runoff process, the processes in the treatment plant and the processes and effects in receiving waters makes it possible to leave more to be determined through the distributed, professional skills, without simple and strict rules. This is the only way in which local conditions can adequately be taken into account.

It is recommended to establish accepted means for calculation of the permissible discharge based on models for the runoff process, for the treatment plant and for the local properties in the receiving water. The models should be simple, accounting only for the most essential phenomena, not including every conceivable process in the system.

Default values should be available for the many cases where the problem does not justify detailed local investigations. This design procedure should be supplemented with other restrictions of a more practical nature, like scumboards and bar screens.

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STORMWATER REGULATIONS FROM LOCAL GOVERNMENTS' VIEW

by L. Scott Tucker[1], ASCE Member

ABSTRACT

Regulations are being prepared by the United States Environmental Protection Agency for permit application requirements for municipal separate stormwater discharges. Local governments in the United States will be required to develop stormwater quality management programs in order to obtain stormwater discharge permits. This paper examines the background, status, and enforcement provisions of the stormwater permit program from the local government perspective. Many metropolitan areas in the United States consist of several independent local governments and the advantages of metropolitan-wide stormwater management approaches are discussed.

INTRODUCTION

Rains finally began to fall on the city. A drought had been in progress and the gentle cooling rains were a welcome relief to the urban residents of Gotham. The rainfall slowly intensified and soon water was making its way from rooftops, yards, parks, and parking lots to the streets and from there to storm sewer inlets in the streets and from there to somewhere else.

The rains also alerted the many government agents who had been standing by the some 896 storm sewer outlets in Gotham for several months. Finally some action. The agents were on the track of one of the biggest busts of this type ever. Gotham had failed to obtain permits for their storm sewer discharges and the agents had suspected that it would eventually rain and illegal discharges would occur. Time was limited for the elected office holders and public works officials of Gotham; they had neglected this problem too long.

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This scenario may be a little tongue-in-cheek, but one aspect is real - soon permits will be required of local governments in order for them to continue the discharge of stormwaters from their municipal storm sewer systems. The issue of how to regulate and control the quality of urban storm sewer discharges has been brewing in the United States since 1972 when the Federal Water Pollution Control Act (FWPCA) was passed. Regulations have been proposed, promulgated, rescinded, and modified; law suits have been filed by environmental groups to force adoption of urban stormwater regulations; and Congress has deliberated and amended the environmental laws. It is safe to say, however, that municipal storm sewers in the United States will soon be regulated. It is no longer a matter of if, but a matter of when. It is also clear that local government, cities and counties, will be required to bear the burden of the costs associated with the regulatory program.

The "problem" is how to control and reduce the discharge of pollutants contained in urban stormwater. However, data gathered to date indicates that the impacts of stormwater discharges on receiving waters are not consistent from place to place, and in many locations stormwater quality has only been subjectively defined as a problem. Never-the-less, local governments in the United States are beginning to realize that they are going to have to develop programs to reduce pollution in urban stormwater. A few local governments in the United States are aware of the regulation train coming down the tracks, and are beginning to think in terms of how they will respond. Many local governments, however, are unaware or choose to ignore the fact that soon they will need to obtain permits for their storm sewers.

BACKGROUND

The paper by Kevin Weiss gives a good summary of the history and status of the regulation of municipal separate stormwater discharges in the United States. That history will not be repeated, but salient points need to be highlighted to put the issues in perspective from the point of view of a local government.

Congress in 1987 in passing the Clean Water Act (CWA) amended the FWPCA to provide further guidance on the control of urban stormwater. Congress made it clear in the 1987 CWA that permits for discharges from municipal storm sewers will be required. Permits will be required initially for municipal separate storm sewer systems serving populations over 100,000. Permits for smaller systems are to follow at a later date. The scenario is basically playing out as follows. The United States Environmental Protection Agency (USEPA) is in the

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process of writing regulations that set forth minimum application requirements for permits for municipal storm sewer discharges. Final regulations are expected to be promulgated by USEPA in 1990. In about 40 of the 52 American states, authority to administer the permitting program has been delegated to the states through the National Pollutant Discharge Elimination System (NPDES) Program. In the few states without such authority, USEPA will be the regulatory agency. Both the states and USEPA have been issuing NPDES permits for point pollution sources such as publicly owned sewage treatment plant effluent and industrial waste discharges for many years. Both USEPA and the states have virtually no experience, however, in the issuance of permits for municipal stormwater discharges.

The USEPA has published proposed regulations and the period for public comment was open from December 8, 1988 to March 7, 1989. USEPA received comments from over 400 parties and comments totaled over 3,000 pages. This is a high level of response and it indicates the concern over the impact of the proposed regulation. The hierarchy of authority is flowing from the federal level down. USEPA and the states will essentially be the regulators and cities and counties will be the regulatees. The cost of implementing controls will be borne at the local level as there is no indication and little likelihood of federal or state financial support. Local governments will be required to submit applications to the state or USEPA for a NPDES permit for their municipal storm sewer system. The regulations being promulgated by USEPA will establish minimum requirements for the application for permits as well as some requirements for compliance. Permits will be issued within a year after applications are submitted, and the permits will set forth in detail what local governments need to do to meet compliance requirements.

Congress in the 1987 CWA specifically identified requirements for municipal separate storm sewer discharge permits thereby establishing the fact that they are to be addressed differently than permits for other point sources of pollution. The 1987 CWA specifically states that permits for discharges from municipal storm sewers may be issued on a system- or jurisdiction-wide basis. Prior to this clarification the approach being taken was to require a separate permit for each storm sewer discharge point. This would have meant literally the preparation of millions of individual permits for all the urban stormwater outfalls in the United States. This was an absurd proposition and the cost of submitting applications alone was estimated to be $8 billion. This was an important change by Congress.

Congress in the 1987 CWA also defined what municipalities were to be required to do to control storm sewer discharges. The 1987 CWA states that permits for discharges from municipal storm sewers "shall require controls to reduce the discharge of pollutants to the maximum extent practicable, including management practices, control techniques and system, design and engineering methods, and such other provisions as the Administrator or the State determines appropriate for the control of such pollutants." The operative words are "to the maximum extent practicable" (MEP). While there does not exist at this time a precise definition of MEP, it is important to note that it must be different from the operative term "best available demonstrated control technology" which applies to other point sources. The implication of the term MEP is that controls need not be end-of-pipe methods. Congress recognized the impracticality of treating all stormwater discharges, and established the requirement of doing the best job that is reasonable, or in their terms practicable. It would not be practicable, for example, to construct treatment facilities for all storm sewer outfalls even though such treatment may have been demonstrated to be technically feasible. It would simply be unaffordable. The 1987 CWA, on the other hand, specified that permits for stormwater discharges associated with industrial activity must meet all existing applicable requirements including technology and water quality based standards. The new act, however, made significant changes to the permit standards for discharges from municipal separate storm sewers as noted above.

In some areas of the United States it is believed that non-stormwater connections to storm sewers contribute significant pollution. Such non-stormwater connections are termed illicit connections. Congress in the 1987 CWA included the provision that permits for discharges from municipal storm sewers shall include a requirement to effectively prohibit non-stormwater discharges or illicit connections into the storm sewers. There seems to be general support from local governments that illicit connections should be eliminated, and in fact some local governments have been actively pursuing the elimination of illicit connections for sometime.

WHERE ARE WE

The regulation and control of municipal separate storm sewers is in its infancy in the United States. Congress has set forth a basic direction and USEPA now has the opportunity to develop a program that is reasonable and implementable by local governments. USEPA is being pressured and even threatened by the environmental community to show no quarter in their

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regulatory requirements. Local governments on the other hand are pleading for reasonable and flexible requirements that can be implemented within an affordable cost framework. The regulations that will be promulgated by USEPA will become the minimum requirements for state administered programs and the requirement for USEPA regulated states. The regulations that have been proposed by USEPA include both good and bad features from a local government perspective.

USEPA has taken the common sense approach that end-of-pipe treatment in most cases is not appropriate for the urban storm sewer problem. Municipal storm sewer permits will not be like industrial discharge permits. One USEPA official explained it this way:

> "These are not permits in the normal sense we expect them to be. These are actual programs. These are permits that go far beyond the normal permits we would issue for an industry because they in effect are programs for stormwater management that we would be writing into these permits" (1988).

USEPA stated in the preamble to the proposed regulations, that the basic approach being recommended is a shift from an end-of-pipe approach towards comprehensive stormwater quality management programs to reduce the discharge of pollutants from municipal separate storm sewer systems. In rationalizing this approach USEPA noted that discharges from municipal storm sewers are highly intermittent, and are usually characterized by very high flow rates occurring over relative short time intervals. This results in a high number of storm sewer outfalls within a given municipality. Traditional end-of-pipe controls are limited by material management problems that arise with high volume, intermittent flows that typically occur.

USEPA also noted in the preamble that the nature and extent of pollutants in discharges from municipal systems depend on the activities occurring on the land which contribute runoff to the system. Municipal storm sewers tend to discharge runoff drained from lands used for a wide variety of activities. Given the material management problems associated with end-of-pipe controls, management programs directed at pollutant sources are often more practicable than relying solely on end-of-pipe controls. Another factor recognized by USEPA is that the water quality impacts from storm sewer discharges depend on a wide range of factors including: the magnitude and duration of rainfall events, the time period between events, soil conditions, the percentage of land that is impervious to rainfall, land use activities, the presence of non-stormwater connections, and the ratio of

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stormwater discharge to receiving water flow. USEPA stated that in enacting the 1987 CWA Congress recognized that permit requirements for municipal storm sewers should be developed in a flexible manner to allow site specific conditions to reflect the wide range of impacts that can be associated with these discharges.

Consistent with the intent of Congress, USEPA has stated their goal to develop permit application requirements that are sufficiently flexible to allow the development of site specific permit conditions. This approach is important to local governments in that management programs can be developed that recognize the particular characteristics of each local government and region. USEPA's thrust in their proposed regulations is to force the development of stormwater quality management plans and programs in the urban areas of the United States. The management plans can be tailored according to the conditions of the local situations.

While the basic regulatory approach as discussed above is sound and is consistent with Congressional intent, some of the requirements of USEPA's proposed permit application will be difficult if not impossible to accomplish in the proposed time period of two years. For example, local governments will have about nine months to install a stormwater quality monitoring system, collect the necessary data, evaluate the data, and use it to estimate pollutant loads from the entire municipal stormwater system. Also four management plans will have to be prepared and an assessment of proposed controls made in addition to many other requirements.

Also, some of the proposed application requirements are too specific for nationwide application. This seems inconsistent with USEPA's basic premise that flexibility is needed to tailor permits to local conditions. For example, USEPA proposes to include in the application sampling from representative outfalls in a very specific manner. Samples shall be collected of stormwater discharges from three representative storm events that occur at least one month apart. In some locations in the United States particularly in the arid or semi-arid west rainfall is unpredictable and seasonable and it may not be possible to obtain data from three representative storm events at least one month apart. Quanitative data is required for a specified list of pollutants totalling 126. The cost of this "shot gun" approach is to be borne entirely by local governments. Earlier federal sponsored data collection programs in the United States, such as the Nationwide Urban Runoff Program (NURP) completed in 1983, indicated that most of the 126 parameters being required are not present in the samples. From a local government's perspective, namely the entity that has to

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pay for it, it would make better sense if knowledge of local conditions were used in the design of monitoring systems.

Public opinion in the United States at this point in time is supportive of programs to reduce pollution. Local governments are beginning to realize that after many years of confusing regulatory false starts that stormwater quality will have to be managed. The main issue of local governments in the United States now should be to work with USEPA and the states in establishing reasonable regulations.

ENFORCEMENT

The incentive for local governments to obtain a permit for their stormwater discharges and to meet permit requirements is civil action that can be brought against them for violations of provisions of the FWPCA. Civil action may be brought by USEPA or by any citizen. Once the municipal separate stormwater permit regulations are promulgated by USEPA, the clock will start ticking. Municipalities will have two years in the current USEPA proposal, to submit applications for permits. If applications are not submitted by the deadlines, the municipality will be open to civil action for violation of the FWPCA. Eventually, municipalities will be given a permit for their separate stormwater discharges. If they violate, do not meet, or in some way do not comply with the provisions of the permit the municipalities will be similarly open to civil action.

The FWPCA as amended by the 1987 CWA clearly allows civil actions and appropriate relief. Any person who violates provisions of the FWPCA is subject to a civil penalty not to exceed $25,000 per day for each violation. In determining the amount of a civil penalty the court is to consider the seriousness of the violation, the economic benefit resulting from the violation, any history of such violations, any good-faith efforts to comply with applicable requirements, the economic impact of the penalty on the violator, and such other matters as justice may require.

The activity of USEPA in the enforcement of FWPCA previsions seems to be increasing. Headlines such as the following are becoming more and more common: "Judge is Tough on Polluter," Engineering News Record, September 28, 1989; "$1 Million Fine Ok'd Against Sewage District," The Denver Post, August 26, 1989; "Enforcement Program Nets Record EPA Fines," Engineering News Record, August 24, 1989; "Prison Terms for Pollution Giving Corporations the Chills," The Denver Post, August 29, 1989; "Consumers Tune Into Environmental Issues," The Denver Post, August

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14, 1989; "EPA Names Water Polluters," Engineering News Record, June 22, 1989; "Pursuing Environmental Crime New Ground for Prosecutors," Rocky Mountain News, June 19, 1989; "Water Plant in Golden Subject of Probe," Rocky Mountain News, June 17, 1989; "EPA Sues Carbondale Residants Over Dumping in River," Rocky Mountain News, April 1, 1989; "EPA, Stuffed with Steroids, Muscles Out Local Control," Rocky Mountain News, March 30, 1989; "Big Fish in Hot Water," Engineering News Record, January 5, 1989; etc., etc.

The message is clear. Municipalities will not be able to ignore the requirement to obtain stormwater discharge permits. Environmental groups appear quite willing to utilize the provisions of the FWPCA to bring civil action against "polluters." The USEPA also seems to be stepping up enforcement actions. And, public support for such enforcement actions also seems to exist. At this point in time cost is not the major issue, but compliance is.

It can be argued, however, that if compliance with the stormwater regulations is "too ornerous or too expensive" there could be a public backlash and loss of public support. Congress appeared to be sensitive to this potential when they introduced the term "maximum extent practicable." The USEPA also has expressed a sensitivity to reality by de-emphasizing end-of-pipe controls and emphasizing source controls.

The states also have to be concerned about any enforcement actions that may be taken against a municipality. The FWPCA contains a provision that whenever a municipality is a party to a civil action brought by the United States, the state shall be joined as a party. The state is liable for payment of any judgement entered against the municipality to the extent that the laws of the state prevent the municipality from raising revenues needed to comply with the judgement. Potentially, Congress has committed the revenues of entire states to the enforcement of civil actions brought by the United States.

WHAT HAPPENS AT THE BORDER

Typical large metro areas in the United States consist of a core city, several large suburban cities, many small suburban incorporated jurisdictions, and urbanized unincorporated areas. However, the current regulations being proposed by USEPA affect only cities larger than 100,000, or only portions of the larger metro areas. The strategy of USEPA is to limit the initial permitting effort to relatively few permittees and require applications from the smaller communities at a

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later date. According to USEPA (1988) permits will be initially required by 170 cities in the United States. This represents a small percentage of all the cities and counties in the United States, but about 25 percent of the population.

Stormwater systems in metropolitan areas are complex and it is not uncommon for storm sewers to pass from one community into another. Certainly, drainage basin boundaries seldom coincide with jurisdictional boundaries and stormwater typically flows from one community to another. While the proposed USEPA regulations will allow or possibly require permits from entities with systems connected to an entity that has to obtain a permit, this will likely be the exception. So initially at least the interjurisdictional complexity of storm sewer systems will be somewhat ignored. USEPA argues, however, that all communities will eventually be required to obtain permits, so it is only a matter of time before entire metro areas will fall under the permitting program.

USEPA has proposed to initially require permits from large incorporated cities and later from smaller cities and unincorporated urban areas. Permits logically have to be given to the unit of government that controls or owns the storm sewer system, and that has land use control in the area tributary to the storm sewer system. This generally means cities and counties in the United States. However, because of the regional nature of stormwater and receiving water bodies there are advantages to an area-wide or regional approach to stormwater quality management.

Because of the large variety of local political arrangements in metro areas of the United States no one single approach will be uniformly applicable. There are few if any metropolitan areas that are alike. It will, therefore, be up to each metro area to forge regional approaches that fit the situation. A possibility will be the requirement of each city and county (for unincorporated areas) in a metro area to obtain a permit, but for a regional organization to be a copermittee for certain aspects of permit requirements. A logical regional activity would be stormwater quality monitoring. If each local jurisdiction has to pursue a monitoring system on their own, the costs would be greater than if one monitoring system for an entire region could be installed. In the Denver, Colorado metro area there are 31 incorporated cities and towns and five counties that have unincorporated areas with significant urban development. Based on the monitoring requirements in USEPA's proposed regulations, the cost of collecting the required quantitative data from representative outfalls for the permit application was estimated for both conditions. For a region-wide monitoring system the cost was estimated to be $150,000, and for 36 separate monitoring systems the cost was estimated to be $1,440,000. These costs are just for the application phase of the permit process. Monitoring could continue indefinitely as a part of the compliance phase and a similar cost differential could be expected.

Other logical areas of regional involvement include development of region-wide criteria for design, application, and construction of BMP's; coordination of permit applications where storm sewer systems are interconnected; assistance in review of proposals to reduce the discharge of pollutants in stormwater from new developments; assistance with design, construction, and maintenance of stormwater quality facilities that serve more than one unit of local government; development of and assistance with educational programs; and development of area-wide erosion control measures to be required for new construction.

Local governments will generally have to be responsible for all actions that require police powers, i.e., land use authority, and any activities that would be peculiar to an individual entity. For example, local governments would have to adopt ordinances that would require developers to install BMP's such as stormwater quality ponds, adopt ordinances requiring that erosion control measures be implemented during any land disturbing activity, implement programs to eliminate illicit connections to their storm sewers, construct or enforce BMP's as necessary where water quality problems require it, and implement public programs to promote improved public practices such as use oil and antifreeze collection instead of indiscriminate disposal.

The approach being taken by USEPA in the initial round of permitting will tend to encourage balkanization because the smaller entities most likely will not have to obtain permits. The likely decision of a smaller city will be to delay as long as possible the day of reckoning, leaving only the cities over 100,000 going through the initial permitting process. Thus, limited portions of metro areas will be going through the initial permitting process, and there may be little incentive for a smaller community to participate and share in the cost of application requirements. Conversely, when the time comes for the smaller communities to obtain their permits the larger cities will have little incentive to assist the smaller communities unless their costs can be recovered or reduced.

Having said this, however, it simply makes sense to approach many of the stormwater quality issues on a

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regional basis. In locations with existing regional entities there may be efforts to obtain permits for the entire region. This could be done with both local general purpose governments and a regional entity being copermittees. The responsibilities of each party would have to be clearly stated so one party could not be held responsible if another party is violating a condition of their permit. The argument can be made to the small cities and counties that they will eventually have to get permits anyway, and it would be logical and could reduce long term costs for the whole metro area to be permitted at the same time. As previously noted, however, to expect all communities to volunteer to apply for permits before they are required to do so is being quite optimistic.

SUMMARY

The United States is heading toward a national requirement of regulating the discharge of pollutants from municipal separate storm sewer systems. The USEPA is now preparing regulations pursuant to the 1987 CWA adopted by the United States Congress that will set forth minimum requirements for the application by local governments for permits for their separate storm sewer discharges. The USEPA has published proposed regulations and is now evaluating comments received during the public comment period. USEPA in their proposed regulations targeted cities with 1980 populations exceeding 100,000. Smaller cities and unincorporated urban areas would eventually be required to obtain similar permits. The proposed regulations emphasize the development of stormwater management programs by the nation's urban areas that would reduce the discharge of pollutants in stormwater to the maximum extent practicable. The USEPA is proposing not to emphasize end-of-pipe standards, but instead to rely heavily on best management practices that would reduce stormwater pollutants to the maximum extent practicable.

The burden of implementing and funding the stormwater management programs will fall on local governments, namely cities and counties. There are no indications that federal or state funding support will be available. The permits that will be issued will specify what the local governments will be required to do as well as time frames for compliance. Local governments are concerned whether the regulations as proposed will have enough flexibility to adopt monitoring requirements and management plans to local conditions. The 1987 CWA provides for severe penalties if permit requirements are not met or if a municipality or county fails to apply for a permit within the time allowed.

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The enforcement provisions in the FWPCA will be a motivating factor for local governments to make serious efforts to submit permit applications in a timely manner and to take seriously compliance requirements. Civil actions may be taken by the USEPA or any citizen. Environment groups have been active in suing polluters and even the USEPA when USEPA has not properly implemented environmental laws. The USEPA also has stepped up enforcement of FWPCA provisions and resulting regulations. Consequently, local governments can look forward to active oversight regarding their response to USEPA regulations now being promulgated.

The regulation of stormwater quality will represent a significant effort in the United States. The cost or the effectiveness of the program is not known at this time, but the commitment of the United States to improving water quality expressed through Congress is clear. Clean water is a high priority, and the clean water effort has finally reached separate storm sewers.

REFERENCES

USEPA, Proposed Rule, "National Pollutant Discharge Elimination System Permit Application Regulations for Storm Water Discharges," Federal Register, Vol. 53, No. 235, p. 49443, December 7, 1988.

USEPA, "Notice of Proposed Rulemaking (NPRM) for National Pollutant Discharge Elimination System (NPDES) Permit Application Requirements for Storm Water Discharges," A summary, Office of Enforcement and Permits, November 23, 1988.

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THE REGULATION OF CSOs AND STORM WATER IN THE UNITED STATES

by James R. Elder[1]

In 1972, the Federal Water Pollution Control Act (referred to as the Clean Water Act or CWA), was amended to prohibit the discharge of any pollutant to navigable waters from a point source unless the discharge is authorized by a National Pollutant Discharge Elimination Systems (NPDES) permit. However, due to limited resources, efforts to control water pollution have traditionally focused on controlling pollutants in discharges from publicly owned treatment works (POTWs)[2] and industrial process wastewaters. This program emphasis has developed for a number of reasons. At the onset of the program in 1972, many sources of industrial process wastewater and municipal sewage were not adequately controlled, and represented pressing environmental problems. In addition, sewage outfalls and industrial process discharges were easily identified as responsible for poor, often drastically degraded water quality condition.

As discharges from POTWs and industrial process wastewaters have become increasingly under control, it has become evident that more diffuse sources of pollution are also major causes of water quality problems. Some diffuse sources of water pollution, such as agricultural storm water discharges and irrigation return flows, are statutorily exempted form the NPDES program. Controls

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[2] In the United States, most sewage treatment plants are owned by local government entities. Sewage treatment plants that are owned by local government entities are called publicly owned treatment works or POTWs.

for other diffuse sources have been slow to develop under the NPDES program.

Although assessments of water quality are extremely difficult to perform and verify, several National assessments of water quality are available. For the purpose of these assessments, urban runoff and other storm water discharges are considered to be a nonpoint source pollution, although legally, most urban runoff is discharged through conveyances such as separate storm sewers or other conveyances which are point sources under the CWA, and are subject to the NPDES program. The "National Water Quality Inventory, 1988 Report to Congress" provides a general assessment of water quality based on biennial reports submitted by the States under Section 305(b) of the CWA.

States are required to submit biennial reports listing water bodies that are not fully supporting designated uses and the pollution sources causing the use impairment. The 1988 Report indicates that a wide range of sources cause water impairment including combined sewer overflows (CSOs), separate storm sewer discharges, agriculture, silviculture, construction, resource extraction, and land disposal as well as POTWs and industrial process discharges. In general, POTWs and industrial process discharges are identified as each contributing to about 10 percent of the water quality impairment problems in lakes and rivers, with diffuse sources of pollution being responsible for most impairment.

As a result of these types of findings, and the 1987 amendments to the CWA requiring the implementation of NPDES requirements for storm water discharges, the Environmental Protection Agency (EPA) has begun to develop and implement National strategies to regulate both CSOs and storm water discharges.

NATIONAL CSO CONTROL STRATEGY

EPA estimates that there are approximately 1,200 communities with combined sewer systems, and these systems operate 15,000 to 20,000 CSOs, many of which are clustered in 'older' developed areas in the Eastern United States.

In a relatively few cities, major effort to control CSOs have already been undertaken. Varied control strategies have emerged, such as: Chicago's underground tunnel system; San Francisco's major interceptor system; a 400 million gallon per day swirl concentrator coupled with other collection system controls in

Washington DC; and the sewer separation projects undertaken by a number of cities.

However, the majority of communities have not adequately addressed CSOs. As a result, EPA issued the "National CSO Control Strategy" on August 10, 1989.

The CSO National Strategy established three objectives:

- To ensure that CSO discharges that do occur are only a result of wet weather; .
- To bring all wet weather CSO discharge points into compliance with the technology-based requirements of the CWA and applicable State water quality standards; and
- To minimize water quality, aquatic biota, and human health impacts from wet weather overflows.

The strategy requires each NPDES approved State with CSOs to develop and submit a state-wide CSO strategy for managing its CSOs to the Region for approval by January 15, 1990. The state-wide strategies consists of three parts:

1) an inventory of all CSO points in the State;

2) the current permit status of each CSO point; and

3) a list of the Stata's CSO priorities.

In addition, the strategy establishes guidance for minimum technology-based limitations, including:

A) proper operation and regular maintenance programs for the sewer system and combined sewer overflow points;

B) maximum use of the collection system for storage;

C) review and modification of pretreatment programs to assure CSO impacts are minimized;

D) maximization of flow to the POTW for treatment;

E) prohibition of dry weather overflows; and

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F) control of solid and floatable materials in CSO discharges.

Additional control measures may also be required on a case-by-case basis to address the particular circumstances of each combined sewer system and overflow point.

STORM WATER DISCHARGES

Since 1972, EPA has developed technology-based numeric standards or effluent guideline limitations for storm water discharges from ten classes of industries: cement manufacturing; feedlots; fertilizer manufacturing; petroleum refining; phosphate manufacturing; steam electric; coal mining; ore mining and dressing; mineral mining and processing; and asphalt emulsion.

However, most types of storm water discharges, including urban runoff in cities, have not been controlled under the NPDES program to date, even though many storm water discharges (with the exception of agricultural runoff) legally are considered point sources which are subject to the NPDES program under the CWA.

In 1987, Congress amended the CWA to require EPA to develop a phased program for regulated storm water discharges under the NPDES program.

Under the initial phases of the new program, the Agency is to begin to develop requirements for:

- storm water discharges associated with industrial activity;
- discharges from municipal separate storm sewer systems serving a population of 100,000 or more; and
- discharges which are designated by EPA or an NPDES approved State as needing an NPDES permit because the discharge contributes to a violation of a water quality standard or is a significant contributor of pollutants to waters of the United States.

The 1987 amendments to the CWA clarified and amended the requirements for permits for storm water discharges. The amendments clarified that permits for storm water discharges associated with industrial activity must meet all of the applicable technology-based and water quality-based requirements of the CWA. However, the amendments made significant changes to the permit requirements for discharges from municipal separate storm sewers. Section 402(p)(3)(B) provides that NPDES permits for such discharges:

(i) may be issued on a system- or jurisdiction-wide basis;

(ii) shall include a requirement to effectively prohibit non-storm water discharges into the storm sewers; and

(iii) shall require controls to reduce the discharge of pollutants to the maximum extent practicable, including management practices, control techniques and system, design and engineering methods, and such other provisions as the Director determines appropriate for the control of such pollutants.

EPA or NPDES States cannot require a permit for other storm water discharges until October 1, 1992. Prior to that time, EPA, in consultation with the States, is required to conduct two studies on storm water discharges. The first study will identify those storm water discharges or classes of storm water discharges for which permits are not required prior to October 1, 1992 and determine, to the maximum extent practicable, the nature and extent of pollutants in such discharges. The second study is for the purpose of establishing procedures and methods to control storm water discharges to the extent necessary to mitigate impacts on water quality.

Based on the two studies, EPA is required to issue regulations by no later than October 1, 1992 which designate additional storm water discharges to be regulated to protect water quality and establish a comprehensive program to regulate such designated sources. The program must, at a minimum, (A) establish priorities, (B) establish requirements for State storm water management programs, and (C) establish expeditious deadlines. The program may include performance standards, guidelines, guidance, and management practices and treatment requirements, as appropriate.

PROPOSED STORM WATER REGULATIONS

On December 7, 1988, (53 FR 49416), EPA proposed permit application requirements for storm water discharges associated

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with industrial activity and discharges from municipal separate storm sewer systems serving a population of 100,000 or more.

These proposed regulations represented a major shift to the NPDES system which has traditionally focussed on end-of-pipe treatment requirements. Instead of emphasizing end-of-pipe treatment for controlling discharges from municipal separate storm sewers, the program emphasizes the development of site specific municipal storm water management programs. The Agency envisions that municipal storm water management programs will generally have four major components:

- control of non-storm water discharges, including illicit connections, spills and improper dumping to municipal separate storm sewer systems;

- control of construction site runoff to the municipal separate storm sewer system;

- control of runoff from residential and commercial sites (this is what the Nationwide Urban Runoff Program or NURP called urban runoff) to municipal separate storm sewer systems; and

- control of industrial site runoff to municipal separate storm sewer systems.

EPA envisions that permit requirements for municipal separate storm sewer systems will be developed in a flexible manner to allow site-specific permit conditions to reflect the wide range of impacts that can be associated with these discharges. Permits for different municipalities will place different emphasis on controlling various components of discharges from municipal storm sewers.

STORM WATER STUDIES

The Agency has begun the development of two studies evaluating other storm water discharges. Two major classes of discharges will be addressed in the studies:

- discharges from municipal separate storm sewer systems; and

- non-municipal storm water discharges from individual facilities.

Municipal Separate Storm Sewer Systems

In the studies, EPA has begun to focus on municipalities that are part of urbanized areas which are defined by the Bureau of Census. These urbanized area are population centers of 50,000 or more people comprised of a central city with surrounding closely settled areas with a population density which is generally greater than 1,000 people.

In 1980, 139 million people, or 61 percent of the total population in the United States lived within 366 urbanized areas. These areas only covered 1.5 percent of the total land are of the United States. Portions of over 3,300 incorporated cities, towns and villages, 601 counties and about 600 unincorporated towns and townships are part of urbanized areas. These local governments account for only 18 percent of the nation's incorporated places, 19 percent of the counties and 4 percent of the unincorporated towns and townships.

EPA estimates that 141 of the 366 urbanized areas are served in part by combined sewer systems. The percentage of area within an urbanized area that is served by combined sewer varies considerably. The Agency estimates that CSOs serve as much as 25% of the population in all urbanized areas, while covering less than 7% of the total area of all urbanized areas. Almost all widespread new development involves separate storm sewers.

The studies will provide a description of a number of pollution sources which affect pollutants in discharges from municipal separate storm sewer system, including non-storm water discharges, construction site runoff, runoff from residential and commercial areas, and industrial site runoff.

Non-Storm Water Discharges

Preliminary information from the studies indicates that non-storm water discharges to municipal separate storm sewers can be caused by one or more of the following:

- illicit connections and cross connections from industrial, commercial and sanitary sewage sources;
- improper disposal of wastes;
- spills;

- leaking sanitary sewage systems; and

- malfunctioning septic tanks.

Most municipalities have not investigated their storm sewer systems for illicit connections or other non-storm water discharge problems. Case studies of cities which have investigated non-storm water discharges indicate that various cities reported different types of non-storm water discharges to their separate storm sewer systems. In some areas of older development, (pre-1972) illicit connections to separate storm sewers were prevalent. Some areas of newer development experienced fish kills caused by spills and improper dumping to the storm sewer system. An investigation of a municipal systems serving industrial land use indicated that concerns from a wide variety of spills, dumping and illicit connections.

Other Pollution Sources

Uncontrolled runoff from construction sites contains high levels of sediment. Pollutants in runoff from industrial land use areas depend on the type of industrial facilities, but in general have a higher potential to contain toxic constituents than other runoff and to be adversely affected by spills and poor material handling practices.

Runoff from Residential and Commercial Areas

Information from the Nationwide Urban Runoff Program (NURP) was used to characterize runoff from residential and commercial areas. In most urbanized areas, the annual discharge volume of runoff from residential and commercial areas is expected to be similar to the annual discharge volume of POTWs. However, the volume of discharges of runoff during most storm events is much greater than the volume of POTW discharges during the same period. Even where separate storm sewer discharges are not affected by either non-storm water discharges or runoff from industrial sources and runoff from construction sites, discharges of runoff from residential and commercial areas have high levels of heavy metals, sediment, bacteria, acidity and floatables relative to discharges from POTWs receiving secondary treatment. Runoff from these areas has concentrations of COD, BOD and oil and grease that are approximately equivalent to POTW secondary treatment discharges. Phosphorus and nitrogen concentrations in runoff from residential and commercials areas tend to be lower than discharges from POTWs, but may cause eutrophication in receiving waters under certain conditions. Discharge locations for POTWs and separate storm sewers also differ. POTWs tend to discharge to larger receiving waters with larger assimilative capacities or, in coastal areas, a significant distance offshore. Separate storm sewers are more diffuse, and discharge at many points within a drainage basin, including for coastal areas, at locations near shorelines.

Non-Municipal Individual Sources

Non-municipal storm water discharges can be classified into eight major classes:

- Mining and Oil and Gas Production Facilities;
- Animal Feedlots;
- Manufacturing Industries;
- Construction Activities;
- Waste Management and Recycling Facilities;
- Automobile Related and Transportation Facilities;
- Electric Power Generation Facilities; and
- Selected Wholesale Facilities

Identifying types of discharges and pollutants associated with the discharges is only an initial step to program development. The Agency must still address the challenge of developing effective regulatory programs for the large number of storm water discharges.

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OPTIMIZATION OF STORMWATER QUALITY CAPTURE VOLUME

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ABSTRACT

There is a need for rational, scientifically based, methods to size urban stormwater runoff facilities for the purpose of water quality enhancement. This paper describes a procedure that utilizes hydrologic principles for optimizing the capture volume. This procedure takes recorded precipitation data and processes it using a quasi-continuous simulation method to determine the number of storm events and total of storm runoff volume being captured within the period being studied. The application of this procedure is illustrated using a 40 year hourly rainfall record at the Denver Raingauge.

INTRODUCTION

The practice of urban stormwater management has until recently focused primarily on quantity issues such as drainage and flood control. Flooding of streets, streams, and rivers has been the main concern. Local governments have constructed thousands of miles of curb, gutter, road side ditches, and storm sewers to convey stormwaters as quickly and efficiently as possible to the nearest stream. This practice along with the increase in impervious surfaces accompanied by urbanization increases the volume and peak flow of runoff for any given rainfall event.

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Because development results in greater surface runoff rates when compared with undeveloped land, it is common for local governments to attempt mitigating these runoff increases by requiring developers to construct on-site stormwater detention facilities. The concept is to hold back runoff for a short period from each development in small ponds, on parking lots, or wherever space can be found at the site to temporarily store the water. However, on-site detention criteria varies considerably from community to community, the impact of muliples of on-site facilities is uncertain, and long term maintenance is not a sure thing when it comes to these randomly placed on-site detention facilities.

The alternative to developer constructed on-site detention facilities is regional detention sites. Most people agree that regoinal facilities are more cost efficient and are much more likely to be properly maintained because they would be owned and operated by a public entity. While preferred, it is difficult to fund regional detention. As a result, individual on-site detention requirements are still commonly enforced and the use of on-site detention is the most common approach.

Urban stormwater management, however, is changing quite rapidly from a focus on quantity to a focus on quantity and quality. Two basic issues have and are exerting considerable influence for this change. The first is a fundamental heightening of environmental awareness and concern by the public. There seems to be public support for environmental programs. Stormwater quality in general is probably not a serious problem in relation to concerns such as global warming, Love Canal, sludge disposal, or the Alaska oil spill, and excapt in some specific situations the impact of urban stormwater on receiving water bodies is not documented or understood. Nevertheless, urban stormwater along with non-point runoff from non-urban sources contribute pollutants to the receiving waters and efforts to do something about it are slowly picking up support and momentum.

The second factor causing a shift toward urban stormwater quality is the Water Quality Act of 1987 (WQA), which amended the Federal Water Pollution Control Act. The WQA of 1987 is a reflection of the public's support for pollution control, and such legislation gives focus and direction to general issues. The WQA requires the Environmental Protection Agency (EPA) to develop a National Pollutant Discharge Elimination System (NPDES) permit program for separate urban stormwater discharges. How the 1987 WQA may impact the citizens, communities, local governments, industry, consultants and the water quality across the United States is yet to be seen. Nevertheless, local governments and industries throughout the United States have a mandate from Congress to control pollutants in urban runoff to the "maximum extent practicable" (MEP). This hopefully means that Congress expects solutions to be practical, pragmatic, and economical.

In order to be practical and effective it is important that technologies for dealing with urban stormwater runoff be available that get the job done. Several simple technologies are emerging that willl be able to be used to remove pollutants from urban stormwater (Urbonas and Roesner, 1986), (Roesner, Urbonas and Sonnen, 1989). These include detention and retention basins, infiltration and percolation at the source of runoff, wetlands, sand filters, and combinations of these techniques. It is important to realize that the same design criteria used to design detention ponds to reduce peak flows cannot be used to design detention and retention basins for stormwater quality purposes.

It is clear from reading the 1986 and 1989 references cited above that the size of runoff event to be captured and treated is a critical factor in the design of stormwater quality detention and retention basins. For example, if the design runoff event is too small, the effectiveness will be reduced because too many storms will exceed the capacity of the facility. Or if the design event is too large, the smaller runoff events will tend to empty faster than desired for adequate settling of pollutants. Thus the larger basins may not provide the needed retention time for the predominant number of smaller events.

A balance between the storage size and water quality treatment effectiveness is needed. Grizzard et. al. (1986) reported results from a field study of basins with extended detention times in the Washington, D. C. area. Based on their observations they suggested that these basins provide good levels of treatment when they are sized to have an average drain time of 24 hours, which equates to a 40 hour drain time for a brim-full basin.

EPA (1986) suggested an analytical methodology for estimating the removal efficiencies of sediments in ponds that have surcharge storage above a permanent pool. Subsequently, Schueler (1987) suggested that the surcharge volume be equivalent to the average runoff event volume. Analysis by the authors in Denver using the EPA analysis technique indicates that wet ponds can be very effective in removing settleable pollutants (i.e., annual TSS removal rates in excess of 80 percent). However, this analysis was limited to ponds that have brim-full surcharge volume equal to one-half inch of runoff from the tributary impervious surfaces, with this volume being

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drained in 12 hours. Never-the-less, there remains little rationale for the sizing of the capture volume that results in reasonable pollutant load removal while providing reasonably sized cost effective facilities.

Until recently, the primary interest was in drainage and flood control. As a result, the focus was on the larger storm events such as the 2- to 100-year floods. Although drainage and flood control engineers traditionally consider the 2-year event as small, at least in the Denver area it is larger than 95 percent of all the runoff events that typically occur in an urban watershed. Also, through experience we have learned that a detention facility designed to control a 100-year, or even a 2-year flood has little, if any, effect on water quality. Thus, focusing on the traditional drainage design storms is not practical or desirable when considering stormwater quality.

This paper will discuss a method that can be used to find a point of diminishing returns for the sizing of water quality detention facilities. It utilizes rainstorm records as its base instead of synthesized design storms. An example based on tha National Weather Service long term precipitation record in Denver is used to illustrate the suggested methodology.

MAXIMIZATION OF STORMWATER RUNOFF CAPTURE VOLUME

Rain Point Diagram.

In 1976 von den Herik (1976) suggested in Holland a rainfall data-based method for estimating runoff volumes. This method is based on long term record of total rainfall and duration of storms. Subsequently Pecher (1978 & 1979) suggested modifications to von den Herik's work to use in the sizing of detention facilities through the use of a Rain Point Diagram (RPD). The authors modified the original method to transform the RPD to a Runoff Volume Point Diagram (RVPD) by multiplying the individual rainstorm depths on the RPD by the runoff coefficient of the tributary watershed.

The PVPD method approximates continuous modelling without setting up a continuous model. The method requires combining individual recorded hourly or 15 minute rainfall increments in a given period of record into separate storm depth totals. Separate storms are identified by a period of time when no rainfall occurs. Very small storms that are not likely to produce runoff can be then be purged from the record. Rainfall storm totals were then converted to runoff depths (i.e.,

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volumes) by multiplying the rainfall depth by the watersheds runoff coefficient (C).

Because the RVPD procedure has not taken into account the effects of several successive rainstorms, it would have a tendency to underestimate the capture effectivenes of detention facilites that have very low release rates. This is because the volume captured during one storm may not be fully drained before the next storm occurs. The RVPD assumes an empty basin for each event.

The procedures used to develop the RVPD method and a case study using the Denver rain gage data will be discussed subsequently. However, to illustrata the use of the RVPD a plot of 63 storms is shown in Figure 1, where the individual storm runoff depth in inches is plotted agaist storm duration. A runoff capture envelope is also plotted on this same figure. This captured storage envelope is bases on the "brim-full" volume of the detention facility and its emptying time. In Figure 1 the runoff capture envelope is based on a detention basin that has a brim-full capacity of 0.3 watershed inches which can be emtied throughthe outlet in 12 hours (sometimes called drawdown time).

All the points above the capture volume envelope line represent individual storms that have sufficient runoff to exceed the available storage volume (i.e., brim-full volume) of the detention facility. Obviously, plotting and counting all points for a long record of rainstorms is a very tedious job. As a result, the authors developed a software package to perform this task.

While this procedure is a simplification of a continuous modelling process, the results should be sufficiently accurate for general planning purposes. This conclusion is supported by the fact that the true accuracy of hydrologic calculations is significantly less than the precision implied by stormwater hydrology models (ASCE, 1984) that are commonly used.

To compensate for storms that may be closely spaced, the authors used a storm separation interval equal to one-half of the emptying time of the brim-full volume. In other words, a storm was defined as separate from a previous storm when this separation condition was satisfied between the end of the last recorded rainfall increment and the beginning of the next one.

The sensitivity of the storm separation period was tested using a storm separation period equal to the brim-full volume emptying time. Virtually no difference was found in the capture volume effectiveness between the separation set at brim-full and one-half of the brim-full

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emptying time. Such sensitivity tests are suggested whenever other precipitation data are used for this procedure.

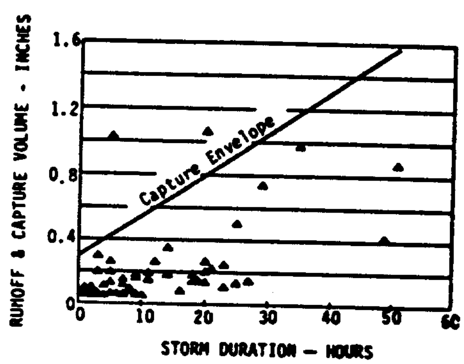

Figure 1. Runoff Volume Point Diagram and Capture Volume Envelope. (1-inch = 24.5 millimeters)

Storage Volume Optimization Procedure

After the total rainfall record is separated into individual storm events, the runoff volume for each storm can be estimated using:

$$V_r = C\ P_t \qquad (1)$$

in which, V_r = total runoff volume for a storm, in watershed inches or meters
C = runoff coefficient
P_t = total precipitation over the watershed for the storm in inches of meters.

For a given detention pond or basin that has a brim-full volume V_p with an emptying time T_e, its average release rate, q, is

$$q = V_p / T_e \qquad (2)$$

The runoff volume capture capacity, V_m, of the detention basin for any storm may be estimated using:

$$V_m = V_p + q\ T_d \qquad (3)$$

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in which, T_d = storm duration. The function ($q\ T_d$) represents the storage beyond the brim-full volume that becomes available during the strom as the result of releases from the basin during the storm's duration.

The actual runoff volume captured and processed for quality improvement through the basin for a given storm is equal to V_r, namely storm runoff volume, when V_r is less than V_e; otherwise it is equal to V_m with the excess runoff volume assumed to overflow without any treatment. Adding the volumes captured for all the storms occurring during the record period gives the total volume captured and treated, V_t, within the period. Thus, the volume capture ratio for the period of rainfall record is defined as,

$$R_v = V_t \ / \ V_{tr} \qquad (4)$$

in which, R_v = volume capture ratio for the record period
V_t = total volume captured during the period
V_{tr}= total runoff volume during the same period.

Similarly, the runoff event capture ratio is defined:

$$R_e = N_f \ / \ N \qquad (5)$$

in which, R_e = runoff event capture ratio for the period
N_f = number of runoff events that are less than or equal to V_m in runoff volume
N = total number of runoff events.

For the total set of runoff events in the record there is a detention volume that will capture all of the runoff events of record. For practical reasons this maximum pond volume, P_m, was defined to be equal to the 99.9 percent probability runoff event volume for the record period. For the Denver raingage period of record studied (1944-1984) this is equal to to the runoff from 3.04 inches (77.2 mm) of precipitation, or 6.9 times the precipitation of an average runoff producing storm for this period of record. This 99.9 percentile value, namely P_m, was then used to normalize all pond sizes being tested using the following equation:

$$P_r = P \ / \ P_m \qquad (6)$$

in which, P_r = relative pond size normalized to P_m
P = pond size being tested
P_m = maximum runoff volume (i.e., 99.9% probability).

The maximization procedure incrementally increases the relative (i.e., normalized) pond size and calculates

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the runoff volume and event capture ratios (i.e., R_v and R_e) using the RVPD method. Figure 2 illustrates an example of the results of such an analysis using the precipitation record at the Denver gauge between 1944 and 1984. In this example the capture volume was maximized using storms defined by a 6-hour period of separation, 12-hour emptying time for the brim-full basin, and a runoff coefficient C = 0.5 for the watershed.

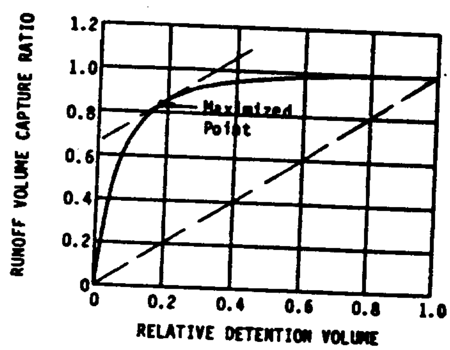

Figure 2. Maximizing Capture Volume.

The maximized pond size occurs where the 1:1 slope is tangent to the runoff capture rate function. Before this point is reached the capture rate increases faster than the relative capure volume size. After this point is reached the increases in the capture rate become less than than corresponding increases in relative capture volume size. In other words, when the point of maximization is passed, diminishing returns are experienced if the capture volume is increased any further. In Figure 2 example, the maximized point occurs when the relative capture volume is equal to 0.18. At this point we capture in total and release slowly approximately 82 percent of the entire runoff depth that has occured during the 40 year study period. This relative capture volume is then converted to actual volume using Equation 6, namely,

$P = P_r\ P_a$
$= (0.18)\ (0.5\ 3.04)$
$= 0.27$ watershed inches (6.86 millimeters)

in which, 0.5 is the watershed's runoff coefficient and P_e = 3.04 inches (77.2 mm), namely the depth of rain during the 99.9 percent probability storm.

CASE STUDY USING DENVER RAIN GAUGE DATA

Developing Regional Detention Sizing Guidelines.

The authors investigated the Denver Gauge precipitation data using several storm separation periods, which has been defined as the time between the end of one storm and the beginning of the next. A statistical summary of rainfall characteristics for all storms that exceeded a total of 0.1 inch (2.54 mm) is given in Table 1. A 0.1 inch (2.54 mm) "filter" was used to eliminate from the record the very small storms, of which most are likely not to produce runoff. The urban rainfall and runoff data in the Denver area indicate that approximately 0.08 to 0.15 inches (2.03 to 3.81 mm) of rainfall depth is the point of incipient runoff.

TABLE 1. DENVER RAIN GAUGE HOURLY DATA SUMMARY 1944-1984 STORMS LARGER THAN 0.1 INCHES (2.54 mm) IN DEPTH

SEPARATION BASIS FOR NEW STORM (HOURS)	NUMBER OF STORMS	AVERAGE DEPTH (INCHES)	AVERAGE STORM DURATION (HOURS)	AVERAGE TIME BETWEEN STORMS (HOURS)	NUMBER OF STORMS SMALLER THAN AV.	PERCENT OF STORMS SMALLER THAN AV.
1	1131	0.39*	7	267	802	70.9
3	1091	0.42*	9	275	782	71.7
6	1084	0.44*	11	275	766	70.7
12	1056	0.46*	14	280	748	70.8
24	983	0.51*	23	293	686	69.8
48	876	0.58*	43	310	613	70.0

* Multiply values by 25.4 to convert to millimeters.

A skewed statistical distribution exists with more than two-thirds of the storms having less precipitation than the 40 year average storm depth. Appearently in the Denver area the average runoff producing rain storm depth is a relatively large event.

The distribution of all (i.e., unfiltered) storms vs. total storm precipitation depth when individual storms are defined by a six hours separation period is shown in Figure 3. Note that sixty percent of the precipitation events produced 0.1-inches (2.54 mm) or less of rainfall depth. Over ninety percent of all recorded storms had 0.5-inches or less of rainfall depth. This indicates that the focus, at least in the Denver area should be on the smaller, more frequently occurring storms whenever water quality is being considered.

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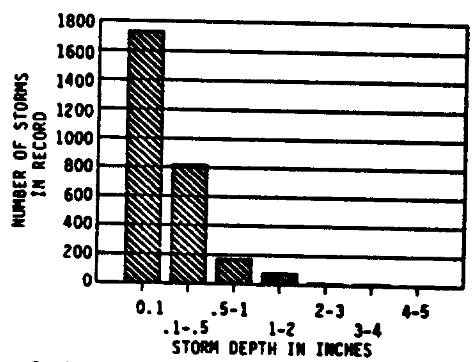

Figure 3. Number of Storms in Denver vs. Storm depth. (One inch = 25.4 millimeters)

Once the precipitation and runoff probabilities were understood, an attempt was made to find a simple yet reasonably accurate relationships for approximating the maximized capture volume of water quality detention basins. As described earlier, the maximized point was defined when additional storage resulted in rapidly diminishing numbers of storms or in the storm runoff volume being totally captured. The final result of this analysis is illustrated in Figure 4, which relates the maximized capture volume to the watershed's runoff coefficient. Separate relationships are shown for the brim-full storage volume emptying time of 12-, 24- and 40-hours.

The captured volume ratio for this relationship exceeds 80 percent and the storm event capture ratio exceeds 86 percent. The storm event capture ratio is of greater importance to the receiving waters because it is the frequency of the shock loads that has the greatest negative effect on the aquatic life in the receiving streams. On the other hand, examination of the precipitation records (i.e., Figure 3) indicates that the volume capture ratio is influenced significantly by the very few very large storms. During these very large runoff events catastrophic flooding is likely to be of primary concern and stromwater quality. It should also be noted that even in these larger events some degree of capture and treatment occurs, although at somewhat reduced efficiency since the detention capacity is exceeded.

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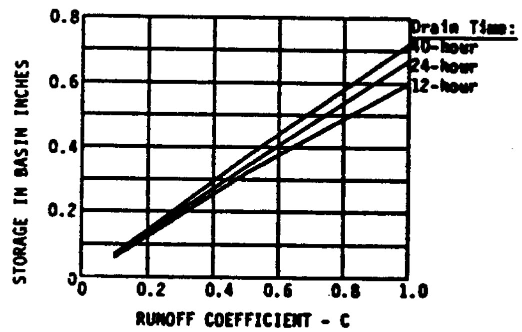

Figure 4. Maximized Capture Volume for Water Quality, Denver Rain Gauge 1944-84 Period. (One inch = 25.4 millimeters)

SENSITIVITY OF PROCEDURE

Capture Volume

Understanding the sensitivity of the event capture ratios to a change in the design capture volume (i.e.. brim-full volume) helps to rationally size water quality facilities. To help define this sensitivity a watershed having a runoff coefficient of C = 1.0 and a storage basin having the maximized volume draining in 12 hours was analyzed. The design capture volume of the basin was increased and decreased in increments and the results were normalized around the maximized volume point. Figure 5 illustrates the findings for this particular case. Although the results varied somewhat between similar tests, the trend was virtually the same for each test that were made using the Denver rain rauge data.

At the ratio of 1.0 on the abcissa, the capture volume has to be almost doubled to capture an additional 10 persent of the runoff events in the fecord. On the other hand, reducing the capture volume by 25 percent results in the reduction of only eight percent in the runoff events that are not captured in total. It needs to be understood that failure to capture a runoff event in total does not mean that the facility will not remove suspended solids. Suspended solids will be removed, but

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at a somewhat diminished efficiency. The sensitivity of the facility's solids capture efficiency will be discussed next.

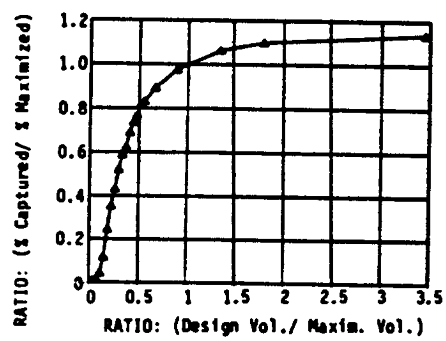

Figure 5. Sensitivity of Capture Volume Size.

__Removal of Suspended Sediments__

An attempt was made to test the sensitivity of the surcharge detention volume above the permanent pool level on the annual removal rates of total suspended solids in stormwater. For lack of local data on sediment settling velocities, the data given by EPA (1986) was use for several capture volume sizes. Estimates were made of the dynamic removals during the runoff events and the quiescent removals in the pond between storms. When using a surcharge capture volume equal to 70 percent of the maximized volume, the annual removal of TSS by the pond is estimated at 86 percent. This compares to an estimated rate of 88 percent annual removal of TSS when using the maximized capture volume, and only a 90 percent removal rate when using twice the maximized volume.

It appears from the preliminary estimates made using the Denver rain gauge records that it is posible to reduce the capture volume for a wet detention pond and see virtually no effect on the annual removal efficiency of the facility. Figure 5 suggests that the the design volume could be set 25 to 35 percent less than the maximized capture volume. Obviously this suggestion needs more testing. If verified, savings in the construction of water quality enhancement facilities should be possible. Continuous modelling and field testing are suggested as posible methods to test this premise.

Extending the Design Procedure

It is clear from the sensitivity analysis that the capture volume may be reduced somewhat from the maximized point without a significant loss in effectiveness. The designer or the water quality administrator may want to target the capture volume size to serve a runoff event of a desired recurrence probability such as the 85%, 80% or lesser runoff event. Figure 6 illustrates the type of relationships that can be developed if such a goal is desired. Obviously economics and practicality of the capture volume size should be considered when selecting the stormwater quality sizing criteria.

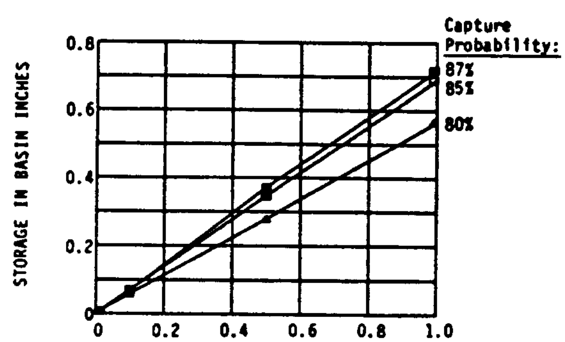

Figure 6. Capture Volumes for a 40-hour Drain Time and Several Runoff Event Capture Probabilities.

From our analysis of the Denver rain gauge data, it looks reasonable, logical and prudent to target the capture of approximately 80th percentile runoff event. This means that the detention facility can be reduced by about 25 to 30 percent in size make it more affordable, while still capturing in total 92 percent of the storm events. When the reduced detention facility is analyzed for impact on the average annual removal in total suspended solids, the difference from the maximized size in water quality being released to the receiving waters is

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practically not measurable. In other words, the 80 percentile capture volume should provide very good long term TSS removal rates. Also, basins of this size should fit easily within either on-site detention facilities designed for control of runoff peaks or within most landscaping areas of new developments.

At the same time, the removal of dissolved nutrients, such as phosphorous or nitrates, is primarily the function of residence time within the permanent water pool of the "wet pond" between storms. Increasing the capture volume above this pool should have little effect on the removal efficiencies of these compounds. Similarly, "dry ponds" have limited removal efficiencies of dissolved nutrients since their primary removal mechanism is sedimentation (Grizzard, et. al., 1986; Schueler, 1987; Roesner, et. al., 1988; Stahre and Urbonas, 1988).

DETERMINATION OF RUNOFF COEFFICIENT

Using Figure 4 or Figure 6 it is possible to quickly estimate an effective size of a stormwater quality detention basin. Since the engineer has to address smaller runoff events when dealing with stormwater quality, an appropriate runoff coefficient needs to be used. In 1982 EPA published data as part of the NURP study on rainfall depth vs. runoff volume. Although EPA did acknowledge some regional differences, much of the United States was found to be well represented by the data plotted in Figure 7. The curve in this figure is a third order regressed polynomial with the regression coefficient $R^2 = 0.79$. This value of R^2 implies a reasonably strong correlation between the watershed imperviousness, I, in percent and the runoff coefficient, C, for the range of data collected by EPA. Since the NURP study covered two year period, in our opinion this relationship is justified for 2-year recurrence probability and smaller storms.

EXAMPLE OF BASIN SIZING

An example is used next to demonstrate how to determine a "maximized" capture volume for an extended detention basin. A 100 acre (40.5 hectares) multi-family residential tributary watershed that has 60 percent of its area covered by impervious surfaces is used as the example conditions.

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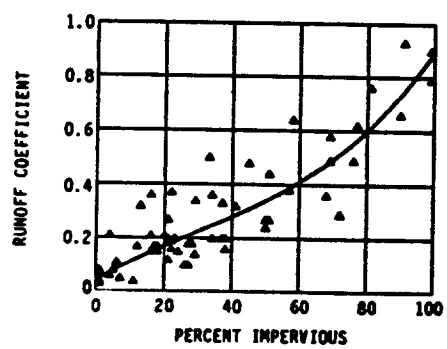

Figure 7. Runoff Coefficient Based on NURP Data for 2-year and Smaller Storms.

Using Figure 7 the runoff coefficient for the watershed, C = 0.4, is estimated. A well performing extended detention basin, according to Grizzard, et. al. (1986), needs to capture approximately the mean seasonal runoff and release it over a 24 hour period, which they suggested could be accomplished if the brim-full volume is drained in 40 to 48 hours. Thus, using the 80 percentile curve on Figure 6 and a brim-full drain time of 40 hours a design volume of 0.22 watershed inches (7.62 mm) is obtained. This is the runoff from a 0.55 inch (14 mm) storm and equates to 1.8 acre feet (2,300 cubic meters) of storage.

CONCLUSIONS

An investigation of sizing stormwater quality facilities for maximized capture of stormwater runoff events and their performance in removing settleable pollutants revealed that simplified design guidelines are possible. These guidelines can be developed using local or regional rain gauge records.

The procedure for the development of these simplified guidelines uses a Runoff Volume Point Diagram method to approximate a continuous simulation process in combination with an optimization routine. This procedure was converted by the authors into computer software.

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Using the Denver rain gauge for the testing of this procedure, a figure was prepared that relates a watershed's runoff coefficient, required capture volume and the drain time for this volume. The procedure consists of the following steps:

1. Reduce the recorded rain gauge record (preferably hourly or 15-minute record) to a Rain Point Diagram using several storm separation periods.
2. Transform these Rain Point Diagrams into a Runoff Volume Point Diagrams by multiplying the individual rainfall depths by the watershed's Runoff Coefficient. This can be done for three or more values of C, such as C = 0.1, 0.5 and 1.0 to provide several points on the final design curves.
3. Process the Runoff Volume Point Diagrams through the optimization procedure described earlier using several capture volumes and brim-full storage volume drain times. Suggest using a Runoff Volume Point Diagram that was prepared using a time of storm separation equal to one-half of the desired brim-full drain time.
4. Plot all of the results on a figure similar to Figure 4 for the specific precipitation gauge being used.
5. Perform sensitivity analysis and if appropriate offer options for the sizing of capture volume for several levels of capture probability (eg. Figure 6) and/or TSS removal.

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DESIGN CRITERIA FOR DETENTION POND QUALITY

by Thorkild Hvitved-Jacobsen[1]

Introduction

A wet detention pond is a structural measure which might reduce potential pollutant impacts on receiving waters from separate sewered catchments. In this introduction the need for urban stormwater pollutant removal will be discussed.

A distinction between acute and accumulative effects in receiving waters is of major importance with respect to urban runoff pollution from combined sewer overflows (CSO's) as well as stormwater runoff (SWR). Acute effects like dissolved oxygen depletion and bacterial contamination are almost exclusively associated with CSO. Accumulative effects like eutrophication due to nutrient discharges and deterioration of the ecosystems from heavy metals and organic micropollutants may be seen in receiving waters from both CSO and SWR. These accumulative effects are related to yearly - or seasonal - loads of pollutants.

Whether CSO or SWR plays the more important role is not only dependent on the relative size of the effective catchment areas but also on the discharged volumes and the concentrations in the urban runoff. Characteristic values of nutrients and heavy metal concentrations in the runoff water from Danish combined sewered catchments - including contributions from resuspended solids in the sewers but exclusive of sewage contributions - and from separate sewered areas are shown in table 1. Typically, heavy metal concentrations are of similar order of magnitude for these two sources whereas nutrient concentrations are a factor of about 5 lower in SWR. However, on a yearly basis discharged volume per unit area of a

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separate sewered catchment is normally considerably higher than from a combined sewered area depending on the actual sewer design and detention capacity. Therefore, even for the nutrients, it is often seen that the discharged yearly amount per unit effective hectare (total area reduced by runoff coefficient) of a separate sewered area is of similar order as from a combined sewered catchment (Hvitved-Jacobsen and Jensen, 1988). For the heavy metals it can be concluded that the specific load from separate sewered areas normally plays the more important role.

Table 1. Concentrations for calculation of pollutant loads from combined and separate sewered catchments. Values recommended by a sub-committee under the Danish Water Pollution Control Committee (PH-consult, 1989).

	combined sewer system		separate sewer system
pollutant	extreme event median value*	flow proportional mean value	flow proportional mean value
SS (mg/ℓ)	120-240	100-200	30-100
COD (mg/ℓ)	100-150	120	40-60
BI_5 (mg/ℓ)	-	25	irrelevant
tot.N (mg/ℓ)	irrelevant	10	2
tot.P (mg/ℓ)	irrelevant	2.5	0.5
Pb (µg/ℓ)	irrelevant	100-150	50-150
Zn (µg/ℓ)	irrelevant	300-500	300-500
Cd (µg/ℓ)	irrelevant	1-1.5	0.5-3
Cu (µg/ℓ)	irrelevant	30-40	5-40
E.coli (100 ml^{-1})	10^7-10^8	irrelevant	10^3-10^4

* These values should be multiplied by a factor (about 1.5-3) dependent on the return period for the design event.

Apart from source control such as soil infiltration, the possibilities of pollutant reduction from stormwater runoff are limited. Since the 1950's almost all new developed urban areas in Denmark have been separately sewered. The situation today is that about 45% out of a total of about 750 km^2 effective urban areas have separate sewers. The need for control of stormwater runoff pollutants discharged is a question of the absolute as well as the relative amount of pollutants coming from these sources compared with CSO's and dry weather sources like wastewater treatment plants. Furthermore, receiving waters like lakes, and to some extent streams and estuaries, need to have loadings of nutrients and eventually heavy metals from SWR reduced in order to improve water quality. The reduction of nutrients in the daily flow from the wastewater treatment plants to 8 mg total N/ℓ and 1.5 mg total P/ℓ effective from 1993 will increase the need for reduction of the wet weather sources.

Also, it is important to appreciate that most lakes in Denmark are phosphorus and not nitrogen limited and that the urban non-point phosphorus sources play a relatively more important role than nitrogen if compared with rural non-point sources (Hvitved-Jacobsen, 1986). Therefore, it is often seen that if a reduction of phosphorus stormwater loadings especially to urban lakes was possible, the receiving water quality might improve.

It must be emphasized that no single control strategy is the complete answer for improving receiving water quality in terms of nutrient and heavy metal impacts. Removal of these pollutants from SWR in detention ponds is probably one of the few realistic possibilities that simple control devices can achieve. Also it should be mentioned that nutrient reduction from SWR should be decided based on site specific investigations and needs and not required generally.

The concept of wet detention ponds

The concept of detention ponds in separate sewered catchments as a stormwater quality control measure is new in Denmark. As far as the author knows the first detention pond designed for urban runoff pollutant removal is now under construction and will be put into operation in December 1989. Traditionally, these ponds have been employed for flood and flow control only. Although design procedures for detention ponds with the dual purpose of stormwater quality and quantity control have been proposed, the basis for design and operation is still not well known (Ellis, 1985; Urbonas and Ruzzo, 1986).

The purpose of this paper is to highlight pollutant removal in detention ponds and discuss current practice for engineering design and operation procedures for these ponds from a Danish point of view. It is important to stress that the actual design procedure is rather crude. More research is needed - especially concerning physical, chemical and biological processes for pollutant removal and accumulation - in order to obtain the fundamental basis for improved design criteria. Also the hydraulics of these detention ponds determined by the inflow and outflow structures, the pond geometry and operation during wet weather periods must be taken into account in order to simulate long term pollutant removal efficiencies based on a historical rainfall record.

The main characteristics for the detention ponds which will be discussed in this paper is the existence of a permanent water volume during inter-event dry periods between successive storms. Therefore, these detention ponds are referred to as wet. Due to this permanent water volume, pollutants in the stormwater runoff are given a residence time before discharge to receiving waters determined by runoff and pond characteristics. Pollutant removal from the water phase by degradation and accumulation in the sediments and plant biomass may take place and thus reduce pollutant mass loadings to receiving water bodies.

Different systems for wet detention ponds can be proposed. Two types are shown in figure 1 and 2 (Cowiconsult, 1989). In the following, emphasis will be given to design characteristics for the type shown in figure 1.

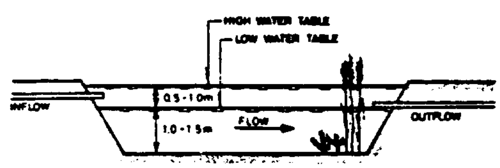

Fig. 1 Principle of a wet detention pond with horizontal flow. Submerged plants as well as marsh plants may be present.

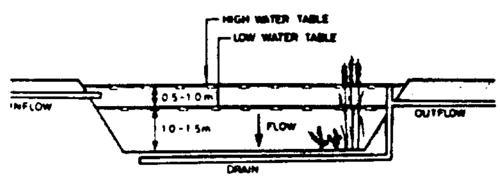

Fig. 2 Principle of a wet detention pond with vertical flow through a stone filter bottom. Rooted plants may be present.

A wet detention pond as a pollutant trap

It is well known that loadings of nutrients, heavy metals and organic micropollutants can accumulate in lakes. The lake sediments particularly act as a pollutant trap and under proper conditions in the water phase and in the sediments an essential part of the loadings may be permanently retained. Furthermore, nitrogen may be partly nitrified and denitrified resulting in a removal from the entire lake system.

It is important to realize that the removal processes taking place in a lake system have also been found to be effective in wet detention ponds (Hvitved-Jacobsen et al., 1984). Therefore, it is obvious to use these pollutant removal processes as a principle of treatment for urban stormwater runoff by the establishment of wet detention ponds. It is a fundamental requirement that these ponds should be considered as treatment facilities and therefore designed and operated based on an optimal function of the removal processes.

In addition it should be mentioned that these wet detention ponds may be effective in case of an accident in the catchment area, e.g. spill of oils and chemicals, which otherwise would result in harmful effects to the receiving water system.

Background for wet detention pond design

The basis for the design procedure which will be discussed in this paper is a result of national investigations as well as experiences from other countries, especially the US. The first Danish investigations in a pond system receiving stormwater runoff were carried out near Copenhagen during the period 1979-80 (Vandkvalitetsinstituttet, 1981). These investigations were oriented towards the loading-effect relationships and not performed as a basis for wet detention pond design. Until now only one Danish investigation include this concept (Hvitved-Jacobsen et al., 1987). From this investigation the general conclusion was as follows:

> For a wet detention pond with a surface area of approximately 1.4% of the effective catchment area the mass removal in the pond for SS, tot.P, Zn, Cd, Pb and Cu varied between 45 and 90%. These findings were based on the study of 10 storm events routed through the pond which - accidentally - through 10 years has been in operation as a stormwater wet detention pond. A study of the upper 12 cm of the

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sediments and the interstitial water verified that accumulation of phosphorus and heavy metals took place.

Available knowledge from other investigations has also been useful for the development of design principles. Especially the reported studies in USEPA (1983) and USEPA (1986) should be mentioned. These publications summarise several useful investigations.

Design principles

In the following, design principles and criteria for wet detention ponds with horizontal flow will be outlined and discussed. The following details will be emphasized:

- Wet detention pond volume
- Water depth and variations
- Eutrophication and plantation
- Establishment of a catch basin
- Specific pond characteristics

Wet detention pond volume

The fundamental criterion for determination of the pond volume is to achieve sufficient residence time for the pollutants in the pond in order to allow removal processes to take place. These processes include a great number of physical, chemical and biological processes like sedimentation, adsorption, biological uptake and particle exchange processes in the water phase as well as in the sediments. The relative importance of these different processes are not sufficiently known today but will probably play an important role for determination of a sound design principle in the future. Pollutant removal equations have been proposed e.g. the following based on first order kinetics by Goforth et al. (1983):

$$R = R_{max} (1 - \exp(-k \cdot t))$$

where R = pollutant removal efficiency
R_{max} = maximum removal efficiency
k = first order removal rate
t = treatment time in the pond

Due to the lack of available information on process design, rather crude criteria to achieve sufficient residence time in the pond have been proposed. In USEPA (1986) a pond volume of 100-200 m³ per effective hectare of catchment area is recommended in order to obtain an average value of 60% removal for phosphorus.

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Observed mass removal of total phosphorus and suspended solids in wet detention ponds can be correlated with the ratio of detention pond volume to runoff volume from mean storm events as shown in figure 3 (USEPA, 1986 and Hvitved-Jacobsen et al., 1987). From these investigations it is seen that the residence time for the runoff water - and the associated pollutants - play an important role for the determination of the pond volume.

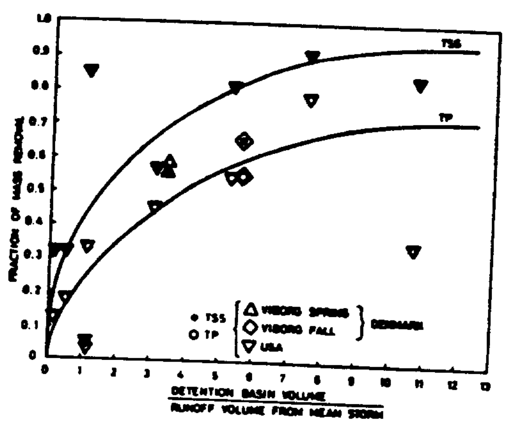

Fig. 3 Mass removal for total phosphorus and suspended solids versus the ratio of detention pond volume to runoff volume from mean storm events. Results from the Danish investigation (the city of Viborg) are compared with the results from 8 different wet detention ponds in the USA.

In order to obtain sufficient residence time for pollutant removal in a wet detention pond it seems important as a basic criterion to ensure sufficient length of an inter-event dry period between successive rainfall events. The rainfall record for the city of Odense, Denmark, was used for this purpose (Johansen and Harremoës, 1979). This series contain complete rainfall data for 33 full years i.e. the total of 1571 storm events with rainfall depths ≥ 3 mm. It is believed that rainfall events < 3 mm will have only a marginal effect on the pollutant removal efficiency. Figure 4 depicts rainfall depths for inter-event dry periods between 2 and

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96 h and for low return periods between 3 months and 3.3 years (Hvitved-Jacobsen and Yousef, 1988). Based on observations it seems reasonable to select about 72 h as a minimum inter-event dry period to allow sufficient time for pollutants removal (Hvitved-Jacobsen et al., 1984 and Yousef et al., 1986). If in addition a 4-6 month return period for exceeding the inter-event dry period is accepted for designing detention ponds, 250-300 m^3 per effective hectare should be recommended for a wet detention pond. Based on investigations and model computations this volume is for example expected to result in about 60% removal of phosphorus (Hvitved-Jacobsen et al., 1987 and Toet et al., 1989).

It should be mentioned that the curves shown in figure 4 are sensitive to the choice of the 3 mm rainfall depth limit for the rainfall record. If the hydraulics of the detention pond is known, probably different curves would be obtained if the runoff water was routed through the pond. However, it seems important to obtain inter-event dry periods with minimum disturbance of the water column - except for small runoff events corresponding to < 3 mm of rainfall depth and wind induced mixing - in order to ensure quiescent conditions in the water phase for improved particle sedimentation.

Moreover, it is important to note that the design procedure proposed does not directly allow consideration of physical, chemical and biological reactions or hydraulic factors in the design criterion. These matters will be emphasized in subsequent studies.

<u>Water depth and variations</u>

Because of the required retention of nutrients (phosphorus) and heavy metals in the sediments of a wet detention pond, aerobic conditions in the water phase and in the top layer of the sediments should be predominant. Furthermore, for aesthetic reasons and to maintain an acceptable level of aquatic life, the dissolved oxygen concentration should be recommended > 4 mg O_2/ℓ.

Due to the demands for an acceptable dissolved oxygen level a fairly shallow detention pond should be recommended. Also this corresponds for security reasons with the intention to let these ponds form parts of recreational facilities in city areas. A maximum water depth under steady state dry weather conditions equal to 1.0-1.5 m should be recommended.

During a runoff event this steady state level will increase. The need for detention capacity versus flow from the detention pond is shown in figure 5 for low

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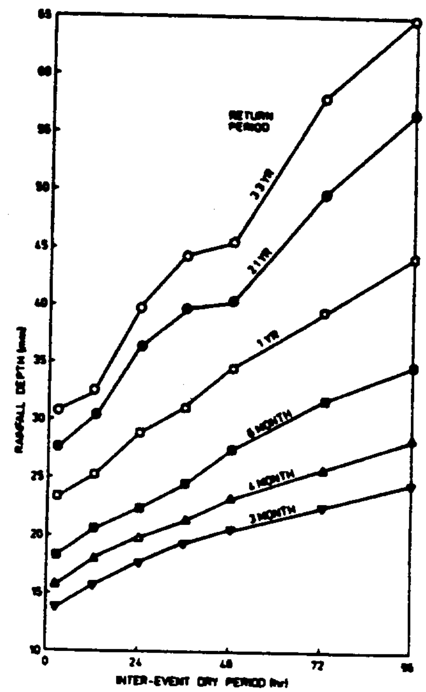

Fig. 4. Rainfall depth - inter-event dry period - frequency curves for low return periods based on the Odense rainfall record.

return periods for exceeding design capacity (Spildevandskomiteen, 1984). As can be seen in figure 5 moderate outflow rates from the pond and return periods about 0.5 year require in addition to the steady state dry weather volume about 100 $m^3 \cdot eff.\ ha^{-1}$. Therefore, during wet weather the total water depth may vary temporarily up to 1.5-2.5 m before overflow from the pond takes place.

What has been mentioned should just be considered as typical levels. For each case specific demands should be taken into account and calculations carried out.

As an example tha dissolved oxygen variations in a wet detention pond should be discussed based on the following conditions:

- Water depth 2 m.
- Reaeration rate from the atmosphere at low wind speed (0-3 $m\cdot s^{-1}$) immediate above the water surface at 20 °C:

  low: $K_L = 0.2\ m\cdot d^{-1}$
  moderate: $K_L = 0.4\ m\cdot d^{-1}$
  high: $K_L = 0.6\ m\cdot d^{-1}$

  These values should under Danish climate conditions be considered as minimum values (Downing and Truesdale, 1955; Thibodeaux, 1979 and Aalderink et al., 1986).
- Sediment oxygen demand, SOD = 2 $gO_2\cdot m^{-2}\cdot d^{-1}$.

  In lakes SOD varies considerably (0.02-2 $gO_2\cdot m^{-2}\cdot d^{-1}$). High values are obtained during summer periods in eutrophic lakes.
- A zero order dissolved oxygen consumption rate for the water phase equal to 0.5 $gO_2\cdot m^{-3}\cdot d^{-1}$. This value should be considered as high.
- Summer conditions; i.e. 20 °C.

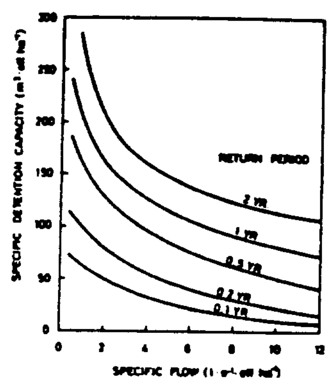

Fig. 5. Required specific detention capacity versus specific flow from detention pond for low return periods based on the Danish rainfall record from the city of Odense. The curves are valid for a full flowing runoff time < 20 min.

Based on a relatively simple dissolved oxygen model for a shallow, fully mixed pond, the following results have been obtained:

Under steady state conditions and based on three levels of reaeration rates (low, moderate and high), dissolved oxygen values of 0, 1.5 and 4 $gO_2 \cdot m^{-3}$ were calculated. For low and moderate reaeration rates a reduction from 7 to 4 $gO_2 \cdot m^{-3}$ should be reached after 2.6 and 3.9 days respectively. The importance of reaeration is therefore quite obvious. The assumption that the water phase is fully mixed need not be correct. Due to a relatively important SOD, the existence of a dissolved oxygen gradient even in a shallow pond might occur.

It is questionable whether wet detention ponds should be exposed to wind. In terms of dissolved oxygen the water quality - and the pollutant removal - should be improved. On the other hand particle settling would be impeded.

The importance of aerobic conditions in the top layer for retention of phosphorus and heavy metals will not be discussed in this paper. However, it should be investigated if low redoxpotential or associated drop in pH is important for sediment release of heavy metals.

<u>Eutrophication and plantation</u>

It should be stressed that a wet detention pond is a treatment facility. In spite of this it is important that eutrophication be suppressed as these ponds should be considered acceptable parts of a recreational area.

Because of heavy loads of nutrients to a wet detention pond eutrophication can cause a potential deteriorating effect. Especially the growth of phytoplankton should be suppressed. The growth pattern of the algae population is very dependent on the residence time in the pond system. Therefore, extended residence time supported by external as well as internal nutrients loads may cause increased concentration of algae biomass and a corresponding high primary production level. Therefore, with respect to the detention pond volume an efficient pollutant removal design criterion may come up against requirements for a low eutrophication level.

In order to evaluate the functioning of these detention ponds with respect to optimal conditions for both efficient pollutant removal and low eutrophication level a simulation model, POND, was developed (Toet et al., 1989). The following goals for the model were set:

- Development of a numerical simulation and eutrophication model for a wet detention pond which includes the removal of suspended solids, phosphorus and heavy metals.

  As for pollutant removal the model was calibrated on data originating from previous investigations (Hvitved-Jacobsen et al., 1987). Parameters and rate constants important for the eutrophication process were selected according to values from eutrophication models for shallow waters (Nyholm, 1978).

- To find design characteristics for a wet detention pond dependent on pollutant removal efficiencies and eutrophication.

From the Odense rainfall record the following three years were selected for the model simulations:

1971: Normal annual total rainfall and wet summer
1976: Dry year and dry summer
1979: Normal annual total rainfall and normal summer

In figure 6 pollutant removal efficiences versus the pond volume per effective hectare are shown. It can be concluded that the pollutant removal obtained from the simulation curves correspond well with previous expectations (Hvitved-Jacobsen and Yousef, 1988). I.e. 250-300 m³ of detention pond volume per effective hectare is still

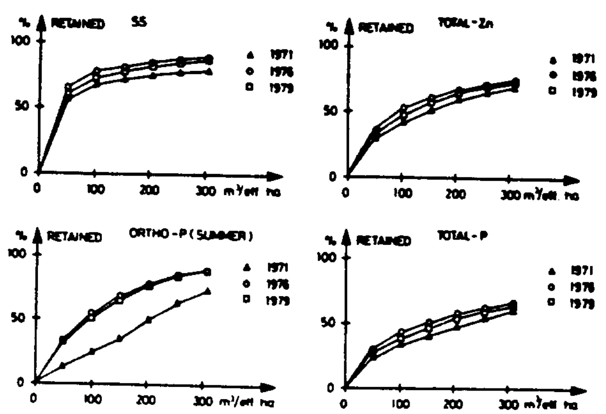

Fig. 6. Mass removal efficiencies for pollutants versus specific pond volume in the model detention pond.

recommended as seen from a pollutant removal point of view.

Results from the simulations of variables and processes related to eutrophication in the model detention pond are shown in figure 7.

The general conclusion is that for detention pond volumes between 100 and 300 m³·eff.ha⁻¹ the main eutrophication variables and processes are almost independant of the pond volume although a minor variation in the yearly mean value may take place due to the rainfall pattern. Therefore, eutrophication caused by phytoplankton should be considered as very likely in wet detention ponds designed for pollutant removal.

On the other hand rooted plants - both submerged plants and marsh plants - may have positive effects on the functioning of a wet detention pond. Especially under Danish climate conditions the risk for excessive growth should be considered as limited.

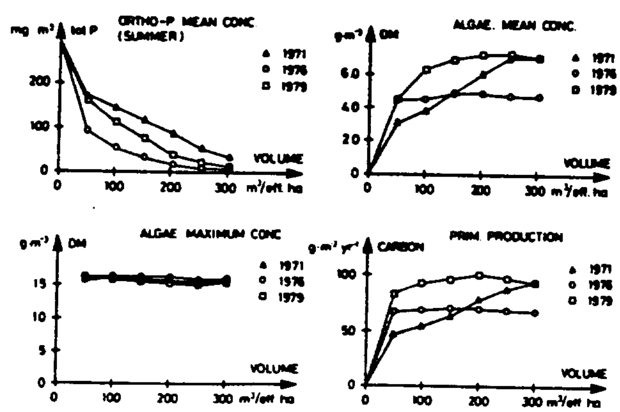

Fig. 7. Variables and processes related to eutrophication versus specific pond volume in the model detention pond.

The following should be taken into account:

- Rooted plants, especially marsh plants in clusters, will add to the recreational value of a wet detention pond.

- Submerged plants will result in dissolved oxygen variations during day and night. Provided that the plant biomass is limited, the dissolved oxygen conditions can be expected to be improved.
- Plants will improve the conditions for sedimentation of particles and reduce the risk of resuspension because of reduced wind exposure. An attendant phenomenon is a reduced reaeration rate.
- Plants will increase the active surface of the water system. Increased physical and chemical adsorption of e.g. colloidal particles and absorption in the biofilms may take place. Also direct plant uptake may be active in the pollutant removal process.
- Observations from Danish lakes have shown that the existence of macrophytes reduce the phytoplankton biomass.

These facts indicate that a limited vegetation of rooted plants is valuable in a wet detention pond. Partial removal of excessive vegetation might take place by hand and by means of special-purpose machines.

Establishment of a catch basin

Suspended solids associated with stormwater runoff roughly consist of large grit particles and small particles made up of organic as well as inorganic constituents. Pollutants are mainly associated with the small particles which might settle far from the inflow structure (Svensson, 1987).

It is observed that grit particles settle near the inflow structure and this part of the detention pond often needs more frequent maintenance than the rest of the pond. For this reason the detention pond should be recommended designed in two compartments. The basin close to the inflow of the stormwater is designed as a simple catch basin (grit chamber) in order to remove inorganic particles > about 0.1 mm. Design of this part should follow common design principles for simple grit chambers, e.g. based on a settling rate of 0.005-0.006 $m \cdot s^{-1}$, a mean storm intensity of 105 $\ell \cdot s^{-1} \cdot eff.ha^{-1}$ and a return period of 0.25 year. A hydraulic surface loading corresponding to 20 $m^3 \cdot eff.ha^{-1}$ for the catch basin should be recommended.

Specific pond characteristics

The following characteristics for a wet detention pond should be mentioned:

- The detention pond should be constructed with sloping banks for security reasons and in order to allow for vegetation along the banks.
- Soil infiltration can be reduced by using a membrane of plastic or clay.

  Investigations have shown that the heavy metals are retained in the upper few cm of the sediments in a detention pond (Yousef et al., 1984 and Hvitved-Jacobsen et al., 1987). Therefore, if a natural steady state dry weather water table can be established there is probably no need for a membrane.
- In order to reduce mixing between incoming stormwater and water in the pond, a length to width ratio of 3-4 should be recommended. Vertical diffusers placed at one of the short sides of the pond is a possible inflow arrangement.
- A sandy bottom layer is appropriate for the macrophytes to take root and to distinguish between original bottom and settled materials.

Maintenance and operation

A wet detention pond should be designed and constructed in a way that maintenance and operation are kept at a minimum level. Although given the present limited experience it is difficult to give recommendations in this respect, the following should be mentioned:

- Grit from the catch basin should be removed at least every second year. Therefore, access with vehicles to this part of the detention pond should be easy.
- Dredging of the sediments in the detention pond once every 10-20 years should be expected. Because of the heavy metal content the sediments should be proper disposed of. The amount to be removed corresponds to an increase in sediment depth of 0.5-1 $cm \cdot yr^{-1}$.

Example of a wet detention pond

The first wet detention pond based on the design principles shown in this paper is now under construction and will be in operation December 1989. The detention pond will be established in the catchment area of the city of Viborg mainly in order to reduce the phosphorus loadings on the urban twin-lakes (Hvitved-Jacobsen and Jensen, 1988).

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The detention pond which is shown on figure 8 and 9 is designed based on stormwater runoff from 16 effective hectares. The outflow from the pond will vary between 5 and 10 $l \cdot s^{-1}$.

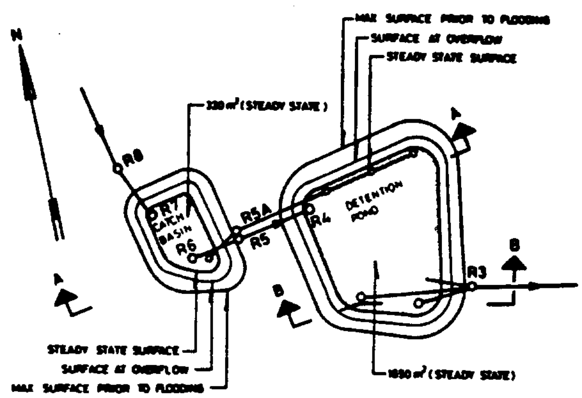

Fig. 8. Wet detention pond under construction in Viborg, Denmark.

Conclusions

Criteria for design and operation of wet detention ponds for pollutant removal from urban stormwater runoff are recommended. The minimum inter-event dry period between successive storms is proposed as a fundamental criterion in order to achieve sufficient residence time for pollutant removal in a pond. Because detailed information on the importance of the removal processes is not available, rather crude design criteria are proposed. Therefore, further investigations directed towards knowledge on the pollutant removal processes and the hydraulic properties should be carried out in order to improve the design principle.

Furthermore, it is important to notice that a wet detention pond is an integrated flood control and quality control structural measure.

The first wet detention pond established in Denmark based on the proposed design principle is under construction and will be effective late 1989.

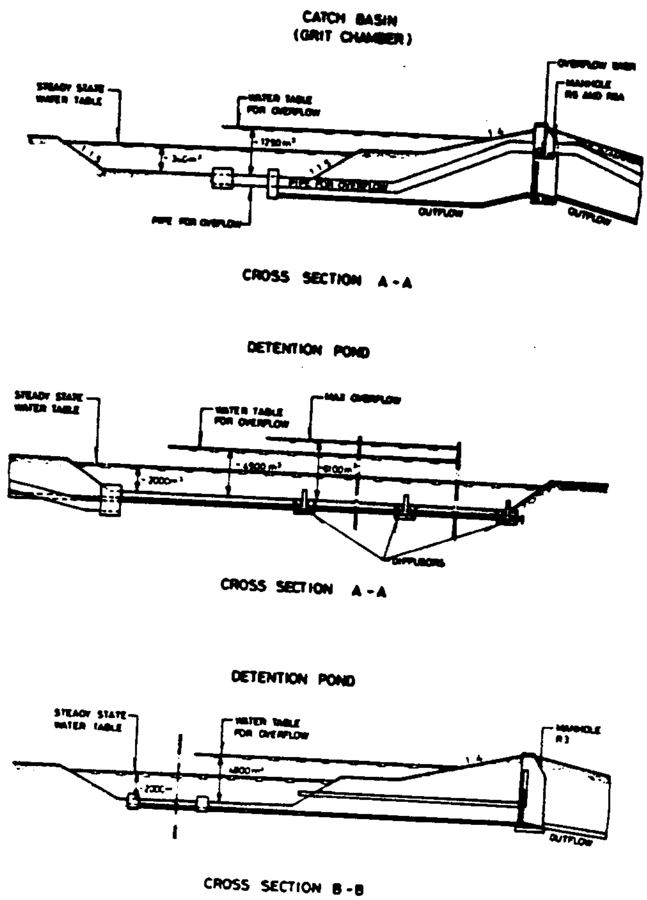

Fig. 9. Wet detention pond under construction in Viborg, Denmark. See figure 8.

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Permeable Pavements for Stormwater Quality Enhancement

by Dr Christoper J Pratt.

Introduction

Natural, permeable ground surfaces occur in various proportions within urban areas and are usually assumed to contribute little, if any, stormwater runoff to urban drainage systems. In some situations the natural ground surface is graded and shaped to convey stormwater from roof downpipes and paved surfaces to a drainage inlet, situated within the permeable, landscaped area of an urban development, but again little runoff is assumed to be derived from the natural surfaces, except in the case of snowmelt conditions. Rain falling on these natural, permeable surfaces is deemed to infiltrate to groundwater, percolate through the upper soil horizons to a nearby watercourse; or be stored near the surface for subsequent evaporation; or to be taken up and used by plants in evapo-transpiration. In general, permeable surfaces contribute little to the problem of hydraulic overloading of urban drainage systems.

Several studies have shown that natural surfaces and the vegetation upon them may be effective at retaining pollutants as urban stormwater passes over them, and hence the quality of the stormwater discharging to receiving waters has been improved (Yousef et al., (1984, 1987)). The processes of sedimentation and adsorption occurring as stormwater flows over soil particles and plants provide a primary treatment, which may be enhanced over a period of time by natural chemical and biological degradation of the pollutants. Man-made, engineered permeable surfaces provide the opportunity to establish similar processes for urban stormwater.

In situations where the ground conditions permit deep percolation of stormwater, the discharge from such permeable surfaces may be to groundwater. However, even where such methods of disposal are not possible, use may be made of permeable surfaces, with suitable sub-structure, to provide peak flow rate control and

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water quality improvements to discharges from the construction to an adjacent sewer or watercourse (Hogland et al., (1987); Pratt et al., (1988)).

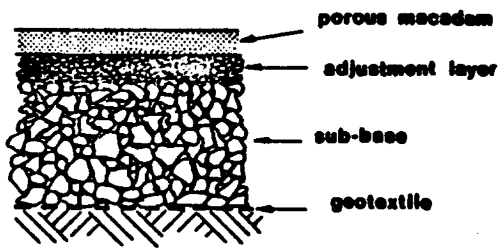

Figure 1 - Permeable pavement with porous macadam surface.

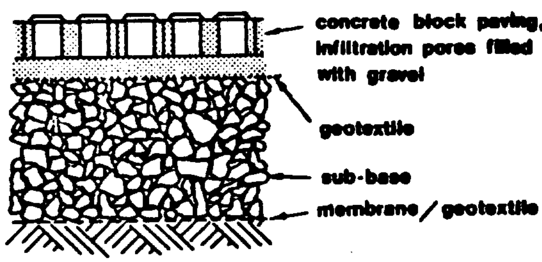

Figure 2 - Permeable pavement with permeable, concrete block surface.

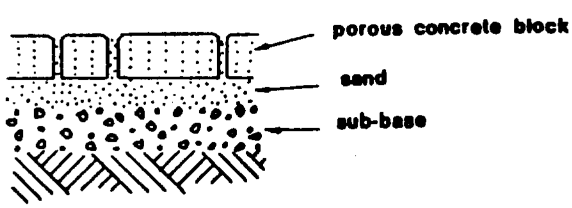

Figure 3 - Permeable paving with porous concrete block surface.

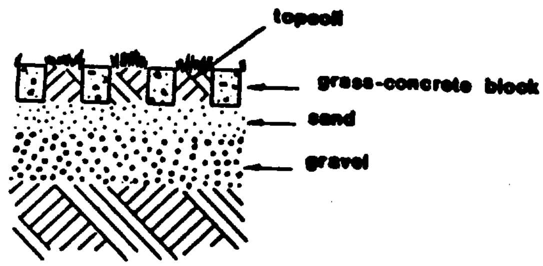

Figure 4 - Permeable pavement with 'grass-concrete' surface.

Engineered Permeable Surfaces

Two general forms of engineered permeable surfacing have been employed in Europe and North America: namely, porous macadam and interlocking concrete blocks, shaped to allow water to flow through spaces between and within the blocks. Both forms of surfacing have been installed over layers of free-draining material, usually clean crushed rock (see Figures 1 - 3). However, it has been more common for concrete block surfaces to be laid on a shallow bed of sand, with soil in the spaces between blocks, to facilitate the growth of grass (Figure 4). This latter form of construction has provided low cost surfacing, frequently for car parking, where problems of surface flooding which might eventually arise with gradual loss of infiltration through the surface could be assumed to be of limited importance. The grass on such surfacing has been seen as advantageous in aesthetic terms; in the context of environmental legislation where such surfaces have allowed the combination of commercial use with the achievement of a 'green' area provision within a development (e.g. requirement on industrial sites in parts of Denmark for 15% area to be 'green' i.e. landscaped with trees, shrubs, grass or grass-concrete); as modifying air temperatures (Smith, (1984)); and in maintenance of infiltration rates into the surface through the action of the grass roots.

The use of grass-concrete surfacing has been limited in the main to locations off the public highway, in situations where landscaping considerations were important and limited heavy commercial vehicle traffic was to be expected, which might destroy the low strength form of construction. Despite this possible limitation, grass-concrete has been shown to provide important water quality improvements to stormwater disposed of to groundwater, and the wider application of such surfacing has been called for in the U.S.A. (Day et al., (1981)).

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With the exception of traditional stone setts and widely spaced concrete block paving which form a semi-permeable surfacing and one not originally designed for stormwater management (Jacobsen and Harremoes, (1982); van Dam and van de Ven, (1984)), it is believed that only in Japan has permeable or porous concrete, block paving been installed on the public highway for the purpose of stormwater management (see Figure 3: Fujita, (1984); Suda et al., (1988)). Pratt et al. (1988) have reported research, concerning the stormwater quality improvements produced in flow through permeable concrete block paving construction (as Figure 2), but that study had been located only on experimental car parking areas on private property.

Generally in public highway situations, porous macadam has been chosen as the form of engineered surface and experiments have been conducted in North America, Japan and Sweden (e.g. Goforth et al. (1984); Fujita (1984); Hogland et al.(1987), respectively). Stormwater entering through the macadam surface may flow downwards to leave the base of the construction and percolate to groundwater in suitable soil conditions. Where ground conditions do not permit deep percolation, sub-base drains convey the stormwater from the construction to a nearby sewer or watercourse. Field measurements of the quality of the sub-base drain effluent have been made by Hogland et al. (1987) for a site at Lund, Sweden, providing useful information on the water quality parameter changes occurring during through-flow.

Water Quality from Grass-Concrete Construction

Laboratory studies were conducted by Day et al. (1981) on three patterns of grass-concrete blocks, which each formed the surface of water-tight bins containing a typical subsoil and construction layers, totalling some 500mm depth (as Figure 4). The blocks were laid upon 50mm sand, over 150mm gravel, on top of soil. The voids in the concrete blocks were partly filled with topsoil and topped with grass sod.

At least ten rainfall events were simulated on each bin, covering a range of rainfall intensities and durations, and every effort was made to simulate identical events on each bin. Rain infiltrating the voids percolated to the base of the bins from where it was discharged. Artificial, polluted rainfall was applied and samples of water were taken from the outflow at the base of the bins. The approximate concentrations of Pb, Zn and Cr in the rainfall were 0.76, 0.55 and 0.07 mg/l respectively, and the percentage pollutant removals by flow through the grass-concrete construction, on both a concentration and mass basis are shown in Table 1.

The three grass-concrete/soil systems achieved significant removal of the three heavy metals analysed in the effluent, however, the removal of phosphorus forms was very variable and nitrate/nitrite were leached from the soil, hence producing

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increased presence in the discharge from the construction. Clearly, the soil characteristics have an important bearing upon the overall performance of these systems. Pb and Cr adsorption tended to increase with depth in the soil, whereas Zn was removed markedly better within the gravel layer above the soil, because of its alkaline nature.

The results of the laboratory study, though limited in duration, indicated the potential for such constructions within a stormwater quality management strategy. Such surfaces tend to concentrate pollutants and limit their rapid transfer to receiving waters. In this case, it was noted that the overland flow, which resulted solely from type B blocks, was only some 0.7% that from an equivalent impermeable concrete pavement under

TABLE 1. Percentage pollutant removal between rainfall input and discharge from the base of the construction for three grass-concrete block types.

a) On a Mass Basis:

Grass-concrete block	Pb	Zn	Cr	
A	94.1	90.0	81.2	(mean)
	6.9	18.3	20.8	(s.d.)
B	98.4	97.1	94.3	
	1.4	1.9	7.0	
C	94.9	95.4	45.5	
	4.3	1.9	21.1	

b) On a Concentration Basis:

Grass-concrete block	Pb	Zn	Cr
A	91.9	77.1	77.0
	8.9	55.8	23.1
B	94.2	91.9	80.2
	4.4	3.4	24.9
C	92.8	93.3	26.1
	5.7	2.8	16.0

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TABLE 2. Mean pollutant concentrations (mg/l) in snowmelt and sub-base drain effluent.

	pH	Cond. µs/cm	SS	TDS	Cl	P_{tot}	KJ-N	NH_4-N
Event 1:								
Snow	8.6	136	378	356	8	0.11	0.54	0.4
Drain	7.5	462	18	324	60	0.13	1.29	1.22
Change +/-, %	-13	+234	-95	-9	+650	+18	+188	+205
Event 2:								
Snow	7.5	55	805	816	14	0.14	0.43	0.23
Drain	7.5	361	38	275	17	0.04	0.50	0.35
Change +/-, %	0	+556	-95	-66	+21	-71	+16	+62

	NO_3-N	NO_2-N	Cu	Cr	Al	Zn	Pb	Cd
Event 1:								
Snow	0.37	0.02	0.25	0.075	12.7	0.30	0.05	0.0003
Drain	4.3	0.04	0.33	0.032	1.15	0.25	0.03	0.0003
Change +/-, %	+1003	+200	+32	-57	-91	-17	-40	0
Event 2:								
Snow	0.14	0	0.38	0.47	18.0	0.58	0.04	0.04
Drain	2.39	0.02	0.22	0.02	2.39	0.22	0.02	0.03
Change +/-, %	+1607	-	-42	-96	-87	-62	-50	-33

the same rainfall regime, and hence any rapid tranfer of pollutants was extremely limited. Field measurements reported by Smith (1984) confirmed the very low overland runoff occurring on grass-concrete surfacing. Any long-term transmission of pollutants to groundwater has not been fully assessed, however, in field studies conducted by Malmquist and Hard (1982) no adverse effects were reported as detectable with disposal to ground of stormwater from residential and light commercial areas.

Water Quality from Porous Macadam Construction

An experimental site at Lund, Sweden, comprising a 470m² parking lot having a structure formed of a 50mm layer of porous macadam, over a 50mm adjustment layer of 4 - 25mm diameter crushed granite, itself overlying the sub-base formed of 13 - 80mm diameter crushed granite, was studied by Hogland et al. (1987) (as Figure 1). Overall the layers were some 500mm in total depth and were placed on a geotextile, which separated the construction from the underlying boulder clay, preventing the passage of fine particles into and out of the construction.

Hogland et al. (1987) reported the results of two snowmelt events on the parking lot; the second event being artificially produced by heaping snow on the experimental surface just prior to a thaw. Table 2 shows the results of chemical analyses of the snow and of the sub-base drain effluent. Generally the same trends in the results were seen in both the natural and the artificial events, except in the cases of phosphorous and copper. Concentrations of suspended solids, SS, total dissolved solids, TS, and the majority of the metals showed a reduction in pollutant concentration between the snow on the macadam surface and the drain effluent. However, there were increases in nutrients and chlorides, which it was suggested might be derived from previous agricultural practices on the site, or were due to the release of nutrients from the macadam and crushed granite themselves.

Pollutant Adsorption by Construction Materials

After one year the Lund experimental site was dug up during resurfacing work and samples of the construction materials were analysed for pollutant attachment. The amounts of pollutants (mg/kg dry weight) varied with depth in the construction but, in general, were highest at the level of the geotextile at the base of the construction (see Table 3). This was true for all but phosphorous, total dissolved solids, copper and cadmium. Lowest concentrations were more often observed in samples taken 250mm below the surface, in the crushed granite sub-base.

Comment was made that the observed pollutant concentrations were rather low in all the layers, which was attributed to the fact, that the permeable construction had been in use for only one year, and that a clay layer had accumulated on the surface due to the passage of construction traffic from adjacent areas, which had blocked the pores of the macadam and prevented entry of some stormwater. In practice, it is the question of operating life expectancy of permeable surfaces before blockage that has most concerned engineers. Nevertheless, the results from Lund suggest that the construction may store significant amounts of pollutants, particularly in the region of the geotextile to which level much of the fine particulate matter and associated contaminants were washed. The problems of blockage and the difficulties of cleansing to reinstate infiltration rates to the

TABLE 3. Pollutant content at different levels in the permeable pavement construction at Lund, Sweden. (Units: mg/kg dry weight)

Location	:Permeable :Macadam	:Adjustment :Layer	:Within :Sub-base	: At Geotextile :Above	:Within	: Below
Depth	:0 - 50mm	50 - 100mm	250mm	(around 500mm ±2 mm)		
pH	8.5	8.5	8.7	9.2	9.0	7.7
SS $x10^3$	147	58	31	89	484	464
TS $x10^3$	108	56	48	84	537	547
Cl^-	80	94	72	135	857	220
SO_4	17	65	17	18	381	138
P_{tot}	0.8	0.6	0.5	0.6	15.5	39
PO_4-P	0.2	0.2	0.2	0.2	4.3	1.1
KJ-N	0	0.6	2.0	0	7.2	1.8
$NO_2 + NO_3$	0.2	0.3	0.7	0.2	2.1	0.9
Cu	1.2	2.0	0.5	2.7	6.2	8.9
Zn	8	8	5	7	49	25
Pb	3.1	1.8	0.7	1.0	14.3	11.2
Cd	0.01	0.003	0.001	0.001	0.06	0.08
Cr	1.6	6.9	4.2	8.0	23.5	11.6
Al	1068	1564	703	1239	9624	4624

surface lead to the assessment by Pratt et al. (1988) of a permeable concrete block paving alternative, which would prove easier, and therefore cheaper, to maintain.

Water Quality from Permeable, Concrete Block Paving

The paving blocks used by Pratt et al. were 200mm long by 100mm wide by 90mm high and were shaped to form a pattern of holes 25mm diameter, when the blocks were laid in the traditional herringbone arrangement. The concrete was formed in hydraulic-

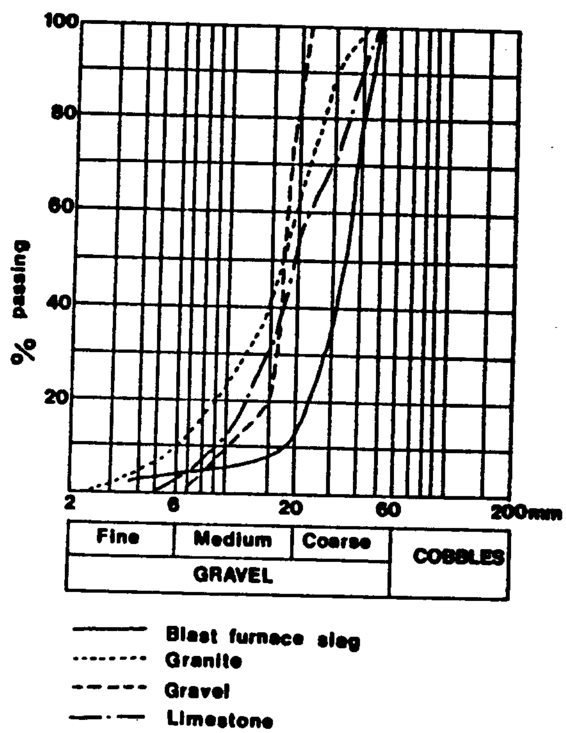

Figure 5 - Grading curves for sub-base stone used in permeable, concrete block paving (After Pratt et al., 1988).

press moulds using a semi-dry mix, which made the blocks themselves have very low water absorption characteristics, and hence low frost susceptability. The upper surface of the blocks had raised discs to carry vehicle tyre loadings preventing the compaction of material in the holes which would decrease infiltration rates. The blocks were laid on a 50mm bedding layer of 5 - 10mm gravel, which also filled the holes between the blocks (see Figure 2). As in the case of porous macadam constructions, the sub-base was constructed of free-draining stone. The gravel bedding layer was separated from the sub-base stone by a geotextile layer to prevent the movement of the gravel into the voids below.

The experimental site at Nottingham studied by Pratt et al. (1988) was similar to the porous macadam site at Lund in being effectively undersealed, preventing any deep percolation of stormwater from the construction. At Lund the boulder clay limited downward movement of water, whereas at Nottingham the construction was entirely sealed by an impermeable plastic membrane. In both cases, discharge from the construction via sub-base drains allowed samples of the effluent to be collected and analysed. Where the two experimental sites differed, apart from in the surfacing and in the construction layers, was that the Nottingham site was sub-divided into four sections, each some 40 m^2 in area, in which a different sub-base stone type was used, instead of the consistent use of granite throughout, as at Lund. The four stone types were gravel, blast furnace slag, granite and carboniferous limestone; grading curves are shown in Figure 5. Each of the stone types was entirely enclosed at its sides and base by an impermeable membrane, and stormwater discharge from the section took place via its own drain which passed through the wall of the membrane at a water-tight flange. The separate drains from the four sections were independently monitored and sampled for both water discharge and quality. Such an experimental set-up allowed assessment to be made of the effects of construction materials upon pollutant discharges, and of the different construction form as compared with that usual with porous macadam.

Short- and Long-term Variations in Pollutant Discharges.

The short-term variation of suspended solids and lead discharge from the permeable concrete block paving construction are illustrated typically in Figure 6 for a storm event on the limestone sub-base section of the car park. In the first months following construction the discharge of suspended solids was higher during an event, but after washout of some of the fine material from the sub-base stone itself, discharges of 40mg/l or less were typical, which was in marked contrast to the very varied concentration profile for impermeable surfacing discharges, illustrated in Figure 7 (Pratt et al., 1986). Similarly, the consistency of the lead concentration at 0.06mg/l, or less for the limestone sub-base, became the norm.

The four different sub-bases produced a range of water quality discharges, which were stone-type dependent. Effluent quality parameters, such as pH and alkalinity, could be reduced by design of the construction with blast furnace slag as opposed to limestone as sub-base. Similarly, reduction of effluent hardness and lead discharge could be achieved through selection of limestone in preference to blast furnace slag. The order of parameter change with stone type was limestone, granite, gravel

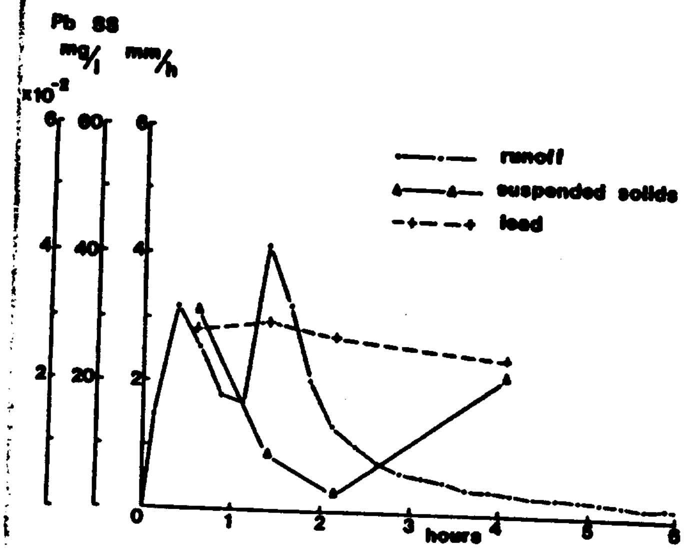

Figure 6 - Hydrograph and pollutographs for sub-base drain effluent from permeable pavement with granite sub-base.

then blast furnace slag. the direction of change depending upon the parameter of interest.

In the long-term. the various sub-base stone constructions showed small. slow variations with time according to stone type. suggesting some limited chemical degradation of the stone. Figure 8 shows the long-term characteristics for effluent from the granite and blast furnace slag sub-base sections. which illustrate the overall range displayed by the four stone types. Blast furnace slag effluent showed a gradual decrease in hardness over an eighteen month period. whilst both granite and blast furnace slag exhibited very slow decrease in conductivity. Suspended solids variation over the same period was limited to a range from near zero to 50mg/l. which was considerably less than is typical for impermeable surfaces with gully pot discharges to a sewer system. From impermeable surfaces. fluctuations in concentration from 30 to 300mg/l occur frequently during storm events: peak concentrations of some 1000s mg/l are not uncommon: and no two events need be similar. since antecedent conditions and the actual storm characteristics determine solids washoff.

Hence, an important feature of permeable pavements is that the effluent discharge quality shows far greater stability in both value and range of pollutant concentrations, in both the short and the long-term.

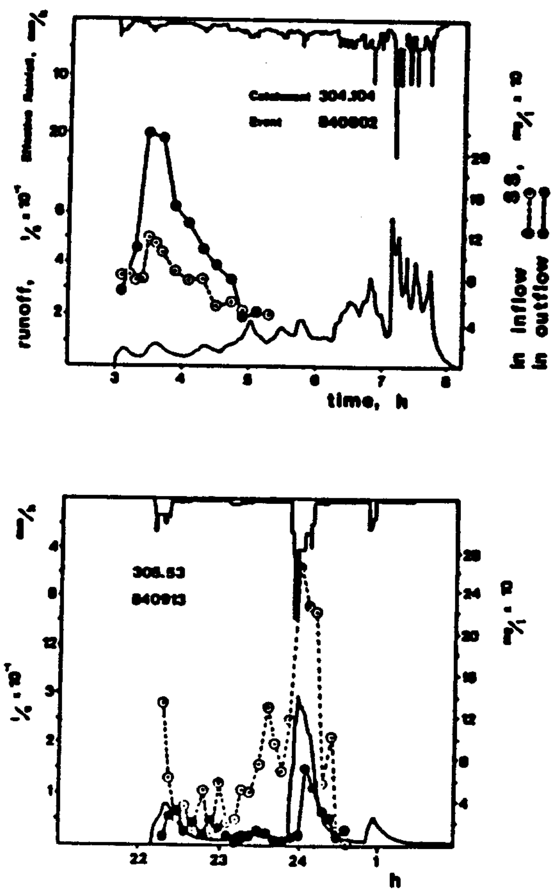

Figure 7 - Hydrograph and pollutographs for highway gulley discharges from traditional urban impermeable pavement.

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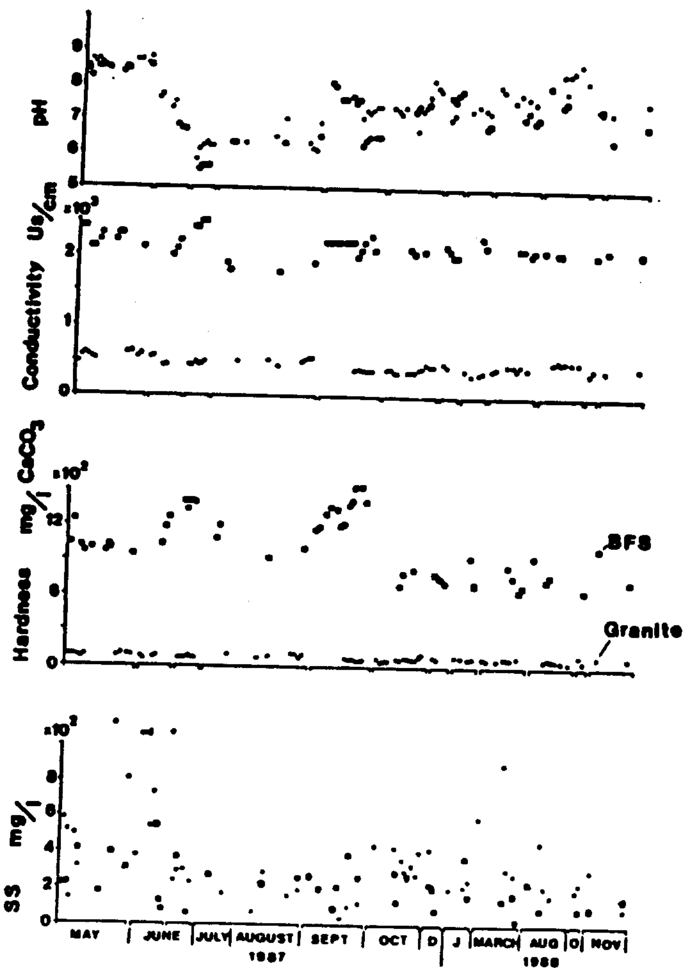

Figure 8 - Long-term variations in chemical parameters for the sub-base drain effluents from blast furnace slag and granite sub-bases of permeable pavement with concrete block surfacing.

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Laboratory Studies of Long-term Performance

The permeable construction using blast furnace slag, granite and limestone was modelled using a series of interlocking plastic rings, 110mm high by 110mm deep, so that the structure could be dissected and the pollutant deposition at various levels investigated (see Figure 9). The permeable concrete block paving was not included in the models for this study. Urban stormwater runoff from traditional impervious surfacing was collected and used to simulate the equivalent of ten years of rainfall on the permeable surface of each model. The 'rainfall' was applied over several days by pump, drawing from a continuously stirred container of stormwater. No attempt was made to simulate the periods of drying between storms, hence any caking of sediment deposits was not reproduced. The model study aimed to investigate where and in what proportions pollutants were retained by the construction.

The results for total sediment accumulation in the three models are shown in Figure 9. The sediments were washed and filtered from each section following the application of ten year's rainfall. In the case of the blast furnace slag and the limestone a half or more of the total dry weight of sediments was found in the gravel bedding layer, however, for the granite a relatively even distribution of sediments was discovered. The sub-base stone in all cases was not pre-washed before building the models, and the results reflect the initial sediment content of each stone type.

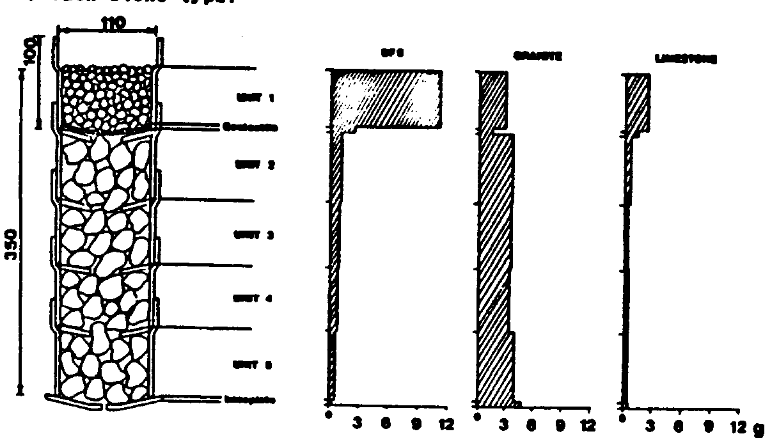

Figure 9 - Weight of fine sediment accumulated on each layer of the section of the model permeable pavements.

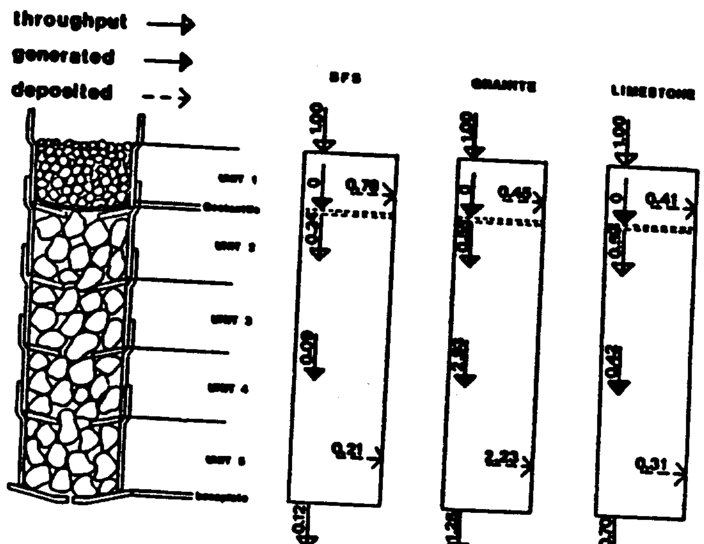

Figure 10 - Sediment balance calculations for model sections of permeable pavement from 10 year's throughflow.

Figure 10 shows the mass balance calculations for sediment in the three models on the basis of unit input of sediment in the rainfall. Again the influence of the initial sediment content of the stone as delivered is evident for the granite, where nearly three times the quantity of sediment was generated from the granite surfaces as was input with the rainfall). However of this internal sediment, most (i.e. 2.23/2.93 = 76%) was retained in the construction, although some did contribute to the increase of sediment discharge over rainfall input by some 25%. This result was not as bad as might appear at first sight, since the nature and pollutant content of the output sediment was different from that input at the pavement surface. The limestone model also demonstrated the internal generation of sediment, where some 13% of the output sediment was derived from the sub-base stone. Only in the case of blast furnace slag, a relatively clean stone with high resistance to abrasion and chemical degradation, was there no contribution to the output sediment from the stone itself i.e. the sub-base was a sink for sediments.

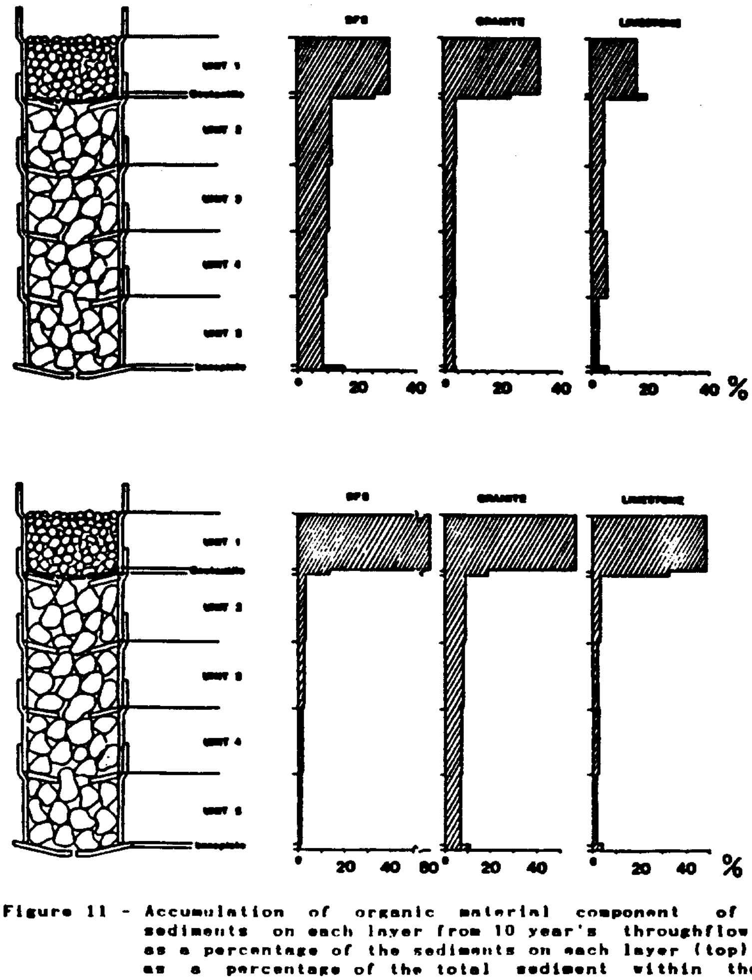

Figure 11 - Accumulation of organic material component of sediments on each layer from 10 year's throughflow: as a percentage of the sediments on each layer (top); as a percentage of the total sediment within the total model section (bottom)

It is unclear why the three gravel layers performed differently in sediment trapping above the geotextile layer. However, the general conclusion that absolute sediment discharge from the construction may be affected adversely by the condition of the sub-base stone at delivery is believed to remain true.

The belief that the output sediments were different from those in the rainfall input is supported by the evidence on Figure 11, where the percentage of organic material in the sediment found on each layer of each model is presented. The organic material is believed to have been solely derived from the applied stormwater and it is clearly illustrated that, below the geotextile layer, the sub-base stones have a relatively constant, low percentage of organic matter throughout the depth of the construction, the percentage being considerably less than that occurring in the gravel layer: unlike the results in Figure 9. Furthermore, if the amount of organic material in each section of each model is displayed as a percentage of the total organic material in a model, the significance of the gravel layer in the accumulation of sediments from stormwater is demonstrated.

The significance of the gravel layer is further illustrated in Figure 12 for the accumulation of lead per gramme of sediment in each layer.

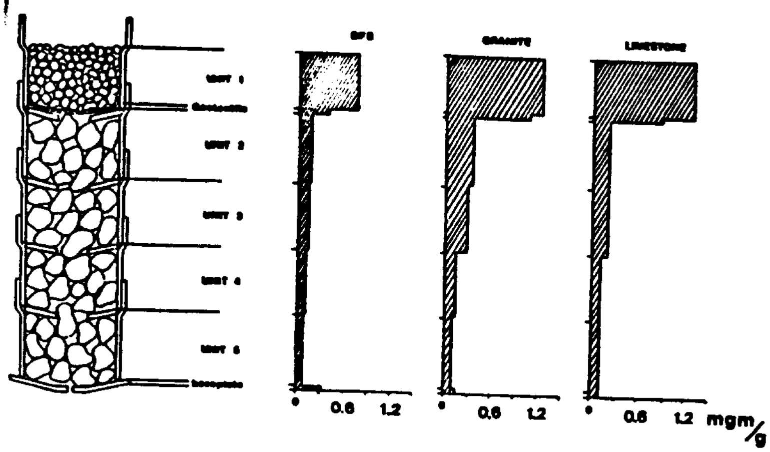

Figure 12 - Accumulation of lead on sediments on each layer from 10 year's throughflow as a proportion of the sediments on each layer.

Permeable Surface Blockage

Both field and laboratory data of inlet blockage have been collected on the Nottingham permeable concrete block paving. The field experimental site was modified in May 1988 and advantage was taken to remove samples of both the gravel bedding layer and the underlying geotextile to assess sediment blockage. Also in February, May, August and November 1988 samples of the gravel in the inlet holes in the block paving were removed and sediment content measured (see Table 4).

Laboratory tests were conducted on samples of the geotextile to determine the sediment content to cause blockage. Blockage was defined to exist when under an initial head of 50mm stormwater, the water had not completely drained through the geotextile in 24 hours. Two sets of stormwater samples were used: gully pot liquor containing both organic and inorganic particles; and liquor from the washing of gravel to remove essentially inorganic silts. The content of sediment in the geotextile specimens to cause blockage was:

for gully pot liquors, 0.060 g/cm^2 organic/inorganic sediment

for gravel washings, 0.094 g/cm^2 inorganic sediment.

The more varied nature and size of particles in the gully liquor presumably produced a more densely packed layer which required less mass of material than in the case of the more uniform inorganic particles to cause blockage. Without the geotextile to retain particles the gravel could not be blocked, as a steady state became established between episodes of deposition and washoff of particles from the gravel layer.

A laboratory model of the complete surface structure, including concrete block, gravel and geotextile, was tested to monitor the deposition of sediments at various levels below the surface. After the equivalent of ten years' rainfall from gully pot liquor applied to one inlet hole, the model was taken apart and the sediment content of the gravel in the inlet hole and in the gravel bedding was measured. Figure 13 shows the results. The upper half of the inlet hole had 0.95% sediment (by weight) as a percentage of the gravel content; the lower half 0.65%; the top half of the bedding layer between 0.5 and 0%, fanning out from immediately below the hole; the bottom half of the gravel bedding layer between 0.6 and 0.2%, similarly fanning out; and the sediment content of the geotextile was 0.007g/cm^2. As the model allowed for inflow through only one inlet, the interaction of adjacent sediment inlets was not reproduced, however, the model did suggest that sediment was transported with stormwater inflow throughout the surface structure, and failure of stormwater to infiltrate the surface could not be assumed to be caused by simple blockage of the inlet holes by sediment. There was the

TABLE 4. Sediment and pollutant concentration in gravel in inlet holes, bedding layer and underlying geotextile for permeable block paving.

Date	Sediment of total material by weight	Volatile fraction of sediment by weight	Pb	Zn	: Sediment : impregnation : in geotextile
			For sediment		
1988	%	%	mgm/g	mgm/g	: g/cm^2
For_Sediment_in_Gravel_Cores_through_Concrete_Blocks					
February	1.43	3.68	0.090	0.116	
May	0.96	3.59	0.082	0.109	
August	1.64	3.01	0.081	0.101	
November	1.66	3.70	0.078	0.089	
(Each the)					
(Mean of N	8	8	8	8)	
For_Sediment_in_Gravel_Bedding_Layer_and_in_Geotextile					
May	1.37	2.76			0.0046
(Mean of N	60	60			10

possibility that the failure was caused by:
a) blockage of the geotextile with sediment content of the order 0.05 to $0.1 g/cm^2$, according to the nature of the sediment;
b) blockage of the entire gravel bedding layer by sediment, thus preventing the movement of additional sediment from the inlet. Further sediment deposition on the surface of the block paving then might not enter the inlet holes and its fate depend upon the use and characteristics of the site e.g. whether wind forces dispersed deposits, or not, in which case they might accumulate to a level at which vehicle tyre loads compacted them, sealing the inlet holes to stormwater.

Overall, it would appear that failure of the permeable concrete block paving to infiltrate stormwater would be the result of general filling of the gravel bedding and inlet holes until sediment was caused to be stored on the surface. From that time, it would require the natural packing of sediment inside the inlet holes to be disturbed by externally applied loads from vehicle tyres to determine eventual failure. Before failure the geotextile and the accumulation of sediments in the gravel layer would generally impede movement of sediments into the sub-base.

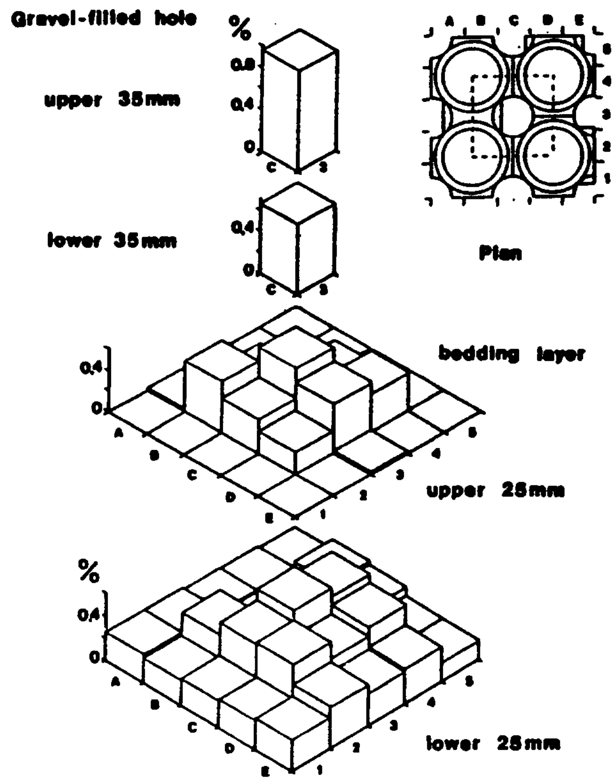

Figure 13 - Sediment accumulation at depths within the gravel-filled hole and bedding gravel as a percentage by weight of the gravel sampled in the surface layers of permeable, concrete block paving.

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This action would become more efficient with time, increasing pollutant concentration near the surface.

Remedial Works to Reinstate Surface Infiltration

The field observations (see Table 4) and the latter model suggest that the stormwater movement of sediment through the gravel in the inlet holes would maintain a sediment content of some 1 - 1.5% (by weight) in the gravel. The need for remedial works on the surface structure to avoid problems of poor infiltration might be forewarned by sediment contents increasing markedly above this range.

The remedial works would involve the lifting of the concrete blocks and their stacking for re-use; the removal of the bedding gravel and geotextile layer for safe tipping in view of their pollutant content; and the placement of new geotextile, new gravel and the block paving over the original sub-base structure.

Experience suggests that the work can be quickly and, therefore cheaply, undertaken. The cost of new materials is small relative to labour and machine costs, which are themselves kept to a minimum by the ease of access to the working area.

Unfortunately, the remedial works required on porous macadam constructions to reinstate surface infiltration rates are not so straightforward. The macadam surface requires machine excavation and, because the passage of sediments into the sub-base is unrestricted, the possibility exists that in some cases the sub-base may cease to be free-draining and require replacement. Hence it may be anticipated that there will be higher costs for reinstatement per unit area with porous macadam.

The effective lifespan of either form of surfacing is difficult to assess as external factors dominate performance. Examples of early failure have been reported (e.g. Hogland et al. (1987)), due to high rates of material deposition on the surfaces by natural or human actions. Under the conditions existing at the Nottingham sites of permeable concrete block paving, where no surface sweeping or maintenance was conducted but the general area was well-established with little erodible soil in the vicinity, it was estimated that the lifespan of the surfaces was of the order of 15 years before remedial works.

Hydrograph Attenuation and Discharge Volume

The absolute effects on pollution discharge from permeable pavements have been outlined above, however, these constructions have the additional benefits that they reduce the rates of stormwater discharge and total volume, even when connected via sub-base drains to a storm drainage system. Hence the total mass of pollutants discharged may be reduced.

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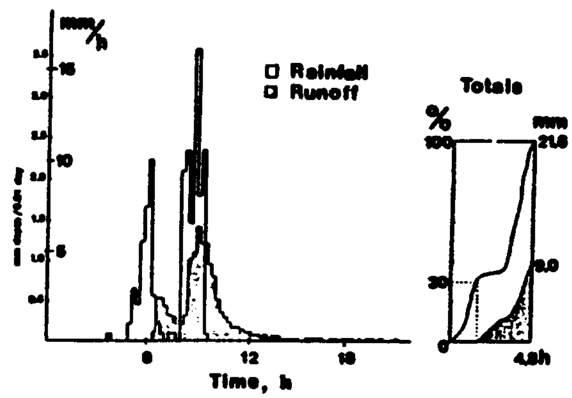

Figure 14 - Hyetograph, hydrograph and cumulative plots for drain discharge from the blast furnace slag sub-base.

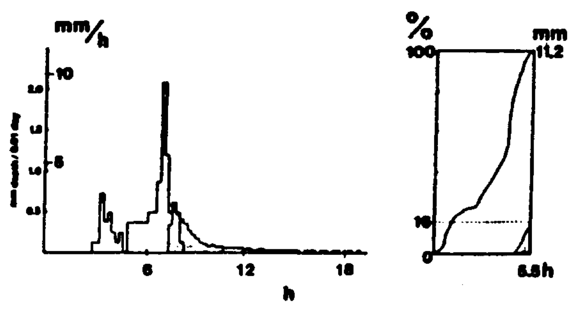

Figure 15 - Hyetograph, hydrograph and cumulative plots for drain discharge from the limestone sub-base following nine days dry weather.

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A typical rainfall-runoff plot for the permeable concrete block construction is shown in Figure 14: runoff was monitored at the sub-base drain outfall. In comparison with traditional impermeable surfaces there was an increased 'initial loss' i.e. surface wetting, depression storage, etc. before runoff commenced - some 6.5mm (30% rainfall) as compared with around 1mm, traditionally. Routing of stormwater through the permeable construction attenuated the hydrograph, extending considerably the period of discharge by many hours beyond the end of rainfall. Impermeable surfaces commonly discharge almost all runoff within the storm duration, whereas here only some 42% (9mm) of the 21.6mm rainfall was discharged in this period.

After 9 days without rainfall for a storm over the limestone sub-base pavement, the 'initial loss' before runoff was 9.5mm for the event illustrated in Figure 15. Only 16% (1.8mm) rainfall was discharged within the storm duration, and only a further 27% (3mm) of the total rainfall ever flowed from the construction.

Comparing the total discharge volumes from the permeable construction, using different sub-base stone types with total rainfall in a typical 30-day period, has produced percentage runoffs for the four different sub-base stone types: blast furnace slag 55%; limestone 61%; gravel 63%; and granite 75%. The difference between total rainfall and the total discharges was the water held long-term in the construction, which wholly or in part evaporated before the next storm event. The blast furnace slag had a honeycomb surface texture which could "pool" water, in addition to the water held at points of stone contact and in general surface wetting. The limestone had a rough surface which was slightly porous, hence surface wetting and stone contact storage characteristics dominated discharge response. The gravel had a smooth, non-porous surface which, when wet from a previous event, could transmit flows moderately quickly to the sub-base drain. The grading of gravel employed in the Nottingham study had a relatively large total stone surface area and a large number of stone to stone contacts, hence following a dry period this sub-base was able to retain moderate amounts of rainfall in surface wetting and at stone contact points. The granite sub-base was a coarse grading of impervious, smooth-surfaced, angular stones resulting in the poorest rainfall retention characteristics.

Conclusions

Field and/or laboratory studies of stormwater discharge from the three types of permeable pavement - grass-concrete, porous macadam and permeable concrete block paving, have in each case demonstrated valuable reduction in pollutant discharges. The forms of construction have been found to retain pollutants and, by virtue of the total discharge volume reductions occurring with these structures, the total pollutant mass transfer to downstream receiving waters has been shown to be significantly reduced.

Two principal mechanisms of water quality enhancement exist in permeable pavements: sedimentation/filtration; and chemical adsorption upon materials within the structures. The selection of appropriate materials at the design stage would allow particular attention to be given to specific site stormwater pollutant removal. The accumulation of sediments must be accepted as essential to the overall effectiveness of permeable pavements in stormwater quality management, and designs adopted which facilitate remedial works at suitable intervals.

Permeable pavements are most advantageous when used over large plain areas, intercepting rainfall at source. The elimination of surface streams on permeable pavements minimises flow velocities and flow paths available for the stormwater entrainment of surface pollutants.

The above features of permeable pavements mean that they offer wide scope for a range of strategies in stormwater management.

1) In appropriate ground conditions it may be possible to dispose of stormwater to groundwater on site.

2) Otherwise, with the enhancement of effluent quality, sub-base drains from porous macadam and permeable concrete block paving constructions may be connected directly to an adjacent watercourse.

3) Because discharge rates are reduced and may be further modified by real-time control mechanisms at the outfall from the construction, it is possible to discharge to treatment works at times of low flow for further improvement in quality before final discharge.

4) The large storage capacity in permeable pavements with stone sub-bases having large void space offers the opportunity for water re-use for on-site irrigation and appropriate 'grey' water purposes.

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SWEDISH WAY TO STORMWATER ENHANCEMENT BY SOURCE CONTROL

by Janusz Niemczynowicz[1]

Introduction

Stormwater attenuation methods were introduced in Sweden primarily in order to avoid flooding, give relief to overloaded severage systems and to reduce combined sewer overflows. Recognition that source controls enhance stormwater quality has only come recently as a result of increasing environmental awarness.

The costs of wastewater and stormwater management are growing fast in Sweden as well as in many other European countries. The reason for this is that the oldest parts of the sewagerage systems, constructed in the beginning of the nineteenth century, are getting old and urgently need renovation. New suburban areas are connected to already overloaded severage systems. Both reasons result in significant reduction of water treatment efficiency, which contributes to the further environmental degradation of surface waters. The total yearly cost of urban water management in Sweden was calculated to be about nine billion Swedish Crowns for the year 1988 (Falk, 1989).

People in the urban communities are not inclined to accept the tax increases needed for an improvement of water management, nor will they accept further degradation of the environment. Hence, more efficient, powerful and cheap methods of water management in cities must be developed.

The idea of separation of waste- and stormwater systems in cities in Sweden was abandoned during the early 1980's, since it was realized that it is economically unacceptable

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and technically insufficient to prevent a further degradation of water quality in receiving waters. The cost of separation of wastewater and stormwater systems in Sweden was estimated to be 100 billion Swedish Crowns in the year 1982 (Darte et. al., 1982). Many examples showed that the separation was wrong from an environmental point of view (Malmquist and Svensson, 1977; Malmquist, 1983; Malmquist and Hård, 1982; Carlson and Falk, 1977; Hogland and Niemczynowicz, 1980; Niemczynowicz, 1989). The only real benefit of such separation is the elimination of combined sewer overflows. However, the total pollution loads from the city would hardly be reduced. The risks of toxic effects on ecologic systems in rivers during heavy rainfalls could be increased.

The local disposal of stormwater before it enters sewage systems seems to many people one of the most reasonable ways to avoid overloading the system.

During the past decades, the use of detention ponds and lakes for stormwater attenuation was popular in Sweden and a number of such facilities exists, mainly in scarcely populated urban areas. However, construction of open detention basins and ponds in densely populated areas is restricted for safety reasons. According to Swedish Construction Regulations (Svensk byggnorm), the open detention ponds must be protected by a 0.9 m high fence if the water depth is more than 0.2 meters (Stahre, 1981). Thus, the number of open detention ponds is not increasing, and the inlet controls consist mainly of various kinds of infiltration and percolation facilities. The method of forced infiltration of storm- and sanitary waters from single homesteads has been used in Sweden for a long time. More systematic use of infiltration and percolation facilities for stormwater disposal on a larger scale began in early 1970's. Several hundred facilities have now been installed.

The utmost extension of the infiltration idea is constructing permeable pavements instead of the traditionally impervious surfaces of streets, parking lots etc. This idea was put into practice in Sweden and a permeable pavement construction, the so-called Unit Superstructure, was developed. During the last ten years, the number of residential areas where pavements have been constructed as permeable Unit Superstructure has grown to about 35, and the number of single surfaces constructed using permeable pavement is now about 300-500. About 100, 000 m^2/year of roads using permeable asphalt types is constructed in Sweden at present. Totally about 7,000,000 m^2 of permeable roads has been already constructed (Hogland, 1989a, b).

Many problems in Swedish cities are created by groundwater depletion caused by fast runoff of rainwater from impermeable surfaces and by groundwater drainage to the conduits. Groundwater depletion in many urban areas in Sweden leads to land subsidence and buildings are damaged due to settling. Repair of buildings damaged by settling costs a considerable amount of money every year in Sweden. All these problems, as well as problems connected to the fast runoff from urban areas would be diminished if traditionally impermeable surfaces could be made pervious.

Infiltration and percolation

The first studies of the effects of stormwater infiltration on groundwater quality were performed in the early 1980's in three locations including the residential, industrial and highway areas in mid-western Sweden (Malmquist and Hård, 1982). The studies showed that there was no significant increase of the nitrogen and phosphorus in groundwater downstream from the infiltration points. The concentrations of heavy metals in groundwater were also, with the sole exception of copper, not influenced. The overall conclusion of the studies was that infiltration of stormwater affects the groundwater quality only to a small extent. This investigation did not claim to give an absolute answer, but nevertheless it gave the "green light" for constructing all kinds of infiltration and percolation facilities, open asphalt pavements etc. Even the infiltration of wastewater is allowed and recommended.

According to the Swedish Environmental Protection Board (SNV, 1985), between 1981 and 1983 more than 14,000 wastewater infiltration facilities have been constructed for single family houses, for settlements with more than 25 persons, have totally 706 larger infiltration facilities been constructed until 1983. Special requirements with respect to design and construction of such facilities have been formulated and published (SNV, 1985 and 1985a). Infiltration facilities must contain construction for sludge separation. For single family houses, the facility must be designed for at least 5 persons or 1,000 liters per person and, depending on soil infiltration capacity, should consist of 3.5 to 7.0 m infiltration conduit per person. For multi-family housing, the recommended load of wastewater is 30-60 l/m' and day.

It was stated (SNV, 1985) that infiltration to the ground gives at least 50 per cent phosphorous reduction. Reduction of coliforms and pathogens in an infiltration bed of 50-80 cm thick is of the same order of magnitude as in active sludge treatment, i.e. ca 99.9 %.

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It is worth noticing that design rules for infiltration facilities are mainly based on the soil infiltration capacity and dilution of effluents in groundwater. Long-term effects of pollution migration, propagation of the adsorption front, influence of acid rain on these processes, metal leakage, etc, are not thoroughly considered.

An inventory of stormwater infiltration facilities in nine communities in Sweden and studies of long-term function and maintenance problems in 11 of the oldest facilities in Nordic countries were performed in 1981 (Lindvall and Hogland, 1981). Three main types of stormwater infiltration facilities are in use: surface infiltration, ditch infiltration and percolation basins. The oldest facility in Sweden has been in operation for 22 years, however most of them are not older than 15 years. The area occupied by infiltration surfaces varies between 0.5 and 100 ha with an average of about 20 ha. The study showed that, with an exception of some construction in cold climate where frost damage occurred, most facilities work without operational problems. Some operational and maintenance problems which were locally observed were due to lack of sufficient information exchange between designers and the maintenance personnel. It is worth noting that no serious investigations about the pollution migration from these surfaces were made.

Porous pavement

When the economical and environmental benefits connected to stormwater attenuation in urban areas were recognized by hydrologists, ecologists and city planners, technicians and inventors started to devise sound technical solutions which would also be economically attractive. One such invention is the Unit Superstructure mentioned above. The construction consists of a layer permeable concrete-asphalt DRAINOR, a macadam bed, and a geotextile underneath to prevent fine soil particles from entering the construction. Excess water from the construction may be collected in a perforated plastic pipe which is connected to the stormwater system or put into an infiltration well. The method can be utilized on streets, roads, parking lots, sidewalks, tennis courts, factory yards, etc. During the rain the construction acts as an infiltration surface. If the infiltration capacity of the soil is small, the structure functions as a storage facility with a strong runoff-delaying effect (Hogland and Niemczynowicz, 1986). Because of generally positive view on the question of water infiltration to the ground in Sweden, and the positive economical outcome, the very intensive increase in the number of sites where the Unit Superstruction has been constructed was possible.

The infiltration capacity of newly constructed Unit Superstructure surface is about 500-600 mm/min. The infiltration capacity tests performed on the parking lot in Nödinge, constructed as Unit Superstructure, showed that after about 5 years of intensive use, the average infiltration capacity was 65 mm/min with a maximum 200 mm/min and minimum 1 mm/min. Infiltration tests made on other surfaces gave similar results, showing that even the oldest surfaces have an infiltration capacity which exceeds by several times the rainfall intensity of any design storm (Hogland et. al., 1987a, b).

The effects on the runoff pattern of using Unit Superstructure pavements, compared to the use of traditional pavements, were tested by means of runoff simulations from an 0.2 km catchment in Gothenburg (Niemczynowicz et. al., 1985). Simulation with the Storm Water Management Model (SWMM) has shown a peak-flow reduction of about 80 % when the Unit Superstructure was employed.

Simulations of the hypothetical situation with permeable pavements in the city of Lund were made using the SWMM, which was calibrated on measured rainfall and runoff during another project (for a detailed description of the modeling procedure, see Niemczynowicz, 1984). With regard to the simulation of runoff from the city, it was assumed that the ground under the pavement was totally impermeable. Permeable surfaces are simulated to act as detention basins; the runoff is delayed, but the volume is not reduced. In practice, of course, there would be some infiltration to the ground and the runoff volume would also be reduced. Results of the simulations for one observed rainfall event are shown in Figure 1. Notice that the runoff from both combined sewers and stormwater conduits is strongly attenuated. The peak-flow reduction from the combined system is about 75% and from the stormwater system about 90%. Simulations made for other rainfall events show the same order of magnitude of peak-flow reductions.

The pollution-reducing capacity of permeable pavements was studied in a full-scale field test conducted in Lund (Hogland and Niemczynowicz, 1986; Hogland et. al., 1987). From analyses of several pollution constituents in the drainage water running off from the test areas, and from analyses of pollution in the body of the pavement, it was concluded that about 50% of the total solids, phosphorus and heavy metals contained in stormwater remain in the body of the pavement. In our hypothetical example involving the

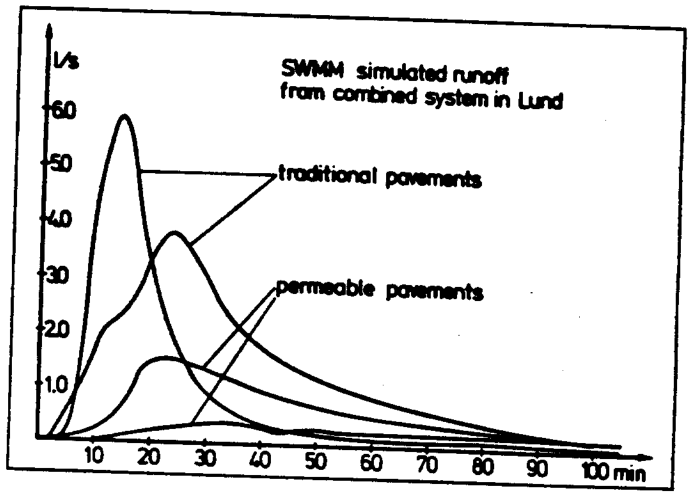

Figure 1. Examples of runoff hydrographs from the city of Lund for the present situation and assuming that permeable pavements were constructed instead of traditional pavements.

use of permeable pavements in Lund, the reduction in the pollution load may be expected to be of the same proportions. The total pollution load reduction would be also combined with a very significant reduction in pollution concentrations in the effluents, due to reduced peak flow and increased time of runoff. Risks of toxic effects on the ecological system during heavy rainstorms and low water flow in the receiving water would be eliminated. Simulated peak-flow reduction is sufficient to stop combined sewer overflows completely in Lund.

Laboratory tests were launched to examine long-term effects of clogging and pollution migration through the structure. The Superstructure surface was constructed in 12 1x1 m boxes in the laboratory. Boxes were exposed to irrigation with original stormwater taken from a conduit beneath. The time was "accelerated" by shortening the dry periods between rainfalls. Irrigation sequences were arranged so that the most important features of rainfall statistical properties were taken into account. Preliminary results of exposure for maximum 30 years of "stormwater rainfall" are very encouraging. Pollution transport through the structure seems to stop on the level of geotextile tissue underlying the construction. There was generally no measurable increase of pollution in the soil beneath the construction observed. Figure 2 schematically shows the distribution of pollution in the construction and in the underlying soil after up to 30 years exposure for "stormwater rain." There were no clogging tendencies observed, and these results have been confirmed by field observations (Hogland and Niemczynowicz, 1986).

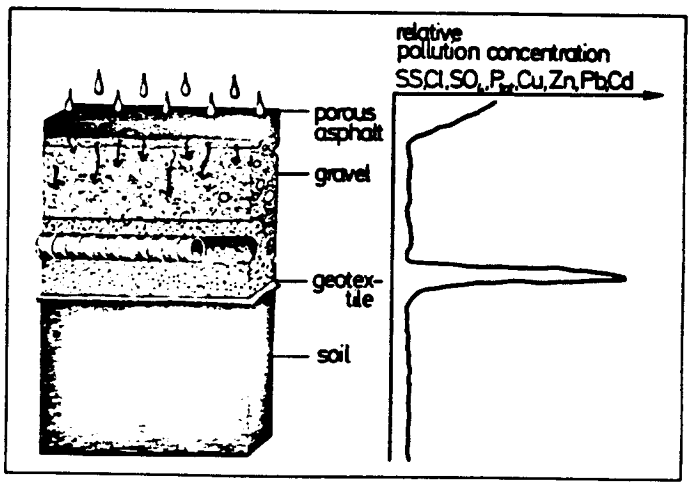

Figure 2. Schematic picture of pollution location in a Unit Superstructure after up to 30 year exposure for stormwater irrigation.

Some maintenance problems may occur if the porous pavement is built before construction in the area is completed. Heavy traffic of lorries and building machinery may damage the pavement construction and result in clogging. The infiltration capacity of the test surface in Lund, which was exposed to extremely heavy traffic of construction machinery during a 9 month period, was reduced to less than 10 mm/min (Hogland et. al., 1987a).

Effective methods of restoring the infiltration capacity of clogged surfaces are under development in Lund. High pressure spray seems to be effective (Hogland, 1989 and Hall et. al., 1988).

Existing permeable pavement surfaces receive the same amount of pollution from fall-out, traffic, corrosion, etc. as any other surface. Additionally, some pollution may be released from the construction itself. The materials of construction may chemically and biologically react with the stormwater remaining in the construction for several days. Most pollution stays in the construction or is accumulated on the textile tissue. Some amount of pollution must migrate to the soil underneath and to groundwater, however this amount is presently not known.

Pollution concentrations in water drained from four existing Unit Superstruction sites were measured and compared with average concentrations in stormwater and with drinking water quality. Table 1 shows the results of these analyses. The following abbreviations are used in Table 1.

Cl	- chloride	P_{tot}	- total phosphorus
PO_4-P	- phosphate phosphorus	Kj-N	- Kjeldal nitrogen
NH_4-N	- ammonium nitrogen	NO_3-N	- nitrate nitrogen
NO_2-N	- nitrite nitrogen	SUSP	- suspended solids
Ts	- dry substance	Ni	- nickel
Cu	- copper	Cr	- cromium
Al	- aluminum	Zn	- zinc
Pb	- lead	Cd	- cadmium
Fe	- iron	Mn	- manganese
K	- potassium		

From Table 1 the conclusion can be drawn that the quality of runoff water from Unit Superstructure surfaces is generally comparable with stormwater quality. The construction has some buffering capacity and the pH of runoff from the construction is usually higher than in stormwater and much higher than in rainwater. The concentration of chlorides is highly reduced by passage through the construction. During a snow-melt period, pollution concentrations are generally much lower in drain water from the construction than from snow melting on impermeable surfaces.

The economic consequences of using permeable pavements on a larger scale were tested by calculating the total costs of two types of pavements: the traditional and the Unit Superstructure. The use of Unit Superstructure results in total costs which are approximately 25 % lower than

TABLE 1. Pollution concentrations in drainwater from permeable pavements at four locations in Sweden. Average concentrations in stormwater and drinking water requirements are also given. Units: mg/liter (after Hall et. al., 1988).

Site (1)	pH (2)	Cl (3)	P_{tot} (4)	PO_4-P (5)	Kj-N (6)	NH_4-N (7)	NO_3-N (8)
Nödinge	.	8	0.03	.	0.05	.	0.62
Bohus	.	2	0.53	.	0.15	.	2.17
Sundsvall	7.1	5.5	0.04	0.04	0.05	0.02	0.51
Ldeon-Lund	7.5	60	0.14	.	1.29	1.22	4.30
Stormwater	6-7	149	0.08	2.0	.	.	.
Drinking water	9	300	.	.	.	0.5	30

Site (1)	NO_2-N (9)	Susp (10)	Ni (11)	Cu (12)	Cr (13)	Al (14)	Zn (15)
Nödinge	0	2	5	20	4	650	5
Bohus	0.03	130	5	30	5	1100	12
Sundsvall	0	6	5	21	5	200	1
Ldeon-Lund	0.04	18	.	330	30	1150	250
Stormwater	.	63	.	180	.	.	410
Drinking water	0.02	.	.	50	50	150	1

(1)	Pb (16)	Cd (17)	Fe (18)	Mn (19)	K (20)
Nödinge	10	5	440	10	1800
Bohus	10	5	2300	90	21400
Sundsvall	10	1	.	.	.
Ldeon-Lund	30	0.3	.	.	.
Stormwater	100	.	.	.	.
Drinking water	50	5	400	100	.

traditional pavements. Most of the cost savings are due to a reduction in the number of necessary inlets and inspection wells, and to reductions in the diameters of stormwater pipes (Niemczynowicz et. al., 1985). Table 2 shows the comparison of total costs for construction of all paved surfaces on a 2 ha housing area in Mölndal in Sweden in two cases: the traditional and permeable pavement construction.

TABLE 2. Total costs of pavements constructed at Mölndal housing area as traditional and Unit Superstructure surfaces (thousand Sv.crowns).

Type of costs (1)	Traditional pavement construction (2)	Unit Superstructure pavement (3)
Conduits	576	429
Inlets and inspection wells	246	72
Pavement materials	540	590
Work	168	118
Work management	34	24
Machinery	67	47
Total	1631	1280

Conclusions

Stormwater enhancement with respect to quantity and quality has became a desirable goal for city planners and practitioners dealing with source control methods in Sweden.

The separation of waste- and stormwater systems in cities in Sweden is economically unacceptable and technically insufficient to prevent a further degradation of water quality in receiving waters. The total pollution loads from the city would not be significantly reduced. The risks of toxic effects on ecologic systems in rivers during heavy rainfalls could be increased.

Since construction of open detention basins and ponds in densely populated areas is restricted for safety reasons, the inlet controls used in Sweden mainly consist of various kinds of infiltration and percolation facilities. Several hundreds of such facilities have been installed.

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The idea of constructing porous pavements as so called Unit Superstructure has been put into practice in Sweden, and during the last ten years the number of residential areas where porous pavements has been constructed is growing quickly.

The porous pavement constructions have a great potential when it comes to reducing and attenuating stormwater runoff. It is highly tempting to use this construction on a larger scale. Field and laboratory tests have shown that the porous pavements have the ability to reduce pollution in stormwater on a temporal scale comparable with the length of operation of existing surfaces i.e. ca 20 years. However, the portion of pollution migrating to the soil and groundwater is still not really known.

Now is the time to decide if the general approval of all methods of infiltration of urban waters to the ground can be given. The obvious hydrological, environmental and economical benefits which are certain on a short time scale of some years must be weighted against potential groundwater contamination risks on a longer time scale. It is necessary to be sure that the old philosophy of dilution, which has been proven wrong for receiving waters, will not be repeated in application to groundwater resources. This is important in terms of the possibility of reaching sustainable development.

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A REVIEW OF THE PRACTICAL APPLICATION OF DRAINAGE CATCHMENT PLANNING

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INTRODUCTION

Urban growth which has occurred prior to the advent of stormwater regulation has taken a large toll on surface water quality and increased the severity of flood incidence, however, it is only recently that stormwater has been recognised as a major issue of concern for Quality as well as Quantity criteria with an increasing awareness that this is a problem needing to be addressed. Yet the means of doing so are not only complex but sometimes difficult to implement. In response to this need the engineering and scientific community is developing techniques and refining existing methods so as to achieve the desirable objectives of enabling urban growth to continue while avoiding a drop in environmental standards.

Where they have been applied, many of these techniques have been demonstrated to be effective yet their general adoption is often hampered by the legal and procedural machinery under which such work is carried out. To enable systematic adoption of these techniques it is usually necessary to prepare a drainage catchment plan so as to ensure that the definition of objectives and drainage measures is based on the best available information.

The paper highlights some of the constraints and concerns that need to be considered when preparing a catchment plan, illustrated by case study examples of such plans.

CATCHMENT PLANNING FOR LAND DRAINAGE

In its broadest sense a catchment plan should enable an objective view to be taken on all the factors that will be affected by drainage considerations. The future development of our towns and countryside is dependent upon the proper management of water resources and we must never forget that any changes in land use affects hydrology, drainage, and pollution aspects. It should therefore be the objective of an integrated catchment plan to consider the effects of change, determine any adverse effects, set down regulations for development and generally to protect and improve the environment.

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Adverse effects are well documented [4] and may be summarised that any development will cause an increase in the volume and rate of stormwater runoff, increase the frequency of significant flooding, and increase the mass and concentration of pollutants discharged to the environment.

Any comprehensive catchment plan may also need to consider such other aspects as:-

- land use and zoning
- transport
- recreation
- areas of scientific interest
- tidal reaches
- archaeological sites
- natural wildlife habitats
- farming
- fisheries
- etc.

CONSTRAINTS ON THE DEVELOPMENT OF A CATCHMENT PLAN

Generally catchment plans are not prepared in advance but are only carried out to meet clearly defined objectives. There is, however, a trend for the planning initiative to move from merely reacting to a problem to pro-active planning for the future. Unfortunately, due to the historical development of our drainage systems, there are often a multiplicity of authorities who may need to be involved or have input to such plans depending on the local legal and procedural framework. In the U.K. for example such authorities may include (amongst others) planning authorities at the county or local level, local councils, highway authorities, water authorities, national rivers authority, local drainage boards and riparian owners. In addition the ownership or responsibility for maintenance and improvement, or liability for flood damage, may rest with any of these, jointly or severally depending on the type of watercourse from sewers to local ditches, privately owned rivers, non-main rivers, or main rivers. Thus there are also three main constraints on the development of a catchment plan:-

Who prepares the plan?

Ideally the plan should be prepared by the authority responsible for the watercourse or responsible for approval and enforcement, however it is more usual for the plan to be developed by the party most in need of the answers (e.g. a private developer seeking consent to proceed).

What is the status of the plan?

Ideally this should be mandatory on all involved parties, but again in reality any plan may be viewed as only advisory or be adopted only so far as local legal requirements insist.

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Who pays for the plan?

As the cost of a full plan can be considerable, this is a most contentious issue on which at present there is no general agreement. Present opinion ranges from the view that as the 'Private Sector' stands to gain most from development and the release of building land they should pay, to the view that as the main beneficiary will be the general public, and more particularly the local residents, in terms of both increased facilities and local taxes, then the full cost should be met from local taxation. In reality neither argument fully stands up to inspection. A proper catchment plan, taking into account all interests for improvement of an existing situation, or the sensitive development of any area means that there will be benefits both to certain private interests and to the general public.

In consequence, present practice seems to be highly variable and reflects an often confusing situation leading for example, to river flooding, sewage system flooding, development on new sites, or redevelopment are often being considered in isolation and not within the complete framework into which such work should fit.

LAND DRAINAGE AND SEWERAGE

The other main limitation to the present use of integrated drainage plans is the artificial distinction between the land drainage function and the severage function. This has arisen due to the historic development of our drainage systems and been enhanced by the development of different sets of performance objectives and design methodologies to the point where there is a distinct difference between the professions of River Engineer and Sewerage Engineer.

HYDROLOGIC MODELLING FOR CATCHMENT PLANS

The heart of any catchment plan is a hydrologic model or methodology whereby the impact of change on a drainage system can be assessed and where the effectiveness of different strategies can be predicted.

Design Methods:-

Land Drainage Catchment Plans generally need to consider the hydrology of fully developed areas, undeveloped land, rural catchments, and the more difficult problem of urbanising catchments. The objectives and problems to be addressed can also range from a highly localised problem up to more widespread flooding.

In response to this a considerable variety of design methods have been developed. In general, however, these are limited in their application to a specific set of circumstances and reviews of present design methods show that each method is only valid within the bounds set for its use [4].

It is not unreasonable to state that at present there is no single method of analysis and design that can be used to fully model a river catchment from the completely rural situation during progressive development to an urban catchment, or to handle hydraulic modelling from local sewers to main rivers. Different methods are appropriate for different conditions and must be selected for use only within each method's area of validity. In addition the criteria used related to each design application can vary and it is common for different design methods [1] to give wildly differing results if not related to each other.

Design Methods tend to fall into two distinct categories:

- River Design Methods
- Severage Design Methods

These vary both in the basic philosophy of their derivation and theory, and in their definition of objectives, which usually are reflected in the design parameters used.

Alternative Design Strategies:-

For any area the objective of Catchment Planning is to provide a strategic framework within which drainage and other related matters can be controlled, with forward planning for demographic change.

As catchments become urbanised then local flooding becomes more likely due to the increased volumes and reduced times of runoff, which can affect the local severage systems by making them more susceptible to short term high intensity rainfall events. The impact on a river flow may be most critical during longer rainfall events.

Typically several alternative strategies are available to permit urbanization or change without increasing the risk of flooding either on site or elsewhere in the catchment. These can include a combination of:-

- Acceptance of increased volume and rates of flow, with channel improvements as necessary to convey these flows through a system.
- Use of diversion or interceptors to bypass flow restrictions.
- Use of source controls to divert or intercept water at the entrance to the system.
- Use of attenuation storage to limit flows to meet downstream capacity restrictions.

The methodology used within the preparation of a catchment plan must be selected to enable all these strategies to be compared on an equal basis so that the optimum strategy can be identified.

This can be particularly difficult where one strategy can change the design parameters. For example when assessing the use of attenuation storage, whether on a local or a regional basis, the very presence of a storage facility affects the time response of a catchment so that the critical design storm to meet objectives may be changed. In addition the isolation of a small sub-area within a large catchment may result in there being two critical conditions that need consideration, the main catchment critical storm event, and the shorter storm that may affect the sub-area to a greater extent.

Design Parameters

a) **Level of service:**

This term is commonly coming into use to identify the trigger point at which action should be taken to alleviate flooding. This depends upon the system and typically at present such frequencies of flooding as once in ten years is considered as a reasonable level of service so that if flooding or damage occurs more frequently than this then work should be put in hand to alleviate the problem.

b) **Level of Performance:**

Once it has been decided that work should be put in hand, then any such work should be carried out so as to provide a reasonable level of performance into the future.

The level of performance generally depends upon the use to which the land is to be put, both the cost/benefit of carrying out the works (which have been the subject of many studies), [7] and also political considerations. Typical values of these are shown in Table 1.

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TABLE 1

Land Use	Level of Performance ie: the system should not overflow more frequently than	Comments
Residential Development	1 in 25 years	
Public Open Space	1 in 1 year - 1 in 10 years	Dependent upon use
Non-Domestic Residential	1 in 25 years	Hotels, hostels etc.
Retail Trading, Offices and Industrial Areas	1 in 25 years	Dependent upon use

The level of performance is one of the main areas of disagreement between the two branches of drainage engineers, mainly due to the differences between Severage and River design methods.

When considering general land drainage and main rivers it is normal to express the level of performance in terms of the actual return period when the banks of a river can be allowed to over-spill. For upper catchments this may be as low as once in twenty five years, however for most main rivers the level of performance is set at a higher level depending on the degree of risk both of damage and to life such an event represents. In many cases these objectives also need to be related to the risk of major disaster where exceedance of the level of performance may require extraordinary precautions to be taken.

When considering local flooding due to the inadequacy of a local severage system the risk to life is normally small and the level of performance is related more to the social effects of flooding where shorter return periods are often considered acceptable. It has been suggested, [8] for example, that it is socially acceptable for domestic housing to flood twice a lifetime or once every 25 to 50 years. To meet this performance, experience backed up by monitoring, has shown that severage design methods provide this level of service if a design rainfall return period of a 1 in 2 or 1 in 5 year frequency is used.

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Here is the main problem of calibration between different models, (and I fear the source of a serious communication problem between different sections of the industry).

A design may be based on a 1 in 2 year storm with a sewerage design method, whereas the river design may be for a 1 in 50 year storm using a river design method and each designer may not appreciate that these are describing the same level of protection.

It is for this reason it was decided during the research that resulted in the CONFLO 88 Guidelines (1) that it is necessary to separate the two concepts of "level of performance" and "design return period". The level of performance describes how the system must perform, the design return period used will depend upon the particular design method that is valid and appropriate to use for the condition under investigation, which may or may not be the same as the level of performance. See Tables 2, 3 and 4.

TABLE 2 (1)

Design Method	Size of Catchment			Method of Calculation		Comments
	0-1 ha	1-10 ha	Over 10 ha	Manual	Computer	
BURTON	✓	✓		✓	✓	For ponds with pumped outflow. Only use for storm durations considerably longer than the time of concentration
COPAS	✓			✓		For preliminary design only
L H DAVIS	✓	Prel. only	Design	✓		Equations and graph only available for 1 in 5 year and 1 in 10 year storms
SARGINSON CIRIA NOTE 100)	✓	✓	✓	✓		On large schemes the preliminary calculations should be checked by routing model

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Design Method	Size of Catchment			Method of Calculation		Comments
	0-1 ha	1-10 ha	Over 10 ha	Manual	Computer	
UNIT HYDROGRAPH (HYDRO RESEARCH & DEVELOPMENT)	✓	✓	✓		✓	Accurate for most urban catchments. Consideration must be given to winter conditions for catchments with significant rural run-off
WASSP SIM	✓	✓	✓		✓	Best suited to catchments with an even density of development. Not suited for rural catchments. Cannot consider backwater effects on pipes with flat hydraulic gradients
WEST (CIRIA NOTE 100)	✓	✓	✓	✓	✓	On medium and large schemes, results should be checked against a full routing model
WYCOFF & SINGH	✓			✓		
POND	✓	✓	✓	✓	✓	Hydrological experience required

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TABLE 3

Land Use	Level of Service (years)	Design Return Period (years)	
		River Method	Severage Method
Residential Development	1 in 25	1 in 25	1 in 5
Public Open Space	1 in 1	1 in 1	1 in 1
	1 in 10	1 in 10	1 in 2
Non Domestic Residential	1 in 25	1 in 25	1 in 5
Retail / Trading, Offices and Industrial areas	1 in 25	1 in 25	1 in 5

TABLE 4 (7)

Land Use	Level of Service (years)	Minimum Provision Underground (years)		Supplementary Storage Overground (years)	
		River Method	Severage Method	River Method	Severage Method
Residential Development	1 in 25	1 in 5	1 in 2	1 in 25	1 in 5
Public Open Space	1 in 1	1 in 1	1 in 1	N/A	N/A
	1 in 10	1 in 2	1 in 1	1 in 10	1 in 2
Non Domestic Residential	1 in 25	1 in 5	1 in 2	1 in 25	1 in 5
Retail / Trading Offices & Industrial Areas	1 in 25	1:5	1:2	1:25	1:5

c) **Permissible Outlet Flow:**

Generally the assessment of rates of flow can be based upon a factual knowledge of the physical capacity of the system. This may depend on specific pinch points where such things as a bridge or culvert limits flow although it may be necessary to use a hydraulic model to determine the capacities and effects of different hydrologic solutions.

A less satisfactory but common concept is that of zero increase in runoff, where an assessment is made of the likely rates of flow prior to development which are used as the target rate of discharge to the receiving waters.

CASE STUDIES

To illustrate how these principles can be applied in practice it is worth considering three example case studies of catchment plans, the development of a planning strategy to solve sewerage overloading problems for the city of Modesto in California, the development of a mathematical model for the Aylesbury catchment in England to provide a means of alleviating river flooding and to provide a planning strategy for future development on an urbanising catchment, and the development of a complete catchment plan covering planning, development and pollution control strategies for the complete city of St. Johns, Newfoundland.

The City of Modesto - California:

A catchment plan developed to provide a cost-effective strategy to alleviate an existing stormwater flooding problem on a sewerage system.

The City of Modesto, a market centre for a citrus growing area in the Sacramento Valley in California, grew up along U.S. Route 99 over the last 80-100 years.

The town has a separate drainage system, generally following the streets, however, the stormwater sewers had been allowed to grow "organically" as the town developed. The original storm drain served the original main street through the city only, however, as development continued there has been unregulated connection to this system until by the mid 1980's stormwater flooding had become more than just a nuisance.

The city is bounded on the north by an irrigation ditch (to which no stormwater may discharge to avoid contamination of water supplies), on the West and South West by a main interstate motorway and a railway. The catchment slopes gradually towards the Toulumne river to the south. Recent flooding events show a pattern of flooding being experienced causing not only damage and disruption within the city of Modesto itself but also flooding on both the railway and the highway. It was decided that the situation was not acceptable and the city decided to put work in hand to alleviate the problems.

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A detailed survey and analysis of the system had shown that the stormwater drainage system is grossly overloaded. The conventional solution to such problems, involving the reconstruction of the system downstream from locations where flooding is experienced so as to convey stormwater from these areas to the river, was shown to be unaffordable both in capital cost and the disruption that would be caused, as it would be necessary to reconstruct virtually the complete stormwater drainage system to achieve any relief.

This would have required, among other things, constructing two 9 ft. dia. pipes laid parallel right through the city's main street in a fairly narrow and busy highway at up to 8 m. depths, closing the main road during construction.

Alternative solutions were therefore sought for this area, and in 1988 Hydro Research and Development through its associated company, HIL Technology Inc., carried out a detailed survey of the area and proposed a stormwater management catchment plan to the city.

The objective of the study was to consider the use of source control and stormwater attenuation techniques to:-

- Prevent health hazards
- Reduce property damage
- Minimise inconvenience from surface flooding
- Minimise high cost alterations to the existing system
- Minimise downstream flooding
- Minimise the cost of the total system and related works
- Minimise maintenance costs

The analysis of the problem fell into three main sections:-

- Data collection
- Construction of a hydrologic model which could be used to test the effects of different alternative strategies and identify the optimum solution
- A detailed analysis of the optimum strategy

To carry out the analysis, two mathematical models were used:-

- A hydraulic analysis model for the severage system that could be used to determine the existing capacity of the system, and to evaluate the effectiveness of any proposed works.
- A hydrologic model for the catchment, broken down by sub-catchment on the storm drainage system, to provide input data for the hydraulic model and to enable attenuation storage requirements for alternative strategies to be considered.

It became apparent during the analysis that, as is often the case, the optimum scheme would be a compromise incorporating many of the techniques that are now being lumped into the general term "Stormwater Catchment Management".

- Such was the inadequacy of capacity of parts of the existing stormwater drainage system that consideration should be given to reconstruction of some sections of the system.
- The location of road intakes (catch basins) in some areas precludes the use of inlet controls.
- In the commercial districts both roof and hardstanding drains are on private land and not directly controllable by the city.
- Surface storage might be acceptable in the less dense developed areas of the city, subject to political concerns (e.g. they were not keen to flood the town's baseball arena).
- More use could be made of discharges to the subsoil through soakaways, however, their capacity is limited due to the relatively impervious subsoil. Experience has also shown deep bored rockwells have a relatively short life before they silt up.

In consequence the optimum strategy recommended for the city involved making use of all the elements of an inlet control system.

It was concluded that the optimum system would be to adopt a staged implementation for the area comprising:-

(1) Initially to make no modification to the existing sewers

(2) To install flow controls throughout the area to limit discharges into the main stormwater system to the capacity of that system, located so as to mobilise any available storage without the use of surface storage within parking areas and highways in the sub catchments.

(3) To monitor the performance of the system for a period of 12-18 months during which approximately 5-10 significant rainfall events can be expected during the wet season (November - April).

(4) To add storage only where unacceptable surface puddles occur.

(5) Allow a second monitoring period.

(6) Add secondary storage in remaining areas as appropriate.

(7) Establish overland flow routes that will be used during extreme storm incidents to avoid nuisance/damage on any storm event.

(8) To implement a requirement on all new developments or redevelopments within the city to limit discharge flows to the presently identified acceptable rates of flow, and within each development to provide source control measures or attenuation storage facilities to meet the requirements for that development.

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These recommendations have been accepted by the city of Modesto and the first stage implementation of the system comprising the installation of flow controls and the establishment of the monitoring programme will have been completed before the end of this year.

The Aylesbury Catchment Model:

A catchment planning model developed to enable comparison of different strategies to be made for the alleviation of existing river flooding and to provide a planning strategy for the future.

Thames Water in conjunction with Aylesbury Vale District Council, initiated a study within Aylesbury (a growing town of population 55,000) with the aim of identifying a cost effective and environmentally sensitive means of reducing the present incidence of flooding and to determine a policy for new development within the town.

The study area comprised the branches to the river Thame that pass through the town of Aylesbury and serve an otherwise largely rural catchment some 5 miles x 2 miles in extent.

Flooding has become an increasingly frequent problem within the lower lying areas of Aylesbury itself, not helped by the complex system of ditches, streams, mill streams, and a canal that has developed over the years. The problem has been highlighted by the recent development of new industrial and commercial parks in areas which in hindsight should, perhaps, have been retained as flood plains to the river.

To determine the optimum strategy to alleviate the present problems and to make provision for future development required the preparation of a catchment plan. The study needed to be able to compare, on an equal and valid basis, the costs and the effectiveness of combinations of six possible alternative strategies.

- A bypass round the town.
- Channel improvements to the various watercourses within the town.
- Use of storage at strategic locations upstream of the town.
- Use of smaller scale attenuation storage schemes within the already developed areas.
- Use of attenuation storage to reduce the impact of new developments.
- Use of storage downstream to reduce the impact of any capacity improvement measures on the main river further downstream.

To enable these alternative strategies to be compared on an equal basis it was necessary to use a modelling technique capable of considering several scenarios. The catchment model falls into three parts.

i) **A hydraulic model of the watercourses through the town:**

The ONDA hydraulic model produced by Sir William Halcrow & Partners, Consulting Engineers, was selected for this purpose as it is capable of simulating open channels; closed pipe systems and culverts, and ancillary structures such as bifurcations, weirs and syphons, that occur on a real system.

The model uses inputs in the form of hydrographs to determine rates of flow and river stage levels at various points through the system.

ii) **A hydrological model of the complete catchment:**

The twin-program UNIHYD (Unit Hydrograph) and FRQSIM (Frequency Simulation) originally developed by the Greater London Council and extended and improved by Thames Water Authority was selected. This model basically adopts the rainfall-runoff approach, using synthetic unit hydrographs and simulated point rainfall.

The model can produce hydrographs and design flows at any chosen point on the channel network, taking into account the catchment shape, distribution of shape within the catchment, soil type, storage within the system and different rainfall profiles.

iii) **A hydrologic model for the Urban area appropriate for use where subcatchments are essentially fully urban:**

The Storm Phase Unit Hydrograph model produced by Hydro Research and Development Ltd was selected for this purpose as it is valid in application to the minor subcatchments defined by the storm sewerage system and has the facility of simulating the use of attenuation storage within urban sub catchments to provide input hydrographs to the hydraulic model.

Development of the Model:-

i) Initially the first two models were used to produce a mathematical model to simulate the hydrologic behaviour of the catchment.

ii) The Second Stage in development was verification and calibration of the model against river gauge data. Rainfall data for observed events was used with the FRQSIM model to produce runoff hydrographs which were input to ONDA and the river stage levels simulated through each storm could be compared to the real observations. The models were then refined so that a realistic correlation between the mathematical model and reality was achieved.

The Storm Phase model for the urban area was also run assuming there to be no storage within the subcatchments and the hydrographs produced compared for the same input data etc. in parallel with FRQSIM so as to establish the calibration on input data between the severage and the catchment model.

iii) Having calibrated the models it is then possible to simulate each alternative strategy, or combinations of these to determine the optimum solution. Bypass options and channel improvements would be simulated in ONDA for the present situation input hydrographs, and during the study the ONDA model was extended to embrace other locations as the design process refined the defined optimum strategy.

iv) Urban Storage on existing developed areas or future development could be simulated using the Storm Phase Unit Hydrograph model to modify the input hydrographs to the ONDA model, and the Unit Hydrograph would also be used to check the critical design storm durations to meet both the watercourse and the local sub-catchment's level of performance.

The appraisal stage using these models has been successful in identifying the most effective strategy to meet the various and sometimes conflicting objectives identified as needing to be addressed by this catchment plan. As anticipated at the start of the development of the model, the optimum cost/effective strategy combined elements of most of the alternatives available and includes carrying out some localised improvement works to watercourses within the urban area to remove the more restricting pinch points, coupled with the use of storage in the rural areas upstream of the town to reduce the incidence of flooding being experienced at present. The addition of storage within the already developed urban area has been concluded to be not necessary, however, all new developments will need to have a controlled discharge to the peak flows identified by the catchment plan with attenuation storage provided on each development to meet its local level of performance. The catchment plan developed for this area will be implemented in order as to overcome the existing problems and enable development of the area to proceed.

<u>Regional Stormwater Management Study for the St. John's Urban Area, Newfoundland</u>:

The development of a catchment plan for the future development planning for the city. [9]

Historically the St. John's area has experienced flooding causing property damage and public inconvenience. With the St. John's area facing pressures to develop the headwater areas of the region's streams and rivers, there was the potential increase in the frequency and magnitude of flooding.

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Earle & Associates Ltd. and Paul Theil Associates Limited were retained to establish a comprehensive and long-term stormwater management strategy for dealing with existing drainage related problems and for minimizing and/or eliminating potential problems that may result from future development. The study area encompassed four major watersheds which drain into and through the St. John's urban area.

The primary objectives of the study were to:-

1) Establish a comprehensive and long-term Master Drainage Plan that will guide future land development in a manner which will not adversely impact downstream areas.
2) Update policies and standards for stormwater management for new developments and for remedial works within existing developments.
3) Identify existing flooding problems and recommend technical solutions.

Based on existing and anticipated land use patterns it is clear that:-

a) A significant degree of future development will be concentrated in headwater areas of the watersheds;
b) Upon ultimate development there will still remain large tracts of undeveloped land (approximately 44 per cent of the study area); and
c) Based on recent rates of development, it is anticipated that about 20 years would be required to fully develop the area.

To identify existing flood susceptible areas and establish the impact of future development on flow conditions, a hydrologic and hydraulic analysis was needed. The hydrologic design and simulation program MIDUSS was used to estimate return period flowrates and the US Corps of Engineers program HEC-2 to determine water elevations. This analysis provided the framework for the preparation of stormwater management strategies for each watershed by identifying storm drainage deficiencies to be addressed in co-ordination with erosion, sedimentation, and environmental concerns. The broad conclusions of study show that:-

1) The potential for extensive flooding on watersheds in the study area is limited as the floodplains are for the most part confined within relatively narrow valleys and most existing development is generally set back out of the floodplain.

2) Four areas on the Waterford River system and three areas on the Rennies River system have been identified and labelled as flood hazard areas.

3) With future development, an increase in peak flows in the order of 20 to 50 per cent would be expected to occur on the Waterford River and Outer Cove Brook watersheds. For the Waterford River this will result in an increase in flood levels up to 0.5 metres for a given return period event.

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4) Due to the topographic features and limited existing development on Outer Cover Brook, the increased peak flows and flood levels will not adversely impact downstream areas.

5) A significant increase in peak flows and flood levels on the Rennies River and Virginia River watersheds will not occur with future development.

6) The major impact of future development will be to increase the frequency and magnitude of existing flooding problems at identified flood hazard areas.

Three stormwater management alternatives were analyzed to develop solutions for existing flooding problems and set forth specific measures to minimize future development impacts. The three alternatives included No Runoff Control (Null or do-nothing option), Post-development to Pre-development Runoff Control, and Runoff Control to a Given Flowrate based on an existing downstream constraint. Stormwater management alternatives were evaluated to establish for each watershed which type of control options would be most environmentally acceptable, cost effective and technically implementable.

The following water management strategies were recommended to achieve a level of runoff control that will minimize the impact of future development on downstream flooding, and address existing flooding, erosion, and fisheries concerns.

1) Control of storm runoff from future developments on the Waterford River system up to the 100-year pre-development level.

2) Storm runoff from future developments on areas tributary to South Brook (Waterford River watershed) can be released uncontrolled.

3) Storm runoff from future developments on the Rennies River, Virginia River, and Outer Cove Brook systems can be released uncontrolled.

4) Implementation of flood protection measures at identified flood hazard areas on the Waterford River and Rennies River systems to provide a 100-year level of protection under ultimate development conditions.

5) To address in-stream erosion concerns, an on-going remedial Erosion Control Plan should be implemented whereby annual walks are made of the watercourses by respective regulatory bodies to identify and prioritize sites of active erosion. A storm drainage levy should be collected to finance existing and future works at erosion sites as identified by the on-going Erosion Control Plan.

6) To reduce the impact of downstream sedimentation from proposed development sites, emphasis should be directed on erosion and settlement control practices during construction.

7) In view of the value of wetlands in the study area from an hydrologic, ecological and water quality perspective, existing wetlands should not be disturbed.

8) To minimize the impact of development on fish habitat, watercourse and floodplain alteration should be restricted, and engineering considerations given to protection of fisheries resources (i.e. provision of oil separators at industrial sites and design of hydraulic structures that do not impede fish passage).

9) Practices that aid in reducing the volume of storm runoff such as discharge of roof leaders onto grassed areas, and use of engineering practices which promote infiltration of water into the ground should be applied.

Remedial works were developed to provide flood relief solutions to a minimum level of protection of up to the 100-year design flood level for areas identified as flood vulnerable.

In addition the following recommendations have been made to provide the respective regulatory bodies with a basis for ensuring that water quantity and quality concerns associated with future development are addressed:

1) Future development within the study area be allowed to proceed subject to meeting the conditions and objectives as described within the Master Drainage Plan.
2) The Master Drainage Plan be used to provide Developers and Consultants with guidelines and criteria as to the works required to meet water management objectives.
3) Functional Stormwater Management Reports be prepared for each drainage area requiring detention storage. The Reports would define, in detail, the characteristics and location of the proposed facilities and provide preliminary engineering specifications. Submission to the regulatory authorities should be made at the Draft Plan stage.

4) To ensure uniformity within the study area, a Storm Drainage Manual be prepared which would apply to all areas of future development. The basic objective of the manual being to provide guidance in design of storm drainage works. The manual to outline design methods, design rainfall hyetographs, runoff coefficients, Major-minor drainage system concepts, options for foundation drain connection, lot grading, and locally implementable techniques for erosion and sediment control, promotion of infiltration, and improving stormwater quality.
5) If the official General Land Use plans are substantially amended, the hydrologic impact of amendments on downstream areas will be addressed by modification of the existing hydrologic model.

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NON POINT SOURCES OF POLLUTION

Most of the catchment planning that has been carried out to date has concentrated primarily upon the quantity aspects of stormwater runoff. The pollution problems of urban washoff are, however, becoming of major concern due to long term effects on the receiving waters.

It has now been recognised that, although rainwater may be relatively pure prior to impact on the ground surface (assuming air pollution and acid rain is not a factor) this water will rapidly become contaminated as it runs over the land surface and can have a severe polluting effect on the receiving watercourse.

To illustrate the impact this can have, a monitoring program on a typical urban stream carried out on the Egerton Park Brook in Bexhill-on-Sea by Southern Water [(1)] demonstrates that even the pollutant washoff from the highways of the first few streets in the town has a much greater impact on the stream, particularly with respect to the impact on the number of invertebrate species of fauna, than the impact of combined sewage overflows further down the catchment.

Typical of the problems being experienced is the identification by the State of Maine, USA, that the biggest threat to the Gulf of Maine is storm water, and the Department of Environmental Protection has carried out studies which show that pollution arising from combined sewage overflows and stormwater sewers is causing pollution problems that can affect recreational use of the sea, swimming on coastal beaches, and jeopardise shell fisheries and sea fish. To control this problem a state directed programme is under development and as total elimination of all the combined sewage overflows is economically prohibitive, realistic targets are being defined so as to progressively raise standards.

TAMPA BAY, FLORIDA, SURFACE WATER IMPROVEMENT AND MANAGEMENT

Similarly the Department of Environment Protection in Florida has recognised that stormwater, both urban and agricultural, is a major issue of concern state-wide.

The 2200 square mile watershed of Tampa Bay has been identified by the South West Florida Water Management District as a priority waterbody. Two projects have been identified under the quality initiative which will result in:-

- The establishment of priority criteria for sub-basins for future rehabilitation work
- The immediate identification and implementation of known projects that will result in water quality improvements in the bay.

Through this approach will be laid the groundwork for future stormwater rehabilitation projects to be initiated not only by the District but also by local municipalities.

Improvements to a watershed the size of Tampa Bay will be expensive, hence decisions will be based on the analysis of the cost of works against the expected benefit to the receiving water. This cost/benefit ranking will ensure that funds are applied where they will be most effective within the priority ranking.

A five step approach to the problem has been developed:-

- Initial Data Collection
- Land use/pollutant loading rate formulation
- Calculation of pollutant loads for each sub-basin
- Sub-basin prioritisation
- Detailed planning for selected sub-basins

CITY OF BRADENTON - FLORIDA

Typical of the implementation of this approach is the Wares Creek, Bradenton Study carried out by Smith & Gillespie Consulting Engineers [9].

Water quality in the Manatee River, which is a tributary to Tampa Bay, is being adversely affected by urban and rural stormwater runoff. Large quantities of pollutants consisting of metals, nutrients, pesticides and herbicides are washed into the river and its tributaries during storms. Typically 85% of the pollutant loading in the Manatee River is the result of stormwater runoff, depending on the time of year.

In an effort to reduce pollutant loadings associated with stormwater runoff, a field-model demonstration project was conducted near Wares Creek. The drainage area contributing to Wares Creek was selected as the site for this project because it possessed characteristics typical of urban and residential stormwater runoff as it experiences high nutrient loadings and siltation. This field-model demonstration project consisted of two treatment systems: A Storm King hydrodynamic separator and a grassed swale retention area.

The climate in Manatee Country and in the Wares Creek Study area is subtropical. The relative humidity is high, the winters are mild and short in duration, and the summers are long and hot with abundant rainfall. A typical year is comprised of a summer wet season lasting from June through September and a dry season lasting from October through May. The average total annual rainfall amounts to 54.29 inches. Climate indirectly affects biologic forces and influences the development of inorganic factors such as soil profile formation. In turn, these factors may substantially affect nonpoint source pollution loading rates during different periods of the year. Most environmental damage caused by urban washoff is the result of the mass "wash off" of pollutants rather than the instantaneous quality at a single point in time. The mass pollutant load depends on washoff and the inter-event antecedent dry period (time between storm events) rather than the severity of the storm event. Furthermore, the mass pollutant would generally persist longer into a storm than the "first flush" quality would suggest. Therefore, treatment systems designed for treatment to reduce the overall escape of the greatest mass of pollutants will need to concentrate more on the frequent small storms than on major storm events.

It is expected that nonpoint source pollutant loads would be greatest during the wet season, since this is when the majority of land surface pollutants are scoured and washed off into surface water bodies. Therefore, climatological factors, such as rainfall, runoff, day length, light availability, and increased temperatures may combine to produce profound biological impacts on surface waters during periods of high primary productivity. These impacts include high nutrient and pollutant loading rates which can produce severe productivity stresses leading to low dissolved oxygen levels, problem algal blooms and potential fish kills.

The results of this study indicate that both treatment units are feasible means for treating urban stormwater runoff, however each project must be reviewed on a case by case basis. The disadvantages associated with large grassed swales or retention/detention basins is that they require large land areas. Adequately sized land areas may not be available in the vicinity of tha project construction. Also, this alternative may not be suitable for treating stormwater runoff from existing systems due to land availability. Erosion control and dewatering costs may also render this alternative unfeasible.

The Storm King Separator System has several advantages over the grassed swale. The unit is hydraulically controlled and hence does not require any electricity to operate. It occupies only a fraction of the land area required for grassed swales. The unit can be installed in existing storm sewer systems with minor modifications, provided required hydraulics are available. The report concluded that depending on tha situation, it may be less expensive than construction of grassed swales or retention/detention basins.

CONTROL OF NON-POINT SOURCES OF POLLUTION FROM URBAN AREAS

The realisation that surface washoff from urban areas can result in severe environmental damage calls into question the complete method of conventional drainage practice:-

The Conventional Combined Sewage System may be an effective means of ensuring that all the water draining from the urban environment is taken to a proper treatment facility. Its disadvantages, which include the need to handle vastly varying rates of flow both in the pipes and at the treatment works and the consequent need for combined sewage overflows during extreme storm events has led to the new construction of such systems being effectively abandoned.

The Separate Sewerage System is a logical development, overcoming most of the gross disadvantages of the combined system. Foul sanitary sewers, handling more constant flow rates provide the necessary transport system to enable sewage to be conveyed to a proper treatment facility, and problems with the foul sewers only tend to be experienced on older systems where "illegal" surface water connections and ground water infiltration can result in overloading. Modern techniques of rehabilitation can overcome many of these problems, however some combined sewage overflows to provide a safety valve to the system will probably always be necessary.

The Storm Drainage System is based on the assumption that stormwater is clean and can be discharged to the local land drainage system, however experience shows this often not to be the case.

Pollution control in this case normally is tackled by two main strategies:-

- **Source Control:**

  The reduction and/or interception of pollutants at source before they enter the drainage system. Use of source control and "Best Management Practices" such as reduced use of fertilizers, banning the use of pesticides and weed killers, street cleaning, car parking controls, dog litter control, use of soakaways etc. to intercept surface water, use of storage, reduction of de-icer use, oil interceptors etc. can make a great contribution to the reduction of pollution, however, the cost in capital and social terms may preclude full implementation of these strategies.

- **Treatment of the Stormwater Sewers:**

  This option is being given serious consideration. Systems including the use of storage, facultative ponds, filtration systems, exfiltration ponds, and treatment plants are in use and new approaches are being researched. The main disadvantage is the same problem as experienced with combined sewers - the need for a treatment system capable of handling vastly varying and intermittent rates of flow, with the consequent inevitability of failure during the extreme storm event.

THE SINGLE PIPE SYSTEM FOR STORMWATER MANAGEMENT [illegible]

An alternative strategy that can be adopted is the systematic use of stormwater management, controls and attenuation storage, so as to iron out the vastly varying rates of flow experienced on stormwater drainage systems so that all the contaminated water that enters a drainage system may be conveyed to a proper water treatment facility.

The use of the principles of inlet control [11, 12] where the inlet capacity is limited so that the rates of flow within a drainage system will not exceed the capacity of the pipes and treatment facility coupled with the systematic use of attenuation storage can enable all the drainage for an area to be handled by one single outlet pipe which will transport all water entering the system to the treatment plant.

The advantages of this approach include:-

- Eliminating the need for costly sewer separation on existing drainage systems
- Can provide immediate relief in areas with the most severe flooding problems, leaving areas less prone to flooding until funds are available
- Can provide a higher level of protection than is usually available from conventional methods, usually at a lower cost
- Permits the highly polluted 'first flush' to be treated by existing treatment facilities
- Avoids pollution arising from combined sewer overflows
- Reduces peak rates of flow to receiving waters resulting in reduced flooding and erosion downstream

The systematic use of inlet control avoids the need for separate drainage systems for foul and stormflows. A single pipe sewerage system discharging a controllable peak rate of flow to a treatment facility ensures that all water that enters the piped drainage system is treated before discharge, and that any facilities provided, or already in existence, are used to their optimum.

It is a feature of this approach that, where appropriate, storage on the surface of the ground can be utilised by controlling the rate of discharge to the pipe system. A primary flood is formed adjacent to the intake, holding the water on the surface until there is adequate capacity to drain the store, so these floods would persist for a short time after a storm ceases. The first flush of surface flow, with the more contaminated water usually at lower rates of flow, will be accepted directly into the drainage system so any primary floods so formed will be relatively unpolluted and should cause no nuisance or damage providing they are correctly located. The advantage in terms of pollution control of flood waters can be clearly seen.

It is necessary when designing a single pipe system to carry out an analysis of the major and minor drainage systems. It is also necessary to formulate a functional policy for the area to consider the limitations to discharge, the internal and external drainage patterns, traffic considerations and street patterns, and to define the major flow system.

The minor system will also be under the constraints for providing adequate sanitary sewers to discharge to the treatment facility. Transient storage can be incorporated in recreational water facilities by permitting surcharge during extreme storm incidents and permitting infrequent ponding in areas where flooding will not cause damage or be a serious nuisance. Transient surface storage can be provided in such locations as parks and green belts, sports facilities, on some rooftops, in car parks, adjacent to watercourses by forming artificial flood plains, etc. or in underground stores constructed for the purpose.

When considering providing relief to an already developed area suffering from flooding, the most economical solution is very often found to be a single pipe system making optimum use of any facilities already in existence and limiting inflow to this system to its capacity using storage to hold the excess.

EXAMPLE OF THE ECONOMIC ADVANTAGES OF THE SINGLE PIPE SYSTEM ON A DEVELOPMENT

This example is based on the drainage requirements for the Staplegrove Development in Taunton, England as designed by the Earnest Green Partnership, Cardiff, for Wales Retirement Homes Ltd.

The design of this development, in accordance with the drainage authority's standard requirements required that the present undeveloped peak rate of flow to the watercourse of 28 l/s should not be exceeded with storage being provided to contain any stormwater runoff so that flooding on site would not be experienced more frequently than once every 35 years (as a level of performance). Underground storage being required for the more frequent storms up to a 1 in 10 year storm after which surface storage in about ground swales or car parking areas would be permitted. A detailed hydrologic analysis showed that the requirements for the three alternative sewerage strategies would be as shown on Tables 5, 6 and 7.

TABLE 5

Conventional Combined Severage System:

Subcatchment A			
Foul Flow : 0.94 Storm Flow: 62.78 Total Flow: 63.72	Pipe 1	-	Dia (mm) 300
Subcatchment B			
Foul Flow : 1.59 Storm Flow: 101.74 Total Flow: 103.33	Pipe 2	-	Dia (mm) 375
Subcatchment C			
Foul Flow : 3.33 Storm Flow: 195.15 Total Flow: 198.48	Pipe 3	-	Dia (mm) 450
Subcatchment D			
Foul Flow : 6.47 Storm Flow: 378.20 Total Flow: 384.67	Pipe 4	-	Dia (mm) 600

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TABLE 6

Conventional Separate Severage System:

Subcatchment A	
Foul Sewer 1	Storm Sewer 1
Flow l/s 0.94 Pipe size 150	Flow l/s 62.78 Pipe size 300
Subcatchment B	
Foul Sewer 2	Storm Sewer 2
Flow l/s 1.59 Pipe size 150	Flow l/s 101.74 Pipe size 375
Subcatchment C	
Foul Sewer 3	Storm Sewer 3
Flow l/s 3.33 Pipe size 150	Flow l/s 195.15 Pipe size 450
Subcatchment D	
Foul Sewer 4	Storm Sewer 4
Flow l/s 6.47 Pipe size 225	Flow l/s 378.20 Pipe size 600

TABLE 7

Single Pipe System

Subcatchment A			
Storage Volume Required		2 year storm (cu.m.)	34.86
		5 year storm (cu.m.)	53.286
Foul Flow :	0.74		
Storm Flow:	4.65		
Total Flow:	5.59	Pipe 1 - Dia (mm)	150
Subcatchment B			
Storage Volume Required		2 year storm (cu.m.)	21.63
		5 year storm (cu.m.)	33.063
Foul Flow :	1.59		
Storm Flow:	7.53		
Total Flow:	9.13	Pipe 2 - Dia (mm)	150
Subcatchment C			
Storage Volume Required		2 year storm (cu.m.)	51.87
		5 year storm (cu.m.)	79.287
Foul Flow :	3.33		
Storm Flow:	14.45		
Total Flow:	17.78	Pipe 3 - Dia (mm)	225
Subcatchment D			
Storage Volume Required		2 year storm (cu.m.)	101.64
		5 year storm (cu.m.)	155.364
Foul Flow :	6.47		
Storm Flow:	28.00		
Total Flow:	34.47	Pipe 4 - Dia (mm)	300

A cost estimate for the three systems on this site suggests the capital cost for these alternatives to be:

Combined system	£63,558
Separate system	£146,656
Single pipe system	£61,725

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The advantage of the latter system being not only the saving in capital cost of 58% over a conventional separate system but also this approach would ensure that all the water entering the drainage system would be conveyed to a proper treatment facility before discharge to the environment.

EXAMPLE OF THE APPLICATION OF THE SINGLE PIPE SYSTEM RETRO FITTED TO AN EXISTING CITY

The Borough of York [7] is a Toronto, Canada suburb with a population of 140,000 and covers about 9 square miles. York is one of six municipalities that make up the Metropolitan Toronto area. York has a combined sewer system and in the past has suffered from severe sewer backup along with combined sewer overflows that pollute the Humber and Don Rivers.

In 1968, following a consultant's recommendations, York embarked on a $50 million program to control flooding and pollution following the traditional philosophy of a structural-intensive solution of sewer separation and storm sewer enlargement to contain a 2 year return period storm. From 1968 through 1976, York spent an average of $646,000 per year, or 22% of its annual budget, on this project.

By 1976 the borough council became quite concerned about the tremendous cost of the project and engaged an engineering firm to find an alternative solution. This firm studied four chronically flooded areas and determined that the conventional method of relief sewers was far too costly. A borough official concluded that for these four areas alone it would cost in the millions to provide relief by conventional means, such as additional sewer capacity and tunnels. As alternatives to the traditional construction, the consultant suggested using regulators in catchbasins, constructing limited-storage underground tanks and either disconnecting downspouts, or installing restrictors in the downspouts.

Under this approach, when sewer system capacity is exceeded, storm water would be temporarily stored in underground tanks or on the surface for slow release into the system. The consulting firm concluded that for $110,000 this approach would provide protection against a 2-year storm. Further, for $830,000 protection could be achieved against a 10-year storm.

York opted for the 10-year storm protection which was completed at a final cost of only $987,633. The alternative approach was completed in October 1978, except for installation of restrictors in the downspouts.

Within the first year after installation York experienced two fairly intensive storms which, according to a York official, represented a good test of the approach. The system has worked effectively and no flooding problems have been reported in the four areas, while numerous complaints have been received from residents in other areas of York.

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CONCLUSIONS

The future planning of our drainage systems to meet the increasing demand for good land drainage, pollution control, and enhancement of our environment requires the means of identifying the best strategy for the management of complete catchments from the point of rainfall to the point of outfall so as to meet the environmental quality objectives for the receiving waters.

Techniques for the preparation of catchment management plans are being developed which are beginning to enable alternative strategies to be compared on an equal basis. The use of these techniques can result in the most cost effective and beneficial means of achieving the objectives to be identified and implemented.

The various examples and case studies discussed herein demonstrate that all the principles and methods discussed herein have been applied to projects in both Europe and North America. The benefits of the concepts described are such that consideration is being given to the review of our present standard requirements and conventional methods, so as to provide a better service to the public and protect our environment at an affordable cost.

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STUDY ON CATCH BASINS IN SWITZERLAND

by F. Conradin[1]

1. Introduction

In Switzerland, as in many other areas in Europe, it is common practice to feed rainwater falling on roads and in squares via catch basins to the public sewer system. The catch basin acts as a settling device, and has always been constructed to protect the sewer system from deposits.

However, the actual situation is such that catch basins only partially perform this task at best. Deposits in sewers cannot be avoided. Nevertheless at least a proportion of the sand and other contaminants produced are fed into the sewerage system. Dauber and Novak (1982) wrote "that the role of catch basins in the road drainage system is questionable insofar as they retain in their mud catch pits not only sand, but also organic suspended matter, when rainfall is low, but are hardly able to retain such substances and instead discharge them from their mud catch pit at a higher level of heavy rain."

Sand, gravel and other materials introduced into the drainage system with the rainwater via street inlets accumulate at different points, one of these points being the catch basin. During cleaning sand is also conveyed from the sewer. After heavy rain some of these materials are fed into the recipients (combined sewer system) via storm water discharges. Large quantities of sand are retained in the sand catches of the wastewater treatment plants. Extremely fine particles reach the sewage sludge via the pre-clarification and biological purification stage.

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2. Changes in the Tasks of the Catch Basins

Today most streets and squares in built-up areas are provided with hard surfaces, with a resultant reduction in the sand and gravel present. But nowadays other fairly fine-grained materials are discharged with the rainwater, such as:

- detritus from highways
- detritus from vehicle tires
- detritus from brake linings
- leakages from vehicles
- residues from fuel combustion
- leaves and other waste materials of an organic or inorganic nature.

Furthermore, the road surface is subjected to polluted precipitation from the atmosphere, due particularly to residues from the combustion of fossil fuels (sulphuric acid, etc.).

However, the mode of operation of today's road catch basin has remained basically the same as it has always been, as these structures can only be used effectively to retain materials of all kinds which can be sedimented relatively easily. Moreover, the catch basin overflow arch (immersion arch) has also been assigned the function of an odor trap to prevent emissions from the sewer system.

3. Questions Raised

3.1. First question

The first question raised is whether catch basins can be improved so that they are much better able to perform their function. "Much better" would have to mean, of course, that deposits of materials are practically eliminated in the sewer system, and that even the extremely fine-grained materials, which appear to be on the increase, could be retained.

3.2. Second question

Since similar materials to those found in the catch basin are also found during sewer cleaning itself, and in the wastewater treatment plant (particularly in the sand catch), the second question would have to be whether the catch basins would have to be dispensed with on economic grounds. One might imagine that it would be cheaper to intensify sewer cleaning slightly, to compensate for the absence of the catch basins, so that an increase in deposits would be prevented.

3.3. **Third question**

The decision to eliminate catch basins should not be based on economic considerations alone. Consideration must also be given to the ecological effects. Will the storm water outlets produce intolerable additional water pollution if they are eliminated? Is the heavy loading of sewage sludge with substances which could be retained in the catchbasins having a negative effect on the use of sludge in agriculture?

4. **The Studies**

In order to answer the questions which have been raised, a working group has been formed by the Swiss Association of Municipal Authorities. The results of the studies conducted are summarised in a report (Swiss Association of Municipal Authorities, 1989).

4.1 **General conditions**

4.11 **Drainage system**

Because the combined sewer system is the principal system used in Switzerland, particularly in the major cities, the studies and following considerations apply mainly to this system. In this country it is common practice to feed the light rainwater runoff to the wastewater treatment plants so that twice the calculated dryweather quantity can be processed. Slightly heavier rain, up to an intensity of 15 l/s ha, is discharged into rain basins and stored, or at least pretreated there in the form of settling. Only very heavy rain is discharged directly into the recipients.

4.12 Street catch basins - Design and arrangement.

Catch basin designs in Switzerland vary from region to region. Catch basin diameters vary from 60 to 80 cm and their water depth, from the bottom to the outlet point, ranges from 60 to 130 cm. The total depth of the catch basin may be up to 2.50 m, depending on the street level, and the useful volume of the street catch basins ranges from 0.25 to 0.45 m3, depending on the type of basin. The type for the city of Zurich is shown in Figure 1.

In the streets the catch basins are installed at average intervals of approximately 30 m, and drain an area of approximately 250 to 450 m^2.

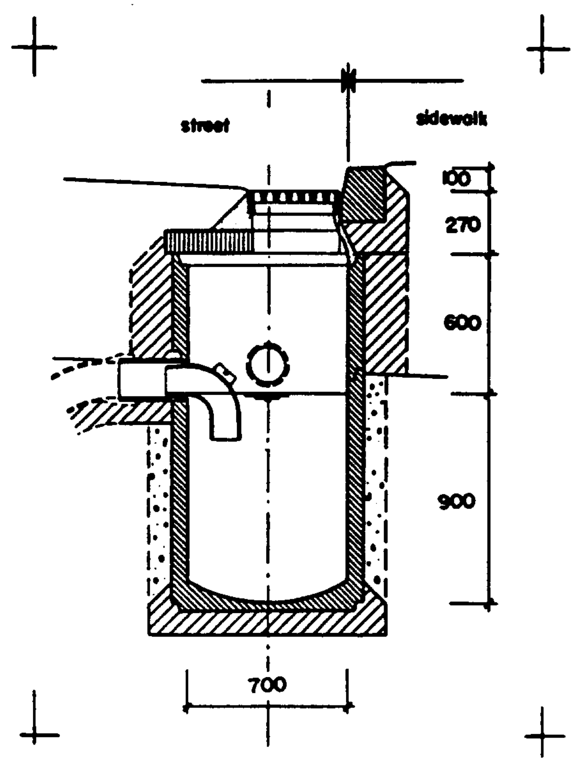

Figure 1. Catch Basin, Zurich Type

4.13 Street Cleaning

Nearly all the streets in the cities considered in the study are cleaned at least weekly by the dry vacuum method.

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4.2 Studies and measurements

4.21 Hydraulic tests

Due to the fact that catch basins cannot completely fulfill the task assigned to them, tests were carried out in the laboratory in 1985 (Zurich City Sewer Department, 1985). In particular, the tests were intended to provide information on the possible siphoning off of the basin contents under certain hydraulic conditions. However, no siphoning effect was observed in the Zurich type catch basin, even at a basin supply rate of 25 l/s (equivalent to a rain intensity of approx. 400 l/s ha on a drainage area of approx. 600 m^2), and a 45% bottom gradient of the outlet pipe 150 mm in diameter. On the other hand it was shown that as the water flow rate and level of the sedimented sludge in the catch basin increased, sludge which had already been sedimented was also washed out. Also washout has been observed with medium rain intensities , even if there is little sedimentation in the catch basin. When the sludge level is approximately 10 cm below the immersion arch, practically the same quantity of material is washed out as fed in.

4.22 Theoretical considerations

It can be demonstrated, by calculations, that the Zurich catch basins, or catch basins of a similar design used in the rest of Switzerland, are not capable of retaining fine fractions.

Under the general conditions described in Section 4.12, only sand grains of approximately 1 mm grain diameter and larger can be sedimented in heavy rain, even under optimum hydraulic conditions. At rain intensities as low as 50-100 l/s, all the sand grains from 0.2mm diam. would be washed out. Such rain events occur more than ten times a year.

The effectiveness of the catch basins is also greatly impaired by unfavourable conditions, e.g. by the fact that the material effectively accumulated in the catch basin can be lighter than sand, as a result of which larger grains are also washed out. A high sludge level reduces the settling space, having an unfavourable hydraulic effect. Most importantly, all the water falling down through the inlet gives rise to considerable turbulence in the settling area, thereby greatly reducing the settling effect and swirling up the material already settled.

4.23 Measurements of sludge levels

Since measurement programmes in the laboratory can never accurately record the effective conditions, it was decided to measure the retained quantities of sludge in several Swiss cities on a large number of catch basins. The degrees of filling of catch basins located in a wide variety of zones were measured over a period of about two years (1987/88) with a simple device, consisting of a disk secured to a tube, and a measuring rod running inside the tube (see Figure 2).

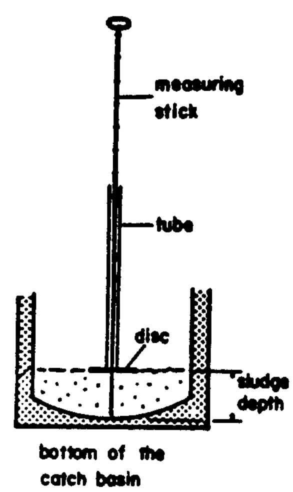

Figure 2. Device for Measuring Catch Basin Sludge Levels

It was supposed that the inlet design, the terrain, the type of developed zones, and the method of street cleaning would have a significant effect on the filling process, and an evaluation of the measured results bore out these assumptions on most points.

(a) Effect of inlet design - Inlet design has no direct detectable effect on the rise in sludge levels, either in flat or in inclined areas.

(b) Effect of terrain (lie of the land) - Catch basins, both in level streets and in streets with a gradient, exhibit sludge level plots which show both low and high rises.

(c) Effect of developed areas - The records do not indicate whether the quantity of sludge accumulated depends on the degree of development in the zone concerned. Taking the figures on the specific sludge inflow, a slightly higher value has been seen for roads carrying through traffic as opposed to residential or business quarters.

(d) Effect of parked cars - It is practically impossible to detect any influence of parked cars on the proportion of sludge on the basis of the data available, although such an effect might be expected from the more difficult street wiping conditions.

(e) Effect of precipitation - In individual cases a rise in sludge level can be associated with simultaneous rainfall, but in other cases the opposite is true, namely a reduction in sludge level at times of precipitation, i.e. the sludge is washed out of the catch basin. However, no correlation is seen between sludge accumulation and the amount of precipitation.

(f) Effect of street cleaning - The evaluation shows that street cleaning is the only factor having a relevant effect on the quantities of sludge reaching the catchbasins. A great deal of granular material and road dust is removed with the mechanical dry cleaning methods practised today, i.e. they are separated from the sewer system. By contrast road dirt is washed into the drainage system and catch basins during wet cleaning on the flushing principle (surface cleaning by flushing). Heavily contaminated streets, e.g. Hagenheimerstrasse in Basel, which is loaded with excavation material and gravel works traffic, must be wet cleaned more frequently, and the amount of sludge accumulating in the catch basins concerned is correspondingly high. The opposite is true in a commercial street such as Rennweg in Zurich, where dry cleaning is often carried out and practically no dirt reaches the catch basins and the sewer system.

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These considerations show that the topographical and settlement-specific characteristics may possibly have a certain influence on the volume of sludge stored in the catch basins, but are much less significant in comparison to street cleaning.

It was expected that the use of gravel on the roads in winter would increase the sedimentation in the catch basins; but a few results have shown that this is not the case. This might be due to thorough road cleaning after the snow melts.

An important result was, however, established in the following observations:

(a) Of 63 catch basins observed, around half reached a sludge level of only about 10 cm or less after a year. An example of this is given in Figure 3.

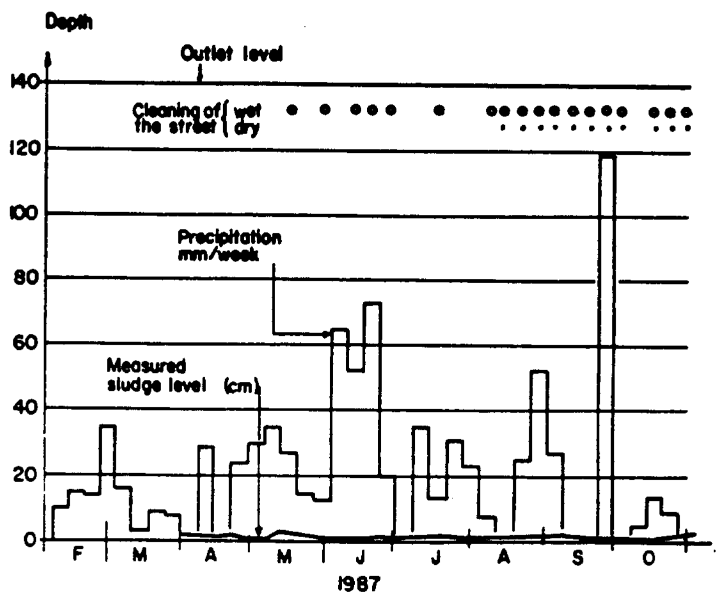

Figure 3. Typical Sludge Levels - Catch Basin with Low Sludge Supply and Insignificant Retention

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(b) Only in less than 10% of cases did the sludge attain a substantial level in the basin. Figure 4 shows a typical plot.

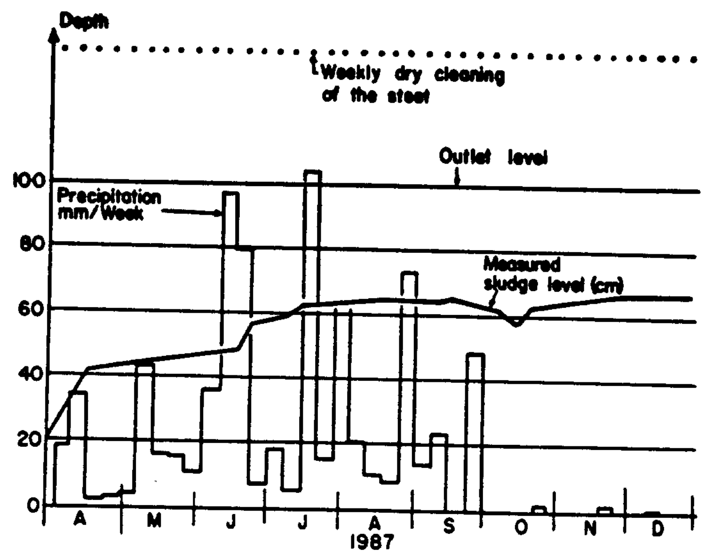

Figure 4. Sludge Level in Catch Basin which Effectively Utilises Settlement Volume

(c) The maximum degree of filling is, in most cases, reached in less than six months, and there is never any continuous increase in the filling depth, extending close to the outlet levels, over a period of time (Figure 5). This means that efficiency is reduced with time.

The following conclusions might be drawn from what has been observed:

(a) Particularly in roads and streets which are dry cleaned, the kind of dirt (sandy material which can be settled) which could be retained in catch basins does not occur.

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(b) Where such dirt accumulates, a catch basin such as that commonly used in Switzerland can only retain it to a limited degree.

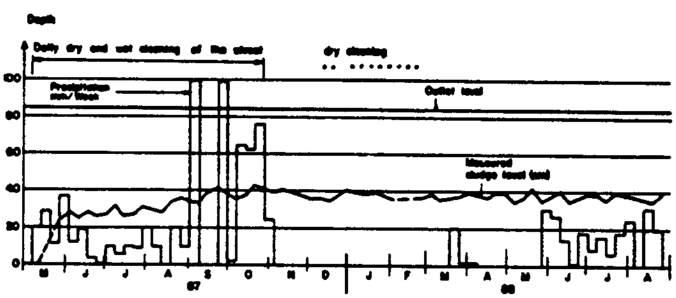

Figure 5. Long-Term Catchbasin Sludge Depths - Retentive Effect Decreases Sharply after 3-6 Months

5. Mass Balance

For a more accurate evaluation of the economic and ecological benefits of catch basins a mass balance was made for the City of Zurich (Figure 6). The quantities of sludge were surveyed by the competent departments, and are represented in Table 1. Certain assumptions had to be made, when converting to dry substance, regarding water content, specific gravity, quality, etc. However, the results obtained lead to some remarkable conclusions:

(a) Over half of the road dirt can be removed by dry cleaning of the road surface (48.6%) and rail cleaning (5.2%). Effective dry cleaning of the traffic areas, by the method commonly used in Swiss cities, can ensure that less than half of road dirt reaches the sewer system.

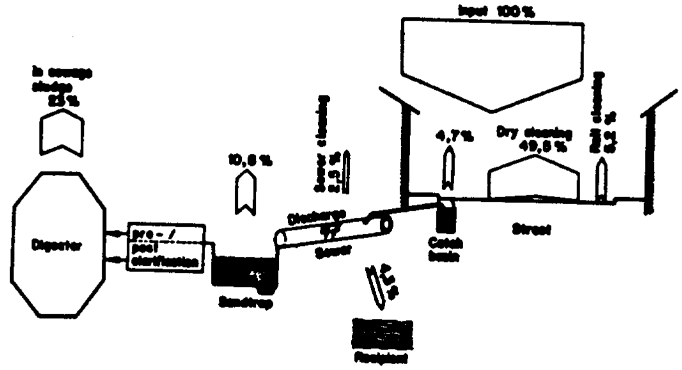

Figure 6. Approximate Catch Basin Mass Balance

Table 1: Annual road sludge volumes in the City of Zurich

Point (1)	Dry Solids (tons) (2)	Dry Solids (tons/ha impervious) (3)	% (4)
Wiped material from dry cleaning	9145	3.9	48.6
VBZ line cleaning	960	0.42	5.2
Catch basin emptying	870	0.38	4.7
Sewer cleaning (direct removal)	455	0.2	2.5
Sand trap (STP's)	2000	0.90	10.8
In digested sludge (STP's)	1250	1.85	23.0
Via discharge works into recipient	800	0.35	4.3
Total	19400	8.00	100.0

(b) Of the road dirt reaching the drainage system:

o approximately half reaches the sewage sludge (fine proportion) in the pre- and post-clarification basins.

o about a fifth can be retained in the sand traps of the wastewater treatment plants

o only about a tenth is retained in the catch basin

o about a further tenth is fed into the recipient stream via discharge structures

o approximately one twentieth is removed from the sewer system by cleaning.

6. **Economy**

Road dirt is removed from many points of accumulation: street cleaning, rail cleaning, catch basin cleaning, sewer cleaning, emptying sand traps, removal of sewage sludge. This raises the specific question of the economy of emptying catch basins, for it appears to be extremely expensive to have to empty around 50,000 catch basins about once a year, when only 5% of the road dirt accumulated is retained, as appears to be the case in Zurich.

For a comparative examination of this economy, the following variants will be compared (Table 2):

Variant A: System with catch basins

Variant B: System with direct inlets (without catch basins) (The associated costs would be incurred, for example, after all the catch basins had been replaced by direct inlets, as part of road reconstruction, etc.).

A consideration of the overall costs of removing road dirt shows very clearly that the construction and operation of catch basins is not economical given the method of dry cleaning the streets, sewer cleaning with high pressure washing practised today, and the efficient sand traps in wastewater treatment plants. The main saving that can be achieved lies in the capital service associated with the catch basins. The savings in operation depend on where the material not retained in a catch basin accumulates, and how it is to be removed. If most of this material is washed into the wastewater treatment plant during the high pressure sewer washing, which takes place regularly, considerable savings may also be expected in both operation and removal.

Table 2: Cost comparison for removal of road dirt from the drainage system, with and without catch basins

Cost item (1)	System with catch basin (2)	Direct inlets (without catch basin) (3)
Sewer cleaning and washing	2,400,000 1)	2,700,000 4)
Catch basin - - Emptying - Removal	1,400,000 1) 100,000 2) up to 300,000	100,000 5) 50,000 5)
Direct inlets, Cleaning	-	250,000 6) up to 700,000
Sand trap, extra costs	-	50,000 7)
Sludge treatment, extra costs	-	200,000 8) up to 600,000
Capital service Catch basin	4,500,000 3)	2,250,000 9)
Total	8,400,000 to 8,600,000 130-135%	5,600,000 to 6,450,000 100%

Notes for Table 2:

1) Data from Zurich City Sewerage Department

2) Removal of material from catch basins, according to measure adopted (e.g. filling or processing), because the material has too high an organic content for filling, according to the Waste Decree).

3) 50,000 catch basins cost SFr. 1,400/- each, return on investment period 50 years, 5.5% interest.

4) Slightly increased expenditure if catch basins were to be removed.

5) Remaining catch basins at a variety of different points.

6) Cleaning every one to two years

7) Removal of additional accumulation of sand in the sand trap in the wastewater treatment plant.

8) Removal of additional accumulation of fine materials in the sludge, according to measure taken (e.g. agriculture, filling or incineration).

9) Assumption: costs of direct inlets approximately half that of catch basins.

7. Ecological and further considerations

The best effect, as far as environmental protection is concerned, is achieved when the roads are dry cleaned. Of the points of accumulation of road dirt in the sewer system, two points are of particular importance from the ecological point of view: stormwater discharges and sewage sludge.

7.1 Storm water discharges

If catch basins were to be dispensed with it could be assumed that some of the quantities of dirt not retained might reach the recipients via storm water discharge works. It is very difficult to quantify this, but logical considerations all point in the opposite direction, namely that catch basins have a detrimental effect from the point of view of water conservation.

When it is considered that most heavy metal pollution, for example, adheres to the finest dirt and sand particles, it should be expected that in light rain the fine dirt from the street is washed into the catch basins and is retained there. But if the rainfall is only slightly more intense, this fraction is washed out of the catch basins in concentrated form, and higher dirt concentrations are found in the overflow water than if the catch basins were not present (Dauber and Novak, 1982).

Measurements of material in catch basins also indicate increases in concentrations of hydrocarbons. The effect during rainfall would probably be the same for the storm water discharge works as in the case of heavy metals. Another point is that the dirt-laden water in the catch basin begins to putrefy. If it is washed into the wastewater treatment plant during rain, this may tend to

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cause negative effects on the wastewater treatment operation.

Thus, water conservation can hardly be put forward as a conclusive argument for the installation of catch basins.

7.2 Sewage sludge

It is conceivable that some of the road dirt which reaches the wastewater system in the absence of catch basins will pass through the sand trap and finally reach the digested sludge.

But when it is considered that the catch basins are extremely poor sedimentation basins, it cannot be assumed that they have a notable retaining effect in terms of the retention of the finest heavily contaminant-laden proportions. It is much more likely that the material which could be retained in the catch basin would also be separated without problem in the sand trap. The assumption that the absence of catch basins has a negative effect on sewage sludge quality, and therefore renders its use or removal difficult, could not really be considered valid.

7.3 Odours

In sewer systems, particularly in flat areas, odours may occur as a result of the long flow time and slow flow rates. There is an example, namely Freiburg in Breisgau (Germany), where over two thirds of all the sludge catch basins have been converted to direct inlets, and no odour difficulties are being experienced. There are also direct inlets in various other cities in Germany, but in most cases they are provided with sludge buckets. Paris also has direct inlets.

In this country perforated manhole covers (ventilation covers) are not uncommon. If the stench from the sewer system were a major problem, unpleasant odours from these perforated covers would also be experienced.

In the final analysis it is a question of whether the digesting processes which take place in the catch basin itself are not a greater source of stench than a sewer system with normal flow conditions.

8. Concluding remarks

In the course of the work carried out it was demonstrated that the construction and operation of catch basins is not really feasible from the economic point of view. Nor would catch basins probably have much justification in the

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combined sewer system, for ecological reasons, when streets are cleaned frequently by the vacuum method. But although catch basins have been used since the beginnings of sewer engineering over 100 years ago, the sceptics have yet to be convinced of their inadequate benefits. Tests in larger areas, extending over several years, in which catch basin emptying will be dispensed with for the time being, are intended to demonstrate the effects on sewer cleaning. In Basel, where such a test has been carried out in a larger area (Bruderholz), hardly any differences relative to the previous condition have been observed.

The dispensing with immersion arches on certain street sections could contribute to obtaining more detailed knowledge of odour emissions.

Scientific tests could contribute towards settling the questions of recipient load and sewage sludge load.

Appendix I. - References

(1) L. Dauber and B. Novak, Quellen und Mengen der Schmutzstoffe in Regenabflussen einer stadtischen Mischkanalisation (Sources and quantities of pollutants in rain runoff in an urban combined sewer system), EAWAG, Dubendorf (Switzerland) 1982.

(2) Swiss Association of Municipal Authorities, Untersuchung der Funktionstuchtigkeit von Strassenschlammsammlern (Investigation into the efficiancy of catch basins) (Draft) of 24 August 1989.

(3) Test Certificates nos. 1439 and 1440, Zurich City Sewerage Department, 19 March 1985.

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POLLUTANT REMOVAL BY CATCH BASINS IN WEST GERMANY STATE OF THE ART - NEW DESIGN

by Matthias Grottker[1]

INTRODUCTION

The discharge of heavily polluted storm water in terms of accumulated loads of chemicals such as heavy metals are becoming an increasingly dangerous hazard. For efficient environmental protection the processes of storm water pollution need to be investigated in detail. The main objectives of this study are to understand the pollutant accumulation and removal processes through various kinds of catch basins and to improve them. The research work is based upon a half year measurement program in a laboratory. Series of tests with variable rates of flow, pollution loads and test durations were simulated for two basic kinds of catch basins. Further a field measurement program was carried out in different catchment areas to expose the state of the art. Based on these investiga- tions new designs were created to improve the removal efficiency, to reduce the maintenance work or to prevent sewer deposits.

LABORATORY MEASUREMENT PROGRAM

Pilot unit

Figure 1 shows the pilot unit which was used to investigate the different catch basins. A weir, mounted on a scaffold, was charged by the water supply system of the laboratory. The rate of flow was regulated by a wedge gate valve and measured by an electromagnetic flow meter. During each test the water fell into a movable trough where the pollution load was added. The polluted water was then discharged to

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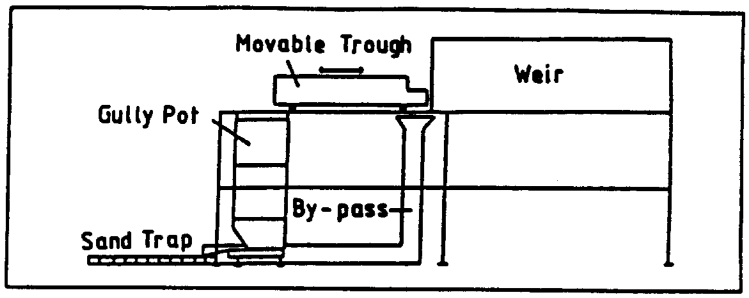

Figure 1 - Pilot Unit

the catch basin. After the water was cleaned in a sand trap it was recycled to the supply system. To finish a test the movable trough was moved away from the weir and the supplied water by-passed the test site.

Test program

The catchment area of a catch basin is normaly limited to 400 m² (1). A discharge of 100 l/s.ha causes a flow rate of about 4 l/s from such a catchment. Under these conditions the flow rates and test duration were chosen, equivalent to the effective depth of precipitation as shown in Table 1.

Test Duration t [min]	Flow Rate Q [l/s]					
	0,50	1,00	2,00	3,00	5,00	10,00
5	0,38	0,75	1,50	2,25	3,75	7,50
15	1,13	2,25	4,50	6,75	11,25	22,50
30	2,25	4,50	9,00	13,50	22,50	45,00

Table 1 - Effective Depth of Precipitation, Flow Rate and Test Duration

The particle sizes and pollution loads to charge the catch basin were chosen based upon earlier research work (2). Table 2 gives an overview about these particle sizes and pollution loads.

Fraction No.	Particle Sizes [mm]	Fraction Load [g]	Fraction No.	Total Load [g]
1	< 0,025	5	2 - 8	35
2	0,025 - 0,08	10	2 - 8	70
3	0,08 - 0,16	15	2 - 8	105
4	0,16 - 0,25	20	3 - 8	120
5	0,25 - 0,50	30	3 - 8	180
6	0,50 - 1,00	40	3 - 8	240
7	1,00 - 1,60	50	3 - 8	300
8	> 1,60			

Table 2 - Particle Sizes, Pollution Loads

The test program concentrated on two kinds of catch basins, shown in Figure 2:

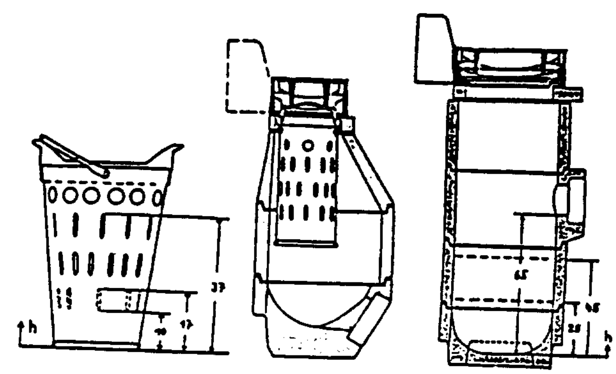

Figure 2 - a) Dry Catch Basin b) Wet Catch Basin

a) Dry Catch Basin (Dry Gully Pct = DGP). The pollution of the surface runoff is reduced by flowing through the slotted bucket. Mainly particles of big size and rubbish

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like papers, tins, sticks or cigarette stubs are removed. After a storm event, the bucket will be drained by the slots. But the content still keeps wet for a long time, because the ventilation and the temperature within the catch basin is low. b) Wet Catch Basin (Wet Gully Pot = WGP). The surface runoff falls into the small settling pit where pollutants partly accumulate by sedimentation. Also particles of small size are removed beside the big ones and the rubbish. This is caused by the different process of removal (sedimentation). After a storm event the sludge deposits and water will remain within the settling pit.

Most of the other common kinds of catch basins differ only in the volume either of the slotted bucket or the settling pit.

Test procedure

Dry catch basin

Two series of tests were carried out with the dry catch basin.

Test 1 - Simulation of the pollutant removal in an empty slotted bucket. These tests simulate a catch basin just after being cleaned by the sewerage department. In this special case the dependencies between parameters influencing the accumulation and removal processes in the catch basin were found. This was necessary to minimize the number of tests without loss of information. Therefore, all combinations of test duration, flow rate and pollutant load mentioned above were tested.

Test 2 - Simulation of the pollutant removal with different accumulated loads in the slotted bucket. Various stages of accumulated debries were investigated by filling the slotted bucket with wet leaves up to h = 10, 17 and 37 cm (Figure 2a). In this series of tests the discharge parameters "flow rate" and "pollutant load" were kept variable.

Wet Catch Basin

Three series of tests were carried out with the wet catch basin.

Test 1 - Simulation of the pollutant removal with different accumulated loads in the settling pit. Similar to the dry catch basin test 1, all combinations of parameters of the test program were carried out. To replace load levels at h = 25 or 45 cm a metal sheet was fixed at these levels (Figure 2b).

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Test 2 - Simulation of the flushing effect from different accumulated loads in the settling pit. Investigations on the flushing effect were carried out with the same load levels in the settling pit as in test 1. The pollutant load was added to the water in the settling pit before the catch basin was charged with water. After ten minutes sedimentation time the test was started. The flow rate was varied from 3, 5 to 10 l/s and the pollutant load was fixed to 100 g of particle size fraction 2-5.

Test 3 - Simulation of the pollutant removal and the flushing effect from different accumulation loads in the settling pit. During the runoff process a superposition of the processes of pollutant removal and flushing takes place. To check this superposition a brief test program was carried out. Hence the pollutant load was added before and during the test comparable to test 1 and 2.

Results

The "passed load" is defined as the part of the pollutant load which cannot be filtered in the catch basin in contrast to the "accumulated load". The description of the passed load as a function of the pollutant load, flow rate, test duration or level of accumulated load is a main objective of the study in laboratory. Therefore coefficients of correlation were computed for all these parameters.

Generally there is no significant correlation between the passed load and the test duration. Furthermore the dependency between the removed load and the pollutant load is linear.

Hence, the generalized function follows as

$L_{pas} = L_{pol} \cdot \mu$	L_{pas} : Passed Load L_{pol} : Pollutant Load μ : Function of flow rate or level of accumulated loads

Function 1 - Pollutant removal

Dry Catch Basin

There is a significant difference between the results of test 1 and 2. An empty slotted bucket (test 1) filters less than half of the pollutant load filtered by partly filled buckets (test 2). The results of the tests with different

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levels of accumulated load show some scatter. However, no functional dependence between the passed load and these levels could be found. Summarizing these results, μ can be described as a function of the flow rate provided that the slotted bucket is not empty.

Figure 3 and Table 3a illustrate the functional description of μ_{sm} for all particle sizes. It is obvious that the bigger particles were better filtered than the smaller ones. Merely in the range of low flow rates the passed loads of the particle sizes are more random. In this range the passed loads vary between 30 and 50% for the particle sizes and the total load (Σ). The exception is fraction 2 which was passed by about 70% of the pollutant load.

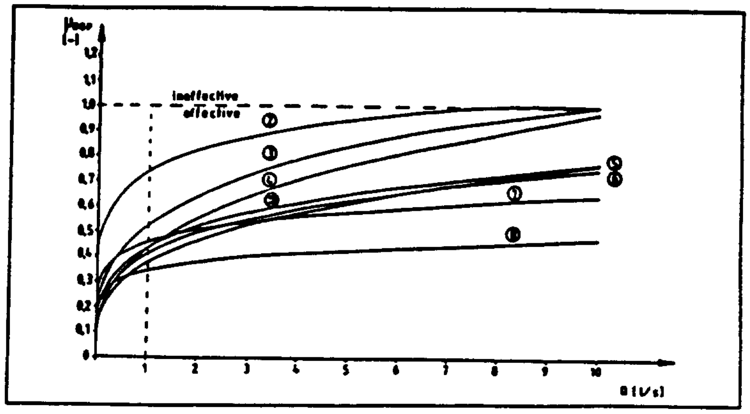

Figure 3 - μ_{sm} - Function

Wet Catch Basin

For all wet catch basin tests no significant correlation between the passed load and the level of accumulated load was found. Except in test 2, the passed load increases from about 10% up to 55% at a flow rate of 10 l/s. Concluding these results μ can be described as a function of the flow rate. Figure 4 and Table 3b illustrate the functional description of μ_{sm} for all particle sizes. Again there is a systematic dependency-among the particle size fractions. The bigger the particles the higher the cleaning efficiency of the catch basin. Merely fraction 7 in the range of low and fraction 2 in the range of high flow rates do not follow this rule. Also the passed loads are limited to 5 to 40% - except fraction 2 with 80% - in the range of low flow rates up to 1 l/s.

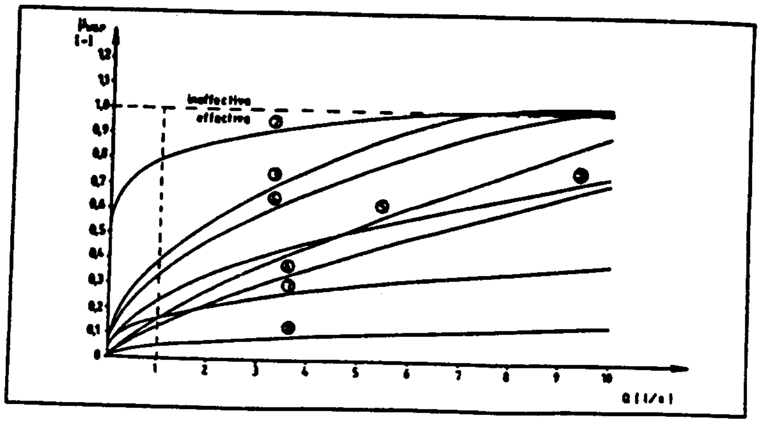

Figure 4 - μ_{sum} - Functions

	a - Dry Gully Pot	b - Wet Gully Pot
Σ	μ = 0,440 $Q^{0,243}$, r = 0,847	μ = 0,236 $Q^{0,496}$, r = 0,846
8	μ = 0,345 $Q^{0,133}$, r = 0,494	μ = 0,046 $Q^{0,492}$, r = 0,639
7	μ = 0,459 $Q^{0,145}$, r = 0,689	μ = 0,166 $Q^{0,372}$, r = 0,777
6	μ = 0,415 $Q^{0,256}$, r = 0,778	μ = 0,132 $Q^{0,734}$, r = 0,783
5	μ = 0,375 $Q^{0,309}$, r = 0,875	μ = 0,165 $Q^{0,737}$, r = 0,766
4	μ = 0,434 $Q^{0,350}$, r = 0,904	μ = 0,335 $Q^{0,497}$, r = 0,858
3	μ = 0,532 $Q^{0,282}$, r = 0,876	μ = 0,391 $Q^{0,481}$, r = 0,828
2	μ = o,739 $Q^{0,151}$, r = 0,935	μ = 0,791 $Q^{0,121}$, r = 0,827

Table 3 - μ-Function a) Dry Gully Pot b) Wet Gully Pot

The flushing effect (test 2) causes passed loads less than 10% of the pollutant load. Merely the passed load of fraction 2 was up to 25% of the initial load. In order to test the results of test 1 and 2 the pollutant removal and the flushing effect was simulated. Generally, the passed load in test 3 was about 10% lower than the separately simulated loads (test 1 and 2). No significant difference between the separate and combined simulation was found among the particle sizes, flow rates and levels of accumulated load.

The acquired results make a continuous simulation of the particle sizes possible. The main uncertainties arise from an empty slotted bucket (DGP) and with the flushing effect at high flow rates (WGP). Therefore, these results have to be verified with data found in real catchments.

Furthermore, a high cleaning efficiency of both dry and wet catch basins were found at flow rates in a range up to 1 l/s. Hence it follows that a revision of the construction of the catch basins could be useful.

FIELD MEASUREMENT PROGRAM

Test procedure

The investigations concentrated mainly on two kinds of catch basins (Figure 5), which are used in the city of Hannover. The dry catch basin differs in the smaller volume of the slotted bucket. The wet catch basin uses a pipe, dipping into the water of the settling pit to hinder smell emissions from the sewer.

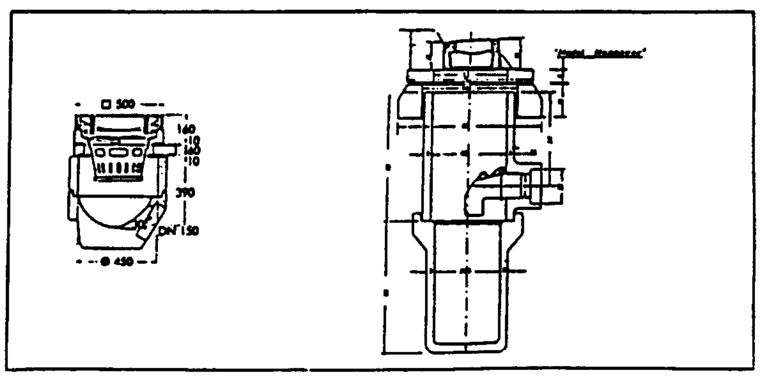

Figure 5 - a) Dry Gully Pot b) Wet Gully Pot

The catch basin maintenance is performed by the municipal cleansing service of the city of Hannover. The dry catch basins shall be cleaned twice or three times a year. A team of 2 or 3 workers empties the slotted bucket into an open trailer. About 70 to 80 catch basins can be cleaned during one day. The annual pollutant removal of each catch basin was measured by weighing the slotted bucket before and after the cleansing procedure. Further on, a sample of the removed matter was taken to analyse some physical and chemical parameters.

The measurement procedure of the wet catch basins was much more difficult. The settling pit is normally emptied by a suction pump lorry. 2 or 3 workers operate the lorry. About 30 to 40 catch basins can be cleaned during one day. The annual pollutant removal of each catch basin was measured by sampling the whole content of the settling pit into suitable sampling bottles. The dry weight was analysed through wet sieving and drying. A part of the removed matter was, further on, analysed like the samples of the dry catch basin.

The investigation was done for both kinds of catch basins in three catchment areas:

1. Residential area, low traffic loading, many trees.
2. Residential area, low traffic loading, few trees.
3. City high traffic loading, no trees.

Later on, a further specification was necessary for each catch basin:

a. The smallest distance of a tree or bush is less than 10 m from the catch basin. b. The smallest distance of a tree or bush is more than 10 m from the catch basin.

Since the characteristics within a catchment area differ very much, we decided to investigate some of the main characteristics of the intake area of each catch basin. The characteristics are:

* intake area (m^2)
* ratio of perviousness of the intake area
* road surface (asphalt, concrete, cobble-stone)
* gutter (width, slope, height)
* slope of road surface (longitudinal, lateral)

The annual pollutant removal of each catch basin was measured and the following parameters have been analysed:

* dry weight
* particle size distribution
* organic matters
* ion exchange capacity
* specific surface
* heavy metal concentrations (few samples of six catch basins)

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Results

The dependencies between the analysed parameters and the catchment characteristics were checked by a correlation analysis. There is no significant dependency between the catchment characteristics and any other analysed parameter. Consequently the accumulation and removal of surface pollution occurs randomly within the intake area of a catch basin. Further on, there is no significant dependency between the different analysed parameters themselves, with the exception of the small particle sizes and the ion exchange capacity or specific surface. These results confirms the results of the half year measurement program in laboratory. Here we found out, that the pollution removal in a catch basin is mainly depending on the flow rate (3). Of course, there are some other dependencies, which could not be found out by the correlation analysis. These phenomena will be pointed out, by using the mean values of the analysed parameters, shown in Table 4 and 5 - (4).

* The intake area of the dry catch basin is about 125 m² within the residential areas and about 250 m² within thoroughfares. The intake area of the wet catch basin is a little bit less than 250 m². The specific dry weight is situated within the range of 45 g/m² to 68 g/m² for the dry catch basin and within the range of 86 g/m² to 93 g/m² for the wet catch basin. In case trees or bushes are near by, the ratio of organic matters in the catch basin is high. This means, the dry weight is less than in catch basins with only few organic matters. The specific dry weight of the surface pollution load, evaluated by single samples, is about 23 g/m² in Hildesheim (FRG) and about 73 g/m² in Baden-Württemberg (FRG). This is nearly the same amount as the annual removal of the catch basins and makes their small removal efficiency obvious.

* The particle size (PS) distribution shows, that the removal efficiency of fraction PS6 to PS8 is low for the dry catch basin and higher for the wet catch basin. The pollution load on the surface has nearly the same distribution as the one within wet catch basin. Among the PS1, there is a big standard deviation for the dry catch basins, due to tins, sticks or papers. The standard deviation of the other sizes is around 5% as for the wet catch basin.

Parameter		DGP < 10m n=77	DGP ≥ 10m n=75	DGP city n=30	WGP < 10m n=8	WGP ≥ 10m n=7	Surface Hi* n=202	Surface BW** n=136
Dry weight [kg]		5,564	6,775	16,960	20,100	22,342	-	-
Intake area [m²]		124,630	125,683	248,370	233,843	240,428	-	-
Specific dry weight [g/m²]		44,644	53,905	68,285	85,955	92,926	-	-
PS1: ≥ 1,6mm		30,066	24,687	11,200	21,037	21,800	22,986	73,036
PS2: 1,0-1,6mm		7,919	7,256	6,413	4,900	5,600	15,883	26,499
PS3: 0,5-1,0mm		20,591	21,893	25,130	14,735	16,900	4,900	5,345
PS4: 0,25-0,5mm		23,907	26,871	34,330	25,125	23,928	18,777	18,329
PS5: 0,16-0,25mm		10,648	12,234	13,747	14,465	14,328	24,060	19,764
PS6: 0,08-0,16mm		4,036	4,228	5,250	9,325	8,800	11,650	13,231
PS7: 0,025-0,08mm		2,540	2,553	3,767	13,175	8,043	7,520	9,974
PS8: < 0,025mm		0,156	0,159	0,360	1,550	0,457	10,904	9,431
ion exchange capacity [mval/...g]		12,458	9,702	9,726	-	-	6,247	0,769
specific surface [cm²/g]		57,976	62,143	80,107	148,814	100,832	5,916	6,512
	PS1	27,463	22,845	20,800	32,625	20,771	238,951	112,466
loss of ignition [%]	PS2	26,876	20,836	18,070	26,712	14,943		
	PS3	17,395	11,846	9,587	13,325	9,128	7,776	6,847
	PS4	9,683	6,724	6,027	7,837	7,529		
	PS5-8	15,133	11,529	14,293	18,350	19,372		

Hi* = Hildesheim, FRG BW** = Baden-Württemberg, FRG

Table 4 - Physical parameter of the catch basin samples

• The ion exchange capacity and the specific surface characterizes the adsorption potential of a sample. Among the ion exchange capacity, there is no significant dependency between the different samples. This is also caused by the missing results for the wet catch basin. The comparison of the specific surface shows again the small removal efficiency for the dry catch basin, since the specific surface mainly depends on the ratio of small particles.

• The loss of ignition is mainly caused by the PS1 and PS2. In autumn, the loss of ignition is about 6% to 10% greater than in spring, for the dry catch basin. Further on, the mean values of loss of ignition are about 16,7% (residential area) or 11,1% (city) for the dry catch basin and 17,9% (residential area) or 15,4% (city) for the wet catch basin. These values are twice as big as the values of the surface pollution, caused by the higher removal efficiency of the big particle sizes in the catch basins.

Parameter [mg/kg]		DGP *=few n=2	DGP *=many n=2	DGP city n=1	WGP *=few n=1	WGP *=many n=1	WGP city n=1	Surface Hi** n=58	Surface BW*** n=12
Fe	< 1,6mm > 1,6mm	18363	6213	13813	47994 17684	33057 14872	52303 16282	23423	10307
Pb	< 1,6mm > 1,6mm	171	48	113	1544 189	444 125	1527 378	362	84,1
Cd	< 1,6mm > 1,6mm	0,81	0,64	0,64	22,65 2,04	6,93 2,28	17,62 2,97	3,95	2,58
Cr	< 1,6mm > 1,6mm	12,8	6,1	19,6	56,5 10,8	28,6 10,3	66,6 20,2	17,0	10,6
Cu	< 1,6mm > 1,6mm	61,5	13,0	44,6	514,6 50,7	170,1 47,2	497,7 99,5	76,7	25,1
Zn	< 1,6mm > 1,6mm	268,3	185,3	214,6	2339,8 792,7	895,7 276,7	2905,7 659,3	187,5	152,0
Ni	< 1,6mm > 1,6mm	22,0	9,2	15,3	123,3 18,1	49,9 21,5	94,3 29,1	26,7	20,4

* = trees Hi** = Hildesheim, FRG BW*** = Baden-Württemberg, FRG

Table 5 - Chemical parameter of the catch basin samples

• Investigations about the heavy metal concentrations have only been done for 8 samples out of 207 for the dry and wet catch basins. The investigations about the surface pollution was done more in detail. A comparison has shown, that the concentrations of the seven heavy metals are similar for the dry catch basin and the surface pollution, except for cadmium. The cadmium load of the surface pollution is dissolved by the storm water and can't be removed within the dry catch basin. Differences between the dry catch basins are due to the different land use of the intake areas. This can be proved by the surface pollution concentrations, since the samples in Hildesheim mainly are taken from a thoroughfare, while the Baden-Würtemmberg samples are taken from streets with different traffic loading. The investigations for the wet catch basin have been done more in detail. Each sample was splitted into the fractions < 1,6mm and > 1,6mm. For every heavy metal the small size samples has the higher concentrations. The concentrations in the big size samples are in the same range as the concentrations on the surface. The concentrations in the small size samples are up to ten times higher. This phenomenon might be caused by the good conditions for ion exchanges or adsorption, within the settling pit.

LONG TERM SIMULATION

Simulation model

The removal efficiency of catch basins is characterized in general by physical and chemical parameters. Due to the lack of information about the accumulation and removal on the surface of all the other parameters, the parameter total suspended solids (TSS) shall be used for long term simulation. The simulation model KOSIM is continuously simulating the processes of precipitation losses, runoff concentration, accumulation and removal of surface pollutants and pollution removal by catch basins. With this model, a 11 year long term simulation was carried out. The measured data were used to calibrate and verify the μ_{ww}-function and the μ_{ww}-function within the different catchment areas. The following functions had been fitting best to the measured data (Fig. 6).

Catchment area	Calibration error	Verification error	Number of samples
Dry catch basin Residential road	16,5%	10,5%	154
Dry catch basin Thoroughfare	≈0,0%	23,6%	30
Wet catch basin Residential road	≈0,0%	17,0%	10
Wet catch basin Thoroughfare	≈0,0%	30,0%	5

Table 6 - Calibration and verification errors

Table 6 shows the errors for calibration and verification. They are in a range of 10% to 30%, which can be accepted for the further simulation. The efficiency of the catch basins in the model of the laboratory was much better than under real conditions on the roads. This is caused by the short term measurements in laboratory.

Synthetic catchment area

The efficiency of storm water treatment depends on the rainfall-runoff process and on the surface characteristics. The main sources of surface pollution are the atmospheric deposition and the pollution caused by the traffic. Therefore the surface areas of roofs, resi-

Dry Catch Basin

Model:

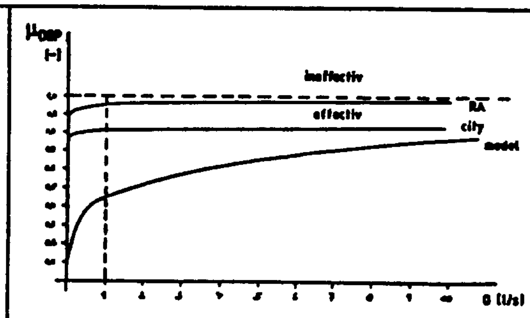
$\mu = 0,440 \cdot Q^{0,243}$

Residential area:

$\mu = 0,956 \cdot Q^{0,010}$

Thoroughfare:

$\mu = 0,810 \cdot Q^{0,080}$



Wet Catch Basin

Model:

$\mu = 0,236 \cdot Q^{0,496}$

Residential area:

$\mu = 0,876 \cdot Q^{0,100}$

Thoroughfare:

$\mu = 0,856 \cdot Q^{0,100}$

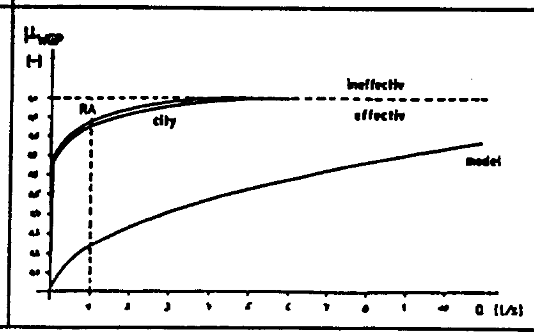


Figure 6: μ-Functions for dry (DGP) and wet (WGP) catch basins

dential roads and thoroughfares are the most significant parameters. These paved areas are defined as follows:

* Roofs include the paved surface within the private property.

* Residential roads include pavements, cycleways and parking lots. The traffic load is less than 6000 cars per day.

* Thoroughfares include pavements, cycleways and parking lots. The traffic load is more than 6000 cars per day.

The roofs are polluted by the atmospheric deposition, the roads are polluted by the atmospheric deposition and the traffic. The average pollution load of the atmospheric deposition (AV 1-4) is in a range of 300 to 900 kg/ha.a. The traffic pollution load is 2000 kg/ha.a in residential roads and 5500 kg/ha.a in thoroughfares. These average values are estimated by data published in the literature. To transfer the results of the simulation to existing catchment areas, a spectrum of synthetic catchment areas is defined like in Table 7:

All together 44 synthetic catchment areas are defined, representing most of the existing catchment areas.

Results

For every synthetic catchment area first a long term simulation was carried out without any treatment of storm water. The discharged annual pollution load of TSS is shown in Table 7. After that the following 12 treatment conditions (Table 8) were simulated:

	Dry catch basin	Wet catch basin
Intake area	50 m^2 100 m^2 200 m^2 300 m^2 400 m^2 500 m^2	50 m^2 100 m^2 200 m^2 300 m^2 400 m^2 500 m^2

Table 8 - Intake areas of the simulated catch basins

Before estimating the removal efficiency of the catch basins the frequence of maintenance was varied for each treatment condition. The necessary frequence is in a range of every 6 to 72 months depending on the kind of catch basin, intake area and land use. Since in the model only particles were simulated, these frequencies are much too great. Mainly sticks, tins, stones or wires may clog the catch basins. To guarantee the hydraulic efficiency the frequency of maintenance should be twice a year for the dry catch basin and once a year for the wet catch basin.

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Type of catchment area A_i * [%] $A_{rf}:A_{rr}:A_{tf}$	AV1 [kg/ha·a]	AV2 [kg/ha·a]	AV3 [kg/ha·a]	AV4 [kg/ha·a]
A_1 = 90: 5: 5	554,5	730,0	905,7	1081,3
A_2 = 85:10: 5	643,2	818,9	994,6	1170,3
A_3 = 70:25: 5	907,5	1083,0	1258,5	1434,1
A_4 = 70:20:10	1019,1	1193,0	1367,1	1541,2
A_5 = 70:10:20	1240,8	1411,7	1582,8	1753,9
A_6 = 55:40: 5	1171,9	1347,3	1522,8	1698,3
A_7 = 55:30:15	1393,6	1566,0	1738,5	1911,1
A_8 = 55:20:25	1616,8	1786,1	1955,7	2125,3
A_9 = 40:50:10	1549,2	1723,0	1896,9	2070,9
A_{10}= 40:35:25	1882,5	2051,7	2221,2	2390,8
A_{11}= 40:20:40	2214,4	2378,9	2543,9	2708,9

A_{rf}: Percentage of roof surface
A_{rr}: Percentage of residential road surface
A_{tf}: Percentage of thoroughfare surface

AV 1-4 : Atmospheric pollution load
AV 1: 300 kg/ha·a
AV 2: 500 kg/ha·a
AV 3: 700 kg/ha·a
AV 4: 900 kg/ha·a

Table 7 - Annual runoff pollution load (TSS) in different catchment areas - no storm water treatment

* The roof areas (A_{rf}) vary between 40% and 90%.
* The residential roads (A_{rr}) vary between 5% and 50%.
* The thoroughfares (A_{tf}) vary between 5% and 40%.

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Depending on the land use of the paved surface, the removal efficiency is 2,2% to 8,3% for the dry catch basin and 10,4% to 43% for the wet catch basin (Table 9). The removal efficiency (%) ie better, the more roads are within the catchment. Of course, the amount of discharged pollution load is also greater then. The removal efficiency is less, if the atmospheric deposition is great, since the pollution load of the roof surface can't be treated by catch basins.

In general the dry catch basin is only useful to hinder clogging within the sewer pipe. It is nearly useless to remove TSS out of the storm water. The efficiency of wet catch basins is much better, but still not good enough to protect the receiving waters.

ENVIRONMENTAL AND OPERATIONAL PROBLEMS

Separate severage system (SSS)

In separate severage systems many environmental problems occur due to the great pollutant loads of physical and chemical parameters. Often the concentrations of many parameters are much greater than at the outlet of treatment plants and sometimes greater than at combined severage overflows (6). Since the discharges are polluting the recei-ving water discontinuously and during every storm event the SSS is a serious source of environmental pollution. The storm water needs to be treated in cases of heavy and medium polluted surfaces. Two treatment strategies can be distinguished and qualified like in Table 10:

* Decentralized treatment as
  - Street cleansing
  - Catch basins
  - Infiltration systems
* Centralized treatment as
  - Detention ponds
  - Swirl separators
  - Infiltration systems
  - Vegetative controls

Type of catchment area A_i = [%] $A_{rf}:A_{rr}:A_{tf}$	AV1		AV2		AV3		AV4	
	DGP max min [%]	WGP max min [%]	DGP max min [%]	WGP max min [%]	DGP max min [%]	WGP max min [%]	DGP max min [%]	WGP max min [%]
A_1 = 90: 5: 5	5,0 3,8	25,7 17,6	4,0 3,0	20,5 14,1	3,4 2,5	17,4 11,9	2,9 2,2	15,2 10,4
A_2 = 85:10: 5	5,7 4,3	29,3 20,1	4,7 3,6	24,4 16,8	4,1 3,1	21,3 14,6	3,7 2,8	19,0 13,1
A_3 = 70:25: 5	7,0 5,3	36,0 24,7	6,3 4,7	32,2 22,2	5,7 4,4	29,7 20,4	5,4 4,1	27,7 19,0
A_4 = 70:20:10	7,2 5,4	37,0 25,4	6,5 4,9	33,5 23,0	6,0 4,5	30,9 21,2	5,6 4,2	28,9 19,8
A_5 = 70:10:20	7,4 5,6	38,4 26,3	6,8 5,2	35,2 24,2	6,3 4,8	32,8 22,5	6,0 4,5	30,8 21,1
A_6 = 55:40: 5	7,7 5,8	39,7 27,3	7,2 5,4	37,1 25,5	6,8 5,2	35,2 24,2	6,5 4,9	33,6 23,1
A_7 = 55:30:15	7,8 5,9	40,5 27,8	7,4 5,6	38,2 26,2	7,0 5,3	36,4 25,0	6,7 5,1	34,9 23,9
A_8 = 55:20:25	8,0 6,0	41,1 28,2	7,6 5,7	39,0 26,8	7,2 5,5	37,3 25,6	6,9 5,3	35,9 24,6
A_9 = 40:50:10	8,2 6,2	42,4 29,0	7,9 6,0	40,6 27,9	7,6 5,8	39,4 27,1	7,4 5,6	38,3 26,3
A_{10}= 40:35:25	8,3 6,3	42,7 29,3	8,0 6,1	41,3 28,4	7,8 5,9	40,2 27,6	7,6 5,7	39,2 26,9
A_{11}= 40:20:40	8,3 6,3	43,0 29,5	8,1 6,1	41,8 28,7	7,9 6,0	40,8 27,9	7,7 5,8	39,9 27,3

A_{rf}: Percentage of roof surface
A_{rr}: Percentage of residential road surface
A_{tf}: Percentage of thoroughfare surface

AV 1-4 : Atmospheric pollution load 300 to 900 kg/ha·a
max: Maximum removal efficiency, intake area: 50 m^2
min: Minimum removal efficiency, intake area: 500 m^2
DGP: Dry catch basin
WGP: Wet catch basin

Table 9 - Removal efficiency of (TSS) in different catch basins

	A	B	C	D	E	F	G
Treatment efficiency	0	-/0	+	0/+	+	+	+
Construction costs	+	0	0	-	-	-	-
Maintenance Costs	-	-	+	0	+	+	+
Space	+	+	-	-	-	-	-

A = Street cleansing
B = Catch basins
C = Infiltration systems, decentral
D = Detention ponds
E = Swirl separator
F = Infiltration systems, central
G = Vegetative controls

Table 10 - Qualification of storm water treatment systems

In urbanized areas often there is no space to install a central treatment system. In these cases only street cleansing and catch basins can be used to mitigate storm water pollution. Further on, the decentralized systems are cheaper in construction. Since inlets are necessary in any case, their treatment efficiency should be improved and their maintenance costs should be reduced as much as possible.

Combined severage system (CSS)

In flat combined severage systems sewer deposits are causing a lot of maintenance work. These deposits may reduce the hydraulic capacity of the sewer pipes and by this cause a higher frequency of flooding in the streets. Further on, the deposits may be flushed during a heavy storm event and discharged by overflows to the receiving waters.

To guarantee the full hydraulic capacity of the sewer pipes and to mitigate the pollutant discharges to receiving waters the deposits shall be flushed during dry periods and catch besins shall reduce the input of solids from the surface. In sewer pipes with high levels of deposits which

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occur within a short period, a new construction of these pipes may be efficient. All these activities cost a lot of work and money. But still the sewer deposits are a serious environmental and operational problem.

Maintenance costs

The maintenance costs for cleansing of catch basins and removal of sewer deposits shall be estimated very rough. The city of BREMEN (500.000 inhabitants) gave us some brief information about their maintenance costs in 1983. This may give an idea of the costs in general. A further investigation shall be done to calculate the maintenance costs in detail.

Removal of sewer deposits

20 special lorries and 40 workers are required to clean all together 1900 km sewer pipes.

Costs:

20 lorries x 500.000,- DM	10.000.000,- DM
Depreciation: 10 years	1.000.000,- DM/a
40 workers x 50.000,- DM/a	2.000.000,- DM/a
Annual costs, whole network:	3.000.000,- DM/a
Annual costs, per meter:	1,58 DM/m

Cleansing of catch basins

About 57.000 dry catch basins (DGP) have to be cleaned twice a year and 19.000 wet catch basins (WGP) have to be cleaned once a year. A team (A) of three workers is cleansing about 100 DGP/day using a small lorry. A team (B) of two workers is cleansing about 40 WGP/day using a special lorry. In average have to be cleaned:

570 DGP/day	6 teams A necessary
95 WGP/day	3 teams B necessary

Costs:

DGP	: 6 small lorries x 50.000,- DM	300.000,- DM
	Depreciation: 10 years	30.000,- DM/a
	6 x 3 Workers x 50.000,- DM/a	900.000,- DM/a
Annual costs, whole city:		930.000,- DM/a
Annual costs, per catch basin:		16,32DM/DGP

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WGP	: 3 special lorries x 500.000,- DM	1.500.000,- DM
	Depreciation: 10 years	150.000,- DM/a
	3 x 2 workers x 50.000,- DM/a	300.000,- DM/a
Annual costs, whole city:		450.000,- DM/a
Annual costs, per catch basin		23,68DM/WGP
Total maintenance costs:		4.380.000,- DM/a

Requirements on sanitation strategies

The pollutant removal by catch basins in West Germany needs to be improved. Different strategies are practicable to improve the systems. In Table 11 the pros and cons of four different strategies are documented very briefly. The strategies can be described as follows.

	No catch basins	Dry catch basins only	Wet catch basins only	Improved catch basins
Maintenance costs	++	+	-	+
Construction costs	-	0	--	0/-
Storm water pollution	--	-	+	+
Smell emissions	-	0	0	0
Sewer deposits	-	0	+	+
Operation reliability	-	0	0	0

Table 11 - Qualification of sanitation strategies

* Remove all the catch basins and use big inlets which don't remove any pollutants.

Maintenance costs: No maintenance is necessary, no costs will occur.

Construction costs: DGP: Slotted buckets have to be removed. - WGP: Settling pits have to be filled by concrete.

Storm water pollution: High pollution - central treatment is necessary.

Smell emissions: May occur in combined severage systems.

Sewer deposits: In combined systems more deposits may occur.

Operation reliability: Less reliability, since sticks, rubbish and other material may clog the sewer pipes.

* Dry catch basins only.

Maintenance costs: Less costs, since no special lorries are necessary and the cleansing of dry catch basins is much faster.

Construction costs: Step by step slotted buckets shall be installed within the wet catch basins.

Storm water pollution: Increase of pollution - central treatment may be necessary.

Smell emissions: No change.

Sewer deposits: In combined systems more deposits may occur.

Operation reliability: No change.

* Wet catch basins only.

Maintenance costs: Increase of costs, since special lorries can be used only and the cleansing of wet catch basins is much slower.

Construction costs: Very high costs, at every dry catch basin a construction site needs to be installed.

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Storm water pollution: Decrease of pollution.

Smell emissions: No change.

Sewer deposits: In combined systems less deposits may occur.

Operation reliability: No change.

* Improved catch basins - (A detailed description of the new designs is given in the next chapter).

Maintenance costs: Less costs, since no special lorries are necessary and the cleansing of slotted buckets is much faster.

Construction costs: In separate severage systems the costs of siphon catch basins are very high, since a construction site has to be installed. In all other cases the costs are little.

Storm water pollution: Decrease of pollution.

Smell emissions: No change.

Sewer deposits: In combined and seperate systems less deposits may occur.

Operation reliability: No change.

We decided to improve the catch basins. An inlet construction is necessary in any case, since the reliabilty of operation must be high. In the following chapter different improved catch basins are described, to be used in different drainage conditions.

SANITATION STRATEGY

In general a cheap and an expensive sanitation can be chosen. The way to improve the system depends on the existing catch basin as well as on the drainage system. Table 12 is pointing out the new designs of catch basins with or without construction work.

Sanitation without construction work

In combined severage systems as well as in separate severage systems the dry catch basin can be improved by a new bucket. This new bucket has no slots, but some holes at the bottom to keep the bucket dry (Figure 6a). This design guarantees a better removal also of small particles.

	Combined sewer system		Separate sewer system	
	Dry catch basin	Wet catch basin	Dry catch basin	Wet catch basin
Sanitation without construstion work	modified bucket	siphon catch basin	modified bucket	overflow catch basin
Sanitation with construc-tion work/new construction	siphon catch basin		sewer deposits: siphon catch basin no sewer deposits: overflow catch basin	

Table 12 - Sanitation strategy

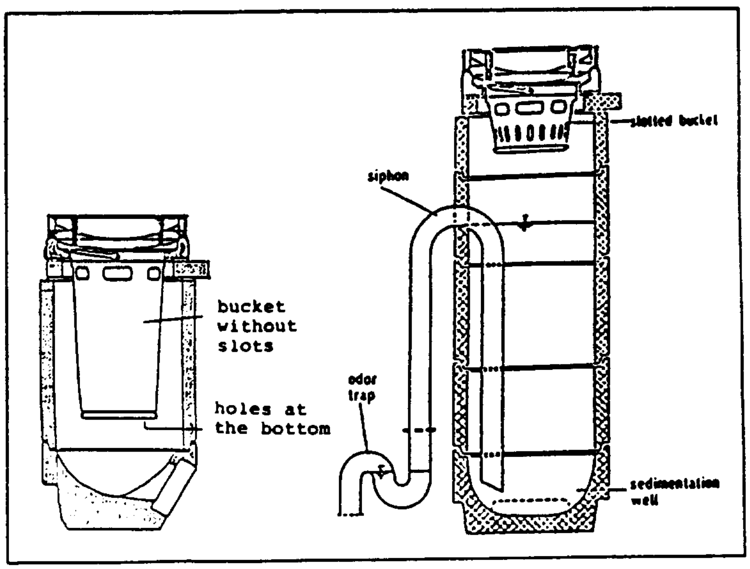

Figure 6 - a: Modified bucket (CSS+SSS) b: Siphon catch basin (CSS)

After the bottom of the bucket is covered with some removed material, the polluted storm water will further be filtered by this material. By this the removal efficiency increases rapidly. If the filtration capacity is less than the inflow rate, the storm water shall be stored within the bucket. In case of very high inflow rates, the big holes at the top of the bucket guarantee the hydraulic capacity of the catch basin. The bucket shall be cleaned as before.

For combined systems with wet catch basins a catch basin is proposed, where the inflow passes a slotted bucket and leaves the catch basin through a siphon (Figure 6b). Thereby, also during moderate storms (inflow > 0,5 l/s) the combined sewer is charged discontinuously with approximately 100-l-flushes, which keep sediments mobil and pipes cleaner. Hydraulic tests proved that the siphon removes all sediments in the sedimentation well. Therefore, expensive suction cleansing of the siphon catch basin is not necessary. Large debris has to be removed from the bucket. The siphon can be installed very easy by inlining the existing outlet with a tube which ends at the bottom of the sedimentation well.

For separate systems with wet catch basins the removal efficiency can be improved by using an throttle/overflow-construction which can be fit into the outlet. The throttle reduces the outflow and by this the turbulences within the sedimentation well (Figure 7b). In case of the inflow rate is greater than the throttle capacity, the storm water shall be stored and later discharged over the overflow. The overflow catch basin has to be suction cleaned, though.

Sanitation with construction work/new construction

In combined systems with or without sewer deposits the siphon catch basin shall be installed. In separate systems without sewer deposits in the sanitary pipe the overflow catch basin shall be used.

In case of sewer deposits in the sanitary pipes of the separate system the siphon catch basin can be adapted to the different conditions (Figure 7a). This catch basin features an additional throttled outlet with overflow as well as a siphon and a slotted bucket. During moderate rainfall the inflow passes the catch basin through the throttle into the storm sewer, while solids settle down in the sedimentation well. In major storms the throttle constrains the regular outlet rate and the catch basin fills up to the siphon crest. The siphon is activated and empties the well including the accumulated sediments into the sanitary sewer. The throttle is sized to have the siphon activated only rarely (e.g. 10 times a year).

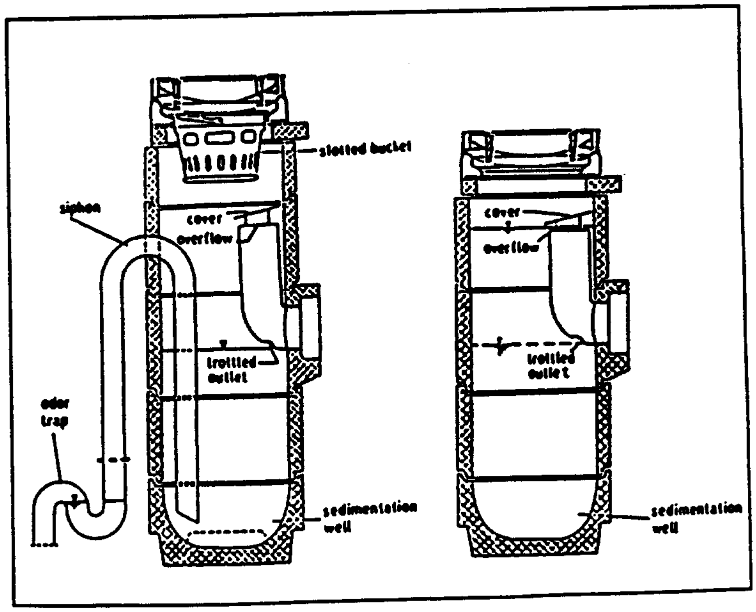

Figure 7 - a: Siphon catch basin b: Overflow catch basin (SSS)

NEW DESIGN OF CATCH BASINS

Laboratory tests

The overflow catch basin and the siphon catch basin have been hydraulically tested in 1:1 scale for a large variety of operating conditions. Thereby details have been optimized to allow for good hydraulic efficiency also at low suction heads of the siphon.

Initial tests showed, that the removal efficiency of both new catch basins is nearly the same as the one of the wet catch basin. Consequently further tests concentrated on different loadings (sand, gravel, leaves, etc.) mainly of the siphon catch basin.

Overflow catch basins: Depending on the diameter of the throttle the overflow was activated at inflow rates between 0,5 and 2,5 l/s. By choosing the diameter the number of overflows can be estimated, taking the intake area of the catch basin into acount. The diameter should be chosen between 2 and 3 centimeters.

Siphon catch basin (SSS): The inflow, outflow and siphon flow during a storm event is illustrated in Figure 8. The process can be divided into four phases. During the first phase the inflow passes through the throttle to the storm sewer, while the water level within the catch basin increases. In the second phase the water level reaches the siphon and flows to the sanitary sewer. During the first seconds there is no suction flow. But soon the siphon starts working and flushing the water of the sedimentation well including most of the sediments to the sanitary sewer. The throttle stops working. In the third phase the well of the catch basin is filled until the throttle starts working again. During the fourth phase there is an outflow to the storm sewer but no more siphon flow. Finally the inflow rate is as big as the outflow rate.

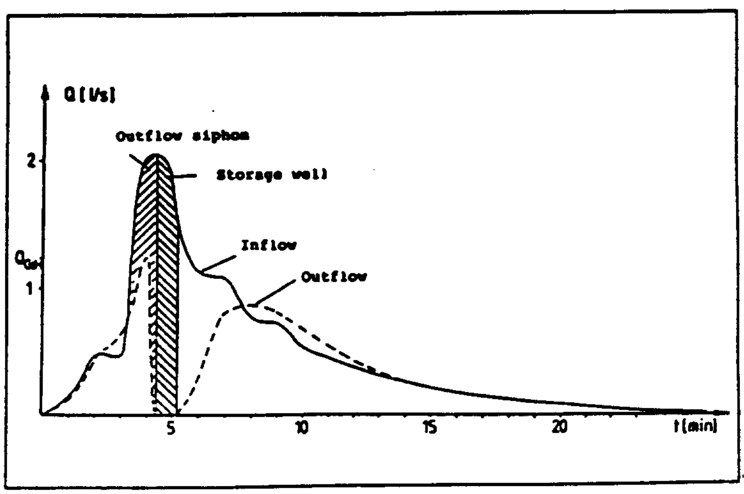

Figure 8 - Hydraulic of siphon catch basin during storm event

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Field performance

The hydraulic tests showed that the siphon sucks the sediments in the well. Even stones of a diameter of 4-5 centimeter have been flushed out. Consequently the siphon catch basins have been prepared for field conditions. Main task was the dimensioning of the throttle. The diameter of the siphon was chosen with 7,5 centimeter, since this was a proved dimension.

Analysing a long record of 1-minute rainfall intensities a dimensioning diagram has been set up for North German meteorological and inlet conditions (Figure 9). The throttle diameter is expressed as a function of the inlet catchment area (100-500 m²) and the desired siphon activation frequency.

Two siphon catch basins with a throttle diameter of 2,5 and 3 centimeters have been installed in the separate system of the city of Hildesheim (FRG). Over half a year the catch basins cleaned themselves. During this summer heavy stroms flushed a huge load of sand from the road which is still under construction. Due to this load the end of the siphon was clogged. But the throttle and overflow have been working without any failure. To improve these catch basins, the diameter shall be decreased and further tested over many years. At least after the construction of the brick stone road is finished the siphon shall work without failure.

The flushing effect of the siphon is avaluated with empirical relations found in the literature (7). They indicate, that in smaller pipes the siphon flush is efficient over a diatance that exceeds the average distance between catch basins.

Example:

$$V_s = (13,5 \cdot L^{1,45} \cdot D^{0,23}) / S^{1,40}$$

V_s : Siphon flush volume = 3,531 cf
D : Diameter = 0,82 ft
S : Slope = 5ft/1000ft
L : Distance = 59,0 m (calculated)

Function 2 - Flushed distance by siphon catch basin

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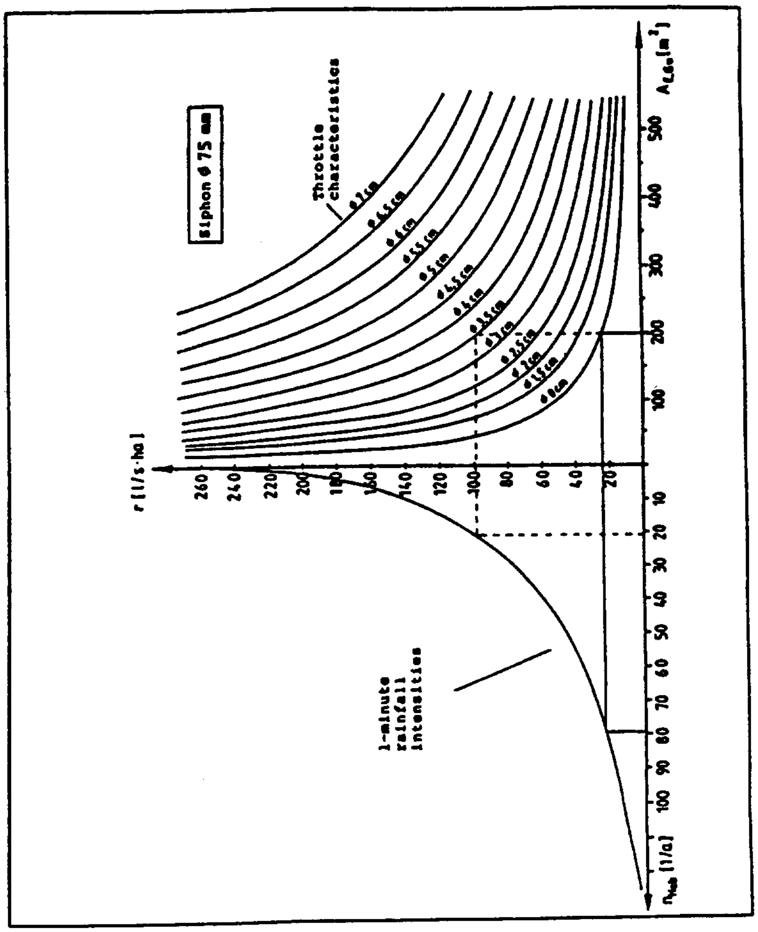

Figure 9 - Dimensioning diagram - siphon catch basin

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CONCLUSIONS

The proposed set of redesigned catch basins allows to cut operating costs and reduce receiving water pollution at the same time. Based on the existing type of sewer system (combined or separate), the existing catch basins (dry or wet) and the need for cost reduction (cleansing) and pollution control an individual sanitation concept can be proposed for a drainage area.

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POLLUTION ABATEMENT IN TOKYO "ESS"

by Takaaki Koyama[1] and Shoichi Fujita[2]

SUMMARY

The Tokyo Experimental Sewer System (ESS) was developed to study the control of urban storm inundation in a densely populated area. Adopting ESS also reduces both overflow pollution loadings and the volume and peak flow of urban storm runoff.

1. DESCRIPTION OF THE ESS

The ESS was developed to reduce the amount and peak flow of urban storm runoff. It is a system comprised of many facilities to effectively catch pollutants, thereby contributing to the improvement in the quality of public water bodies. The facilities have two primary functions, infiltration and storage. Figure 1 shows the drainage area in which the ESS was installed.

1.1 ESS Facilities

The ESS facilities include:

(a) Infiltration

o Infiltration Inlets - placed every 20 meters along both sides of the roads (see Figure 2)

o Infiltration Trenches - laid along both sides of the roads, and connected with the infiltration inlets, as shown in Figure 3.

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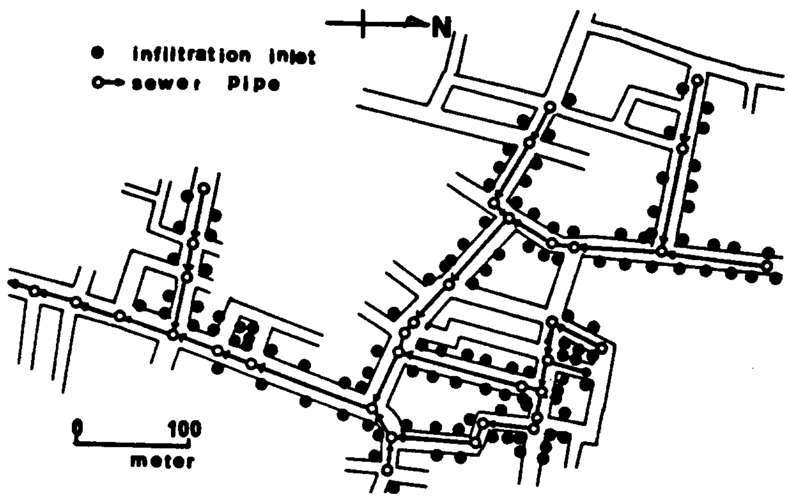

Figure 1. Model Drainage Area (actual installation of ESS)

o Infiltration LU-Curb - used instead of infiltration trenches in narrow roads where trenches are difficult to install (see Figure 4).

o Permeable Pavement - applied to all roads running along sewer mains.

(b) Storage

o Storage inside the infiltration facilities - the entire capacity of the infiltration facilities is used for storage. Storm water is stored in the backfilling materials of the infiltration facilities.

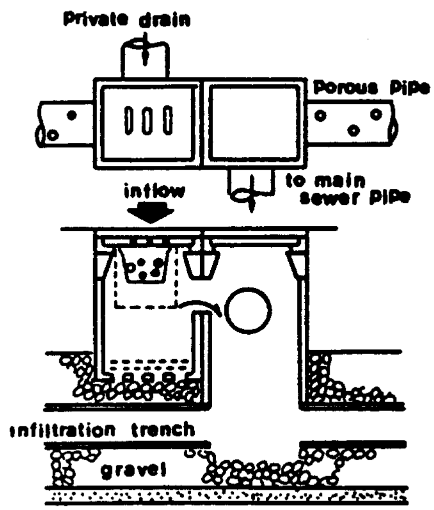

Figure 2. Infiltration inlet

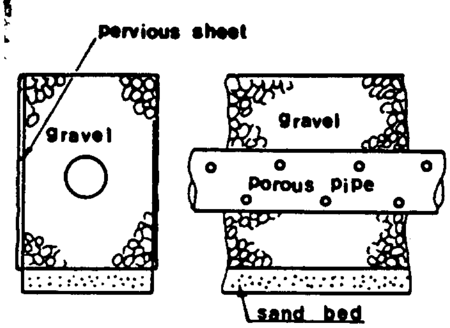

Figure 3. Infiltration trench

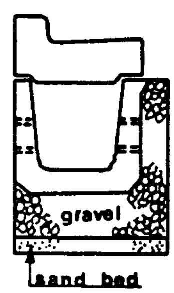

Figure 4. Infiltration LU-curb

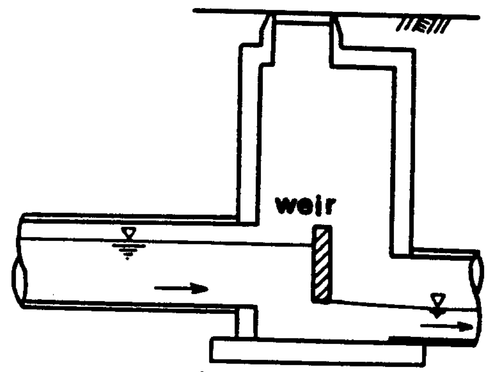

Figure 5. Storage Manhole

o Storage Manhole - a weir is installed inside the manhole (Figure 5) to utilize the storage capacity of the upstream trunk sewer for the attenuation of peak flow.

o Circuitous Routing of Sewer Pipes - sewer pipes are laid in such a way as to prolong the travel time of sewage.

A conceptual layout of the facilities in the ESS is shown in Figure 6, and the arrangement of the ESS in the combined sewer system is illustrated in the flow chart in Figure 7.

Although it is a combined sewer system, wastewater and stormwater should be introduced separately. Stormwater is introduced into the first chamber of the infiltration inlet. Sand and grit are settled in the mudpit. Stormwater which overflows the mudpit proceeds to the second chamber of the infiltration inlet, and flows in

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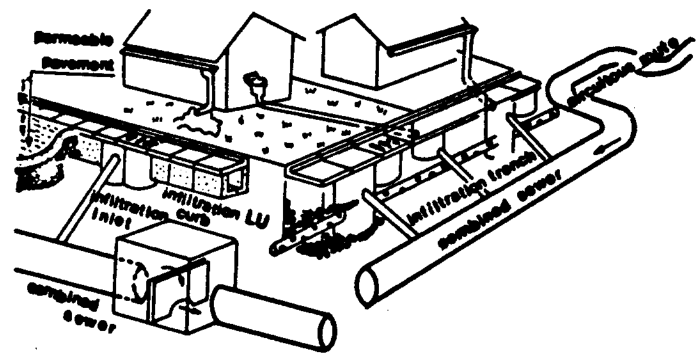

Figure 6. Conceptual Layout of ESS Facilities

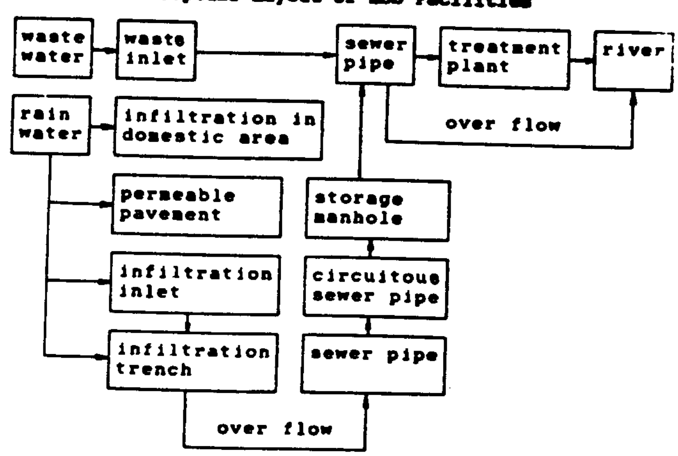

Figure 7. Arrangement of ESS in Sewer System

excess of the infiltration capacity of the inlet are introduced into an infiltration trench or infiltration LU-Curb. Consequently, stormwater does not flow into the combined sewer main until the amount of precipitation exceeds the capacity of these infiltration facilities. Thus, the ESS allows reduction in storm runoff and increased pollution control.

The capacity of the infiltration facilities depends on how effectively they can reduce the incoming clogging materials. Devices to capture such materials are therefore installed in the inlets.

All of the facilities in the ESS are readily-available items in common use, and are thus economical.

1.2 Full-Scale Testing of the ESS

Full-scale ESS testing commenced in April, 1980. on the Shakujii and the Shirako river basins. The kinds and numbers of facilities used in the experimental area are shown in Table 1.

Table 1. Implemented Runoff Control Facilities of the ESS

Facilities (1)	Shakujii River (2)	Shirako River (3)	Total (4)
Infiltration Inlets	4,778	15,218	19,996
Infiltration Trench (km)	43	84	127
Infiltration LU-Curb (km)	22	49	71
Permeable Pavement X 10^3 (m^2)	200	408	608
Construction Cost X 10^6 (yen)	12,588	24,310	36,898
Area (hectares)	305	597	902
Population	39,600	72,100	111,700

The construction costs of the ESS are about 20 percent higher than the cost of conventional sewer systems. The authors believe, however, that the ESS should not be regarded as expensive considering its ability to reduce runoff and pollution loadings.

1.3 Reduction of Stormwater Runoff by the ESS

In combined sewer systems, the amount of stormwater overflows to the public water bodies depends on the total amount of inflow. Therefore, controlling incoming stormwater will also contribute to reduced pollution loadings. In the ESS, facilities typically show high infiltration capacities. In time, however, such capacity may be reduced by the accumulation of clogging materials.

As a result, actual measurements of the accumulation of these materials, and their effects on infiltration capacity, were carried out for the study area. The progression of capacity reduction is shown in Figure 8. For practical design purposes, the infiltration capacity for each type of facility is shown in Table 2.

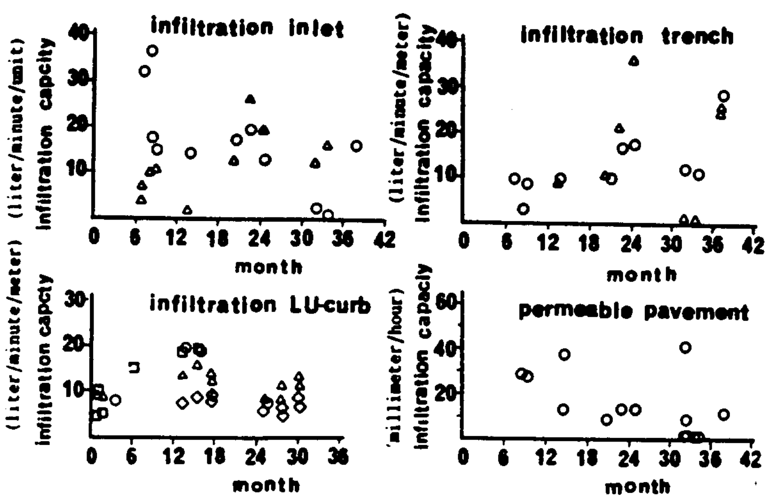

Figure 8. Progression of Capacity Reduction

Table 2. Infiltration/Storage Capacity of ESS Facilities

Facility (1)	Infiltration Capacity (2)	Storage Capacity (3)
Mudpit	0 l/min/unit	0.059 m³/unit
Infiltration Inlet	3 l/min/unit	0.141 m³/unit
Infiltration Trench	8 l/min/meter	0.261 m³/meter
Permeable Pavement	10 mm/hr	0.045 m³/m²

Applying these capacities to the Shirako River basin, it was estimated (see Figure 9) that a 60 percent reduction in stormwater runoff will be obtained at the downstream end of the basin with a rainfall intensity of 50 mm/hr, compared with the conventional combined sewer system.

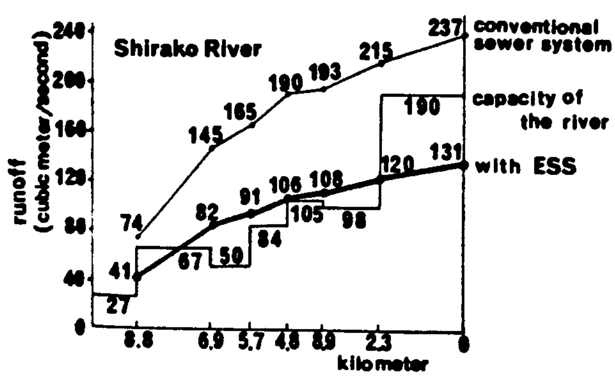

Figure 9. Estimated Effects of the ESS - Shirako River

1.4 Removal of Clogging Materials in the ESS

There are many methods used to maintain the infiltration capacity of ESS facilities. Data on captured materials initially obtained from the study area are shown in Table 3.

Table 3. Weight of Captured Materials (mean value)

Bucket	4.71 kg/yr/unit
Basket	1.68 "
Mudpit	5.39 "
Porous Plate	0.07 "
Screen	No data

2. EVALUATION OF POLLUTION LOAD REDUCTION BY THE ESS

The effects described here focus on the overflow rate and overflow pollution loadings, compared to a conventional sewer system.

The idea of controlling storm runoff using the ESS was introduced at the Fourth International Conference on Urban Storm Drainage held in Lausanne in 1987 (Fujita, 1987). This paper is based on the results of Dr. Fujita's work.

The Tokyo Metropolitan Government started field research in 1971 in the Yabata, Momozono and Tachiai river basins, amongst others. The research accumulated field measurements of flow rate and change in water quality, and was also aimed at establishing model formulas for stormwater overflow and pollution loadings. This section presents the results of a simulation of the Tachiai as a model river basin (see Figure 10) to evaluate the effects for water pollution control.

2.1 Outline of Model River Basin

The Tachiai River basin is located in the southern part of Tokyo and is a residential area. It has an area of 467 hectares, and is serviced by a combined sewer system. Data on the basin are given in Table 4.

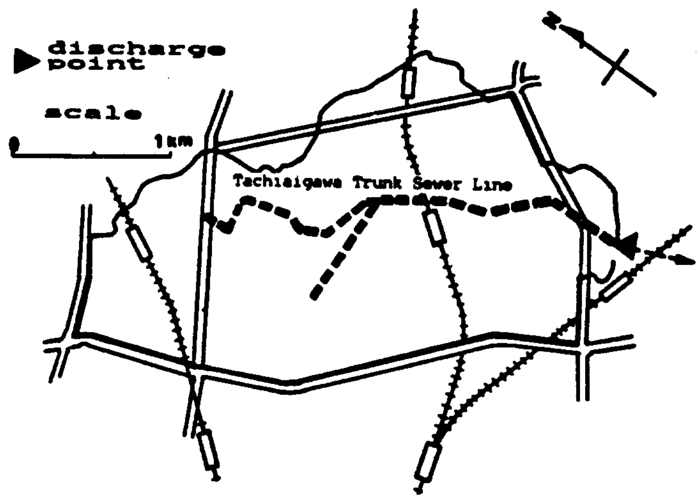

Figure 10. Tachiai Model Drainage Area

2.2 The Calculation Model

(a) Model of Stormwater Runoff - The model is derived from the TRRL method (Ministry of Construction, 1981), which was originally developed by the Transport and Road Research Laboratory in England to estimate the runoff hydrograph in areas where no runoff data exists. The model includes an estimation of the effective amount of precipitation, and a corrected S-Q curve developed by the Public Works Research Institute of the Ministry of Construction in Japan.

The basic formulae used in the calculation are as follows. The modified RRL method is an alternative to storage function methods which estimate stormwater runoff at a

Table 4. Tachiai Model Basin Data

Sewage Treatment District Name:	Morigasaki
Trunk Sewer Line:	Tachiaigawa
Drainage Area:	467.7 hectares
Drainage System:	Combined sewers
Flow System:	Gravity flow
Size of Sewer (Box Culvert)	width = 5900 mm height = 3600 mm
Population:	99,404
Land Use:	
Residential	365.1 hectares (78.0%)
Commercial	72.4 hectares (15.5%)
Industrial	30.2 hectares (6.5%)
Surface Condition	
Impermeable area	57.6%
Permeable area	42.4%

point by making an equal-arrival-time map for the region, with sewer storage capacity as the perameter of interest.

$$I_n = \Sigma(re_{n-i+1} * Ai) / A \quad (1)$$

$$S = K * q^p \quad (2)$$

$$(dS/dT) = I - O \quad (3)$$

Where,

I = rainfall intensity, mm/hr
re = effective rainfall intensity, mm/hr
Ai = equal-arrival-time area, hectares
A = total drainage area, hectares
S = amount stored in sewer, mm
K,p = constants
q = flow rate in sewer, mm/hr
O = rate of runoff, mm/hr

(b) Model of Pollution Loadings Discharges - An accumulative loadings evaluation model developed by the Public Works Research Institute was adopted for the simulation of pollution loadings discharges. The concept of the model is described in Figure 11. The characteristics of the model are:

1. The exponents m and n are employed to express various discharge characteristics of different water quality components.

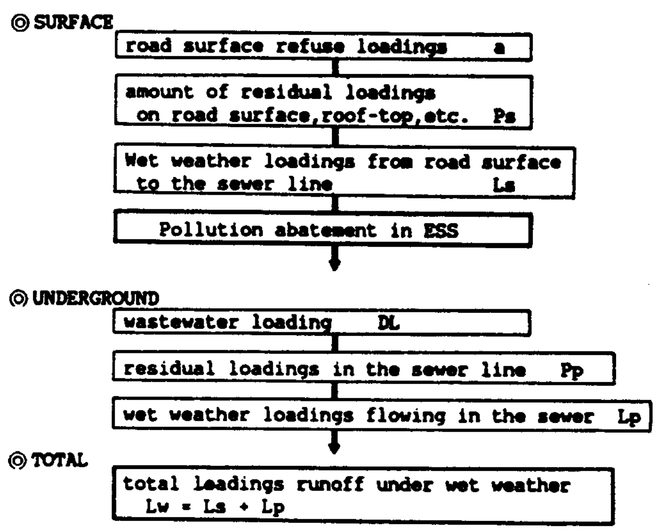

Figure 11. Calculation Procedure

2. It can express total pollution loadings discharge.

3. It can express the "first flush."

4. It can express the re-accumulation after a rainfall event.

The basic formulae for dry-weather pollution loadings discharges are:

$$L_p = C * Pp^{a} * Q^{b} * (Q - Qc) \quad (4)$$

$$(dPp/dt) = D_L - L_p \quad (5)$$

The formulae for wet-weather discharges are:

$$L_w = Lp + Ls \quad (6)$$

$$L_p = C * Pp^m * Q^n * (Q - Qc) \quad (7)$$

$$Ls = (1/3.6) * K * Ps * (re - rc) * A \quad (8)$$

$$(dPp/dt) = D_L - Lp \quad (9)$$

$$(dPs/dt) = a - Ls \quad (10)$$

$$K = CCI * CR * Imp \quad (11)$$

where,

L_p = rate of dry-weather flow loadings in sewer, gm/sec
C = Discharge coefficient of loadings (constant)
Pp = Accumulated residual loadings in sewer line, gm
Q = Flow rate, m^3/sec
Qc = critical flow rate, m^3/sec
D_L = Rate of dry-weather loadings (normal wastewater), gm/sec
m, n = exponent parameters (constant) m=2 and n=0 for BOD and COD, m and n = 1 for SS
Lw = total rate of wet-weather loadings, gm/sec
Lp = Rate of flowing loadings (wet-weather) in sewer line, gm/sec
Ls = Rate of wet-weather loadings from road surface, gm/sec
Ps = amount of residual loadings on road surface, roof tops, etc., kg/hectare
CCI = ratio of loads-generating area to the impermeable area. CCI = 1 for this study.
CR = Coefficient of loadings from road surface, 1/mm
Imp = Percent imperviousness
rc = critical rainfall intensity, mm/hr
a = rate of pollution loadings (road surface refuse loadings), gm/sec

2.3 Calculation Conditions

(a) Precipitation Used for Calculation - The evaluation was conducted on the record of the Tokyo Central Meteorological Observatory for 1975, since 1975 precipitation was found to be closest to the 20-year average value (1962 - 1981). The precipitation data were based on observed precipitation greater than 0.5 mm over a 5-minute interval. A precipitation event was defined as one followed by 3 hours of no precipitation (Tables 5 and 6).

Table 5. Precipitation in Tokyo

Year (1)	Number of Rainfall Events per year (2)	Annual Precipitation (mm) (3)	Total Rainfall (hours) (4)
1962	88	1203	717
1963	87	1550	812[1]
1964	76	1078	718
1965	80	1557	665
1966	65	1495	549[2]
1967	77	1056	615
1968	91[1]	1562	767
1969	77	1362	726
1970	66	1143	678
1971	74	1391	657
1972	68	1577[1]	781
1973	61[2]	1122	554
1974	88	1472	772
1975	71	1483	657
1976	88	1453	702
1977	66	1449	648
1978	68	995[2]	549
1979	78	1402	714
1980	77	1482	740
1981	65	1422	589
Average	76	1363	680

Note: [1] = Maximum and [2] = Minimum

(b) Ratio of Impermeable Area - The ratio of impermeable area (Imp) was measured on aerial photos using a digitizer. Roofs were generally counted as impermeable in the area served by combined sewers, since roof runoff is introduced through storm water inlets. However, after the survey of this model area, 20 percent of roof runoff was found to flow into permeable areas, such as gardens. As a result, the impermeable area was found to cover 57.2 percent of the total model area.

(c) Calculation conditions for runoff - these conditions are described in Table 7, and one of the results is shown in Figure 12.

Table 6. Precipitation Range in a Year

Range of Times (1)	Fre- quency (2)	Range of Precip. (3)	Fre- quency (4)	Range of Total Rainfall Hours (5)	Fre- quency (6)
61-65	3	901-1000	1	501-550	2
66-70	4	1001-1100	2	551-600	2
71-75	2	1101-1200	2	601-650	2
76-80	6	1201-1300	1	651-700	4
81-85	0	1301-1400	2	701-750	6
86-90	4	1401-1500	8	751-800	3
91-95	1	1501-1600	4	801-850	1

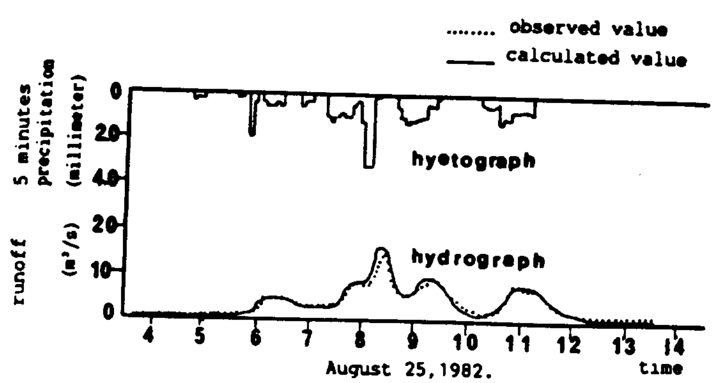

Figure 12. Results of Runoff Simulation

Table 7. Calculation Conditions for Runoff Simulation

a. Effective Rainfall Model

Drainage Area (Tachiaigawa)	467.7 hectares
Imperviousness	57.2%
Ratio of Depression Storage in	
Impervious Area (Ai)	60%
Permeable Area (Ap)	80%
Volume of Depression Storage in	
Impervious Area (Di)	2 mm
Permeable Area (Dp)	6 mm
Infiltration Capacity in Permeable Area (fc)	10 mm/hr

b. Area of Equal-Arrival Time

Range of Arrival Time (minutes) (1)	Area (hectares) (2)	Ratio (%) (3)
0 - 5	54.5	11.7
10	92.6	19.8
15	138.4	29.6
20	102.1	21.8
25	61.9	13.2
30	18.2	3.9
Total	467.7	100.0

c. S-Q Curve

S (millimeters) (4)	Q (mm/hr) (5)
1.27	5
2.11	10
2.82	15
3.46	20
4.05	25
4.61	30
5.65	40

(d) Calculation conditions for loadings discharge - These conditions are listed in Table 8, and a sample result is shown in Figure 13.

Table 8. Calculation Conditions for Loading Discharge Simulation

a. Drainage Area	467.7 hectares		
b. Sewer Line Model			
	BOD	COD	SS
Dry-Weather Loading Rate, DL (kg)	5150	2930	4700
Loading Discharge Coefficient	1.0×10^{-11}	1.0×10^{-11}	1.0×10^{-8}
Accumulated Residual Load in Sewer Line, Pp (kg)	10000	8000	10000
(kg/hectare/day)	23.381	17.105	21.381
Critical Flow Rate, Qc (m^3/sec)	0.1	0.1	0.1
c. Surface Model			
Coefficient of Loading From Road (1/mm)	0.25	0.25	0.25
Ratio of Impervious Area, Imp	.572	.572	.572
Amount of Residual Loads on Road Surface, Ps (kg/ha)	1.0	2.0	20.0
Critical Rainfall Intensity, rc (mm/hr)	2.0	2.0	2.0
Loading Supply Rate, a (gm/sec)	0.0022	0.0056	0.116

(e) Overflow Conditions - The total pollution load is the sum of the overflows from storm water outfalls and the wastewater treatment plant effluent. The overflow conditions are based on the case when three times the amount of the maximum hourly dry-weather flow can be intercepted and transported to the treatment plant.

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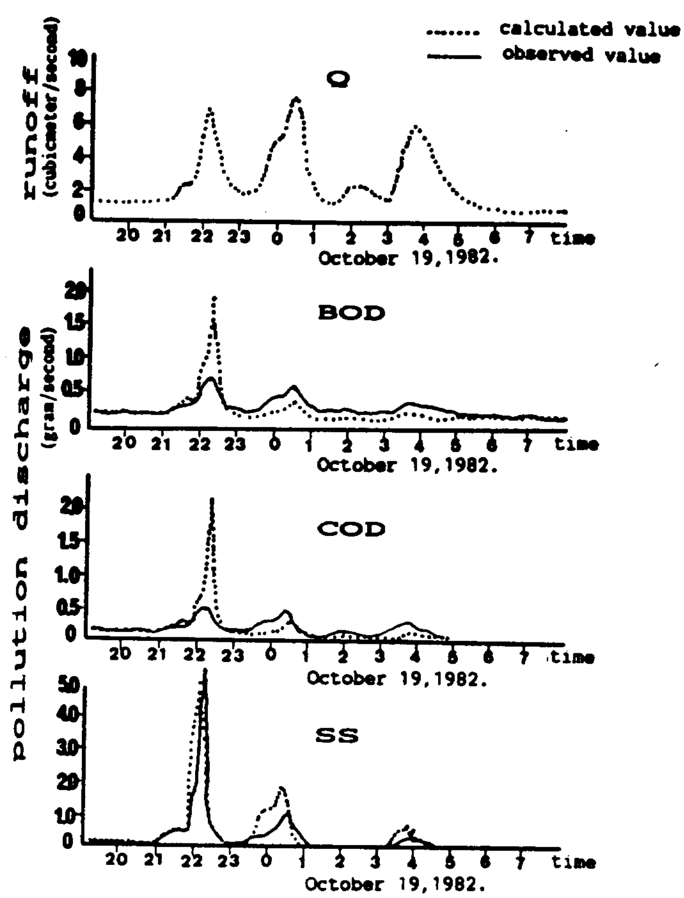

Figure 13. Results of Pollution Loading Discharge Simulation

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The maximum hourly dry-weather flow was estimated as follows:

Maximum Daily flow = 1.35 x observed average daily flow
= 1.35 x 0.475 = 0.641 m^3/sec

Maximum hourly flow = 1.5 x maximum daily flow
= 1.5 x 0.641 = 0.962 m^3/sec

Maximum interception = 3.0 x maximum hourly flow
= 3.0 x 0.962 = 2.886 m^3/sec

(f) Treatment plant efficiency - treatment plant efficiency was based on the data shown in Table 9:

Table 9. Efficiency of Sewage Treatment

(1)	(2)	BOD (3)	COD (4)	SS (5)
Primary Treatment	Removal Rate (%)	30	20	30
	Effluent Quality (mg/l)	30	30	30
Secondary Treatment	Removal Rate (%)	90	80	90
	Effluent Quality (mg/l)	15	20	15

(g) ESS Facilities - The total area of roads is 64.3 hectares for the model river basin (average road width = 5 meters; road length = 128.6 kilometers). The concentration of infiltration facilities is given in Table 10:

Table 10. Concentration of ESS Facilities

Facilities (1)	Concentration (2)	Total Quantity (3)
Infiltration Inlet	Both Sides of Road unit / 25 meters	4938 units
Infiltration Trench	120% of Road Length	125,456 meters
Permeable Pavement	All Roads in ESS Area	308,640 m^2

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(h) Infiltration/Storage Capacity of ESS Facilities - Infiltration and storage capacity was estimated assuming a specified progression of clogging, and these values were shown in Table 2.

(i) Amount of Materials Captured by ESS Facilities - Data from Section 1-4 (Table 3) were used in this calculation.

2.4 Overall Estimation of Pollutant Load Reduction

The amount of pollutant load reduction from a combined sewer system depends on the frequency and volume of overflow to public water bodies. With ESS, the overflows are determined by the runoff reduction and interception ratios, taking into account the removal of clogging materials.

The results of calculetions for 1975, based on the conditions outlined above, are shown in Tables 11 and 12, and may be summarized as follows:

(a) Frequency of Overflow - Overflow frequency was reduced to 7/year using ESS (with a total of 71 rainfall events in the year), compared to 36/year without ESS, or a reduction of 81%.

(b) Overflow Loadings - Overflow loadings were reduced to 4.7, 3.4 and 19.2 kg/hectare for BOD, COD and SS, respectively, using ESS. Without ESS the loadings were estimated to be 103.1, 76.1 and 223.3 kg/hectare, respectively. Loadings were thus reduced 95% for BOD, 96% for COD and 81% for SS.

(c) Total Wet-Weather Loadings - Under wet-weather conditions, the total discharged load from ESS was 96.2, 110.0 and 156.4 kg/hectare, respectively, for BOD, COD and SS. From the combined system without ESS these loadings were 326.2, 294.5 and 642.3 kg/hectare, respectively. Thus, total loadings were reduced by ESS by 71% for BOD, 63% for COD and 76% for SS.

(d) Total Annual Loads - Total annual discharges using ESS were 528.9, 686.9 and 589.1 kg/hectare for BOD, COD and SS, respectively, while without ESS these were estimated to be 758.9, 871.4 and 1075.0 kg/hectare, respectively. Thus, total loads were reduced by ESS by 30% for BOD, 21% for COD, and 45% for SS.

Table 11. Estimated Effects of ESS on Pollution Load Reduction (in 1975)

Weather (1)	(2)	Sewer System (3)	Runoff Loadings (4)	Discharged Loadings: Treatment Plant (5)	Sewer Outlet (6)	Total (7)
BOD	wet	Combined	636.4	223.1	103.1	326.2
		ESS	399.1	91.5	4.7	96.2
	dry		3620.0	432.7	0	432.7
COD	wet	Combined	437.0	218.4	76.1	294.5
		ESS	252.4	106.6	3.4	110.0
	dry		2059.5	576.9	0	576.9
SS	wet	Combined	1240.5	419.0	223.3	642.3
		ESS	532.3	137.2	19.2	156.4
	dry		3303.7	432.7	0	432.7

Table 12. Estimated Effects of ESS on the Reduction of Storm Runoff (in 1975)

Weather (1)	Sewer System (2)	Total Runoff Volume (3)	Discharged Storm Runoff: Treatment Plant (4)	Sewer Outlet (5)
wet	Combined	11533.4	8778.6	2754.8
	ESS	4860.8	4788.5	72.3
dry		28847.3	28847.3	0

Total precipitation in 1975 = 1483 mm
Total Wet-Weather Days = 36 days, 6 hours
Total Dry-Weather Days = 328 days, 18 hours
Total Number of Rainfall Events = 71
Total Number of Combined Sewer Overflows = 36
Total Number of Overflows when ESS Applied = 7

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(e) Effects Of Infiltration Inlets on Pollutant Load Reduction - devices such as buckets, baskets, screens, etc. are used in the infiltration inlets to prevent clogging, and also to remove pollutants flowing from the road surface to the inlet. The amount of these materials is shown in Table 3.

From Table 3 it can be seen that the annual amount of material removed is 12 kg/unit/yr, which corresponds to a SS load reduction of 3.6 kg/unit/yr (the moisture content is approximately 70%). There are 22 infiltration inlets/ hectare, and the SS removal is therefore 22 x 3.6 = 79.2 kg/hectare.

Meanwhile, as shown in Table 13, the reduction in SS loading using ESS based on runoff attenuation is estimated to be 156.4 kg/hectare. Thus, considering both the effects of runoff control and of pollutant removal, the total SS discharged is 156.4 - 79.2 = 77.2 kg/hectare, a 53% reduction. This explains the high removal efficiency at the infiltration inlets of the ESS. Similar results would be obtained with BOD and COD, and it can thus be seen that ESS has a high potential for reducing wet-weather overflow loadings as well as the total discharges from the sewer system to the receiving waters.

3. CONCLUSIONS

The ESS was originally focused and developed as a means to compensate for delays in urban river improvement, and to promote sewer construction. Since 1980, when full-scale ESS testing was started, the Tokyo Metropolitan Government has installed an area of over 902 hectares in the Shirako and Shakujii river basins, located on the northwest side of Tokyo.

In order to be successful, ESS requires some essential conditions:

(a) Soils should be favorable for infiltration

(b) The ground water level must be low

(c) Conditions must be suitable for the construction of infiltration facilities

In addition, ESS requires the separation of stormwater from the wastewater in combined drainage areas. A good public information program is necessary to provide understanding of the effects of ESS and to encourage cooperation from residents. This has been accomplished with a series of

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public meetings held in advance of construction, as well as the use of an easily-recognized symbol for all ESS-related publicity. Finally, good system operation is dependent on a regular maintenance program.

4. ACKNOWLEDGEMENT

The authors wish to thank the Tokyo Metropolitan Government Sewerage Bureau for permission to present this paper, and their gratitude is also expressed to Prof. Arata Ichikawa of Tokyo University for his support in the preparation of the paper.

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INLET CONTROL CONCEPTS ON CATCHBASINS
U.S. EXPERIENCE

by William C. Pisano *

This paper summarizes U.S. practice of utilizing inlet control concepts to reduce the impacts of urban runoff flooding and pollution by manipulation of street inflow to catchbasins. Today , there exist over 15,000 such installations in North America. Most installations involve restriction of catchbasin outflow to cause surface inflow to be re-directed by overland routes to more suitable discharge points or to underground storage tanks. A relatively small fraction of these installations are meant to directly induce street ponding. The preponderance of installations involve retro-fitting existing systems to mitigate collection system surcharging , to reduce exfiltration and infiltraton exchange within adjacent sewer systems , and to cause reduction of downstream combined sewer overflows .

The paper first capsulates the general concept of inlet control or stormwater management (SWM) within the urban setting. Descriptions / project concepts , costs , cost savings are presented for implemented,projects in Cleveland, Ohio; Saginaw,Michigan; Montreal,Canada; and Skokie, Illinois. Common types of flow controllers used in the US are described along with operational experience . Several research efforts aimed at defining the cloggability limits of various types of catchbasin controllers are described. Several case studies are presented , including an overview of an ongoing Boston, Ma, CSO Facility Planning investigation which entails catchbasin retrofitting using inlet controls to reduce the cost of combined sewer overflow control in approximately a thousand acres of dense urban area.

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1 STORMWATER MANAGEMENT IN URBAN CONTEXT (SWM)

1.1. OVERVIEW

SWM has its historical roots in Scandinavia where the concept has been used throughout Sweden and Denmark for rehabilitating undersized combined sewers to relief basement flooding . The central idea is to control or limit surface stormwater inputs into underlying sewers, and is often referred to as "inlet control" . This practice is widely used for basement flooding and drainage control in Ohio , Maine , Illinois , and Quebec and is widely used as a CSO control throughout Ontario (Canada).

Many sewerage system hydraulic surcharging problems can be mitigated using " inlet control" as a way to lessen the costs of expensive "outlet control" relief sewers. Hybrid solutions employing both concepts generally result , and are cost-effective .

Such solutions were developed for several areas totaling about 1200 acres in Parma, Ohio (Cleveland metropolitan area) . SWM was applied to storm drains ("over/under" systems - see Figure 1) to lessen the "outlet relief" need for surging sanitary lines to mitigate basement flooding (Pisano et al., 1982). For one such area (290 acres) in Parma ,the hybrid approach reduced the cost of new construction by over 100 % and generated a broader range of benefits than anticipated. (See Section 3 - " Ridge Road , Parma Case Study").

In Euclid, Ohio (near Parma and situated on the shoreline of Lake Erie) nearly 2000 catchbasin restrictors (vortex throttles) have been installed to limit storm flow to over/under sewerage systems to relieve basement flooding. Since the land mass in Euclid monotonically slopes to the Lake , released catchbasin flow moves by overland routes to storm drains outletting to the Lake (Smisson, 1981).

A good example showing the Combined Sewer Overflow (CSO) control potential of the catchbasin SWM is depicted in Figure 2. Four vortex controllers are proposed to be placed in catchbasins which are connected to a combined sewer lateral on Westmoreland Street (Boston) to induce surface gutter flow down to an existing separate system on Adams Street (Pisano and Pierstroff, 1988). This micro catchment is in the lower Neponset CSO Facility area in Boston. The action saves $120,000 in new storm drains needed to separate the combined sewer on this street for the purpose of CSO reduction . This scheme was one of six small- scale SWM projects which collectively with other earlier completed (1981) CSO control elements, satisfied regulatory requirements for the sewer shed (750 acres) .

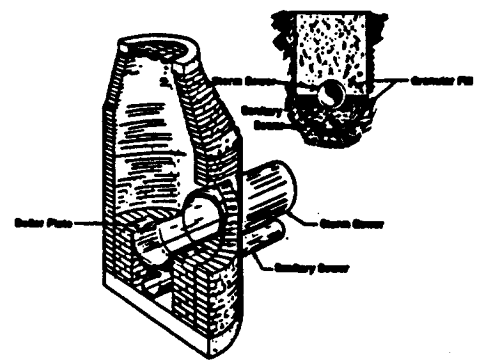

FIGURE 1 - Typical Over / Under Sewer Construction

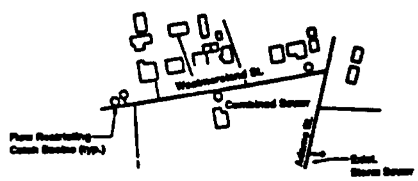

FIGURE 2 - Catchbasin SWM Example for the Lower Neponset Project, Boston.

This new plan was developed as part of a Value Engineering study (Havens and Emerson, 1987) to determine if a new relief trunk sewer, the final element of 1981 CSO program Plan , needed to be constructed . This new relief sewer would require construction along the main egress into the community. Disruption would be significant and the cost of construction was estimated at 1.2 $M . It is estimated that the new SWM program will save an estimated $0.5 million , and will eliminate the need to implement an unpopular project. Boston is presently experimenting with catchbasin flow controllers in one of these micro SWM projects.

An overview is presented in Part 3 of SWM considerations investigated as a part of the ongoing Boston CSO Facility Plan . Roughly a thousand areas of mixed combined and separated (overlayed) systems) were investigated for SWM opportunities similar to the Westmoreland Street solution.

Recently a SWM solution was proposed as part of a scheme for deflecting stormwater " first - flush " from an urbanized area impacting Lake Quinsigamond in Worcester, Mass. The Lake has an enormous recreational usage and preservation of water quality is vital to the community. The program is underway and is reviewed in Section 3- Case Studies.

1-2 SWM CONCEPT

Conceptually, "the stormwater management strategy " in the urbanized context starts at the very top of sewershed and searches for opportunities to control and manage stormwater so that the pipes do not overload as you move downstream (Smisson, 1981; Wisner, 1984). All possible forms of above/underground storage are used to hold the water till the receiving pipe can handle the flow without surcharge, or sometimes to transfer surface flow from combined systems to separated systems (see Figure 3). The analysis begins at the top of the system and progressively moves downstream to the outlet. The idea is either to reduce combined sewer overflow peaks or to reduce combined sewage volumes .

The amount of stormwater that can be feasibly detained by "inlet control" methods is in part a function of the sewer system's capacity to convey flow. "Inlet control" enables the designer to maximize the detention storage potential of any system given its ability to convey flows. Rigorous application of "inlet control" reveals the marginal cost effectiveness of positive relief measures.

Figure 3 pictorially shows some of the SWM methods". For example, a widely employed method in the midwest and Ontario , Canada is to reduce direct uncontrolled flow to the sewer by rerouting roof downspouts to splash pads with drainage to dutch drains/ dry wells / created previous areas/ street catchbasins.

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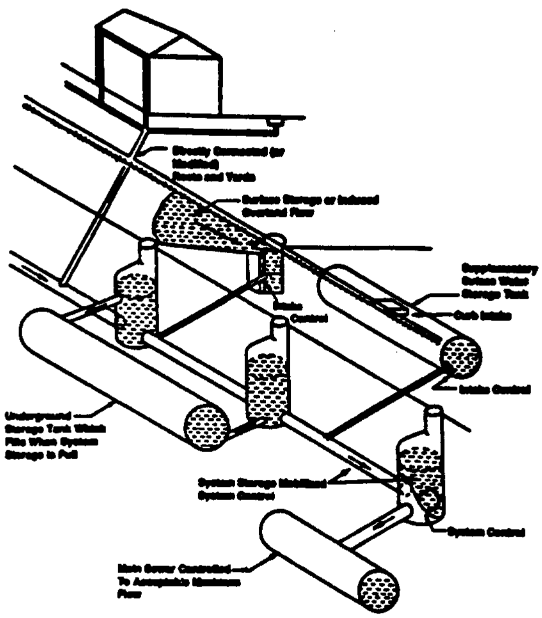

FIGURE 3 - Surface / Subsurface storage Components of Inlet

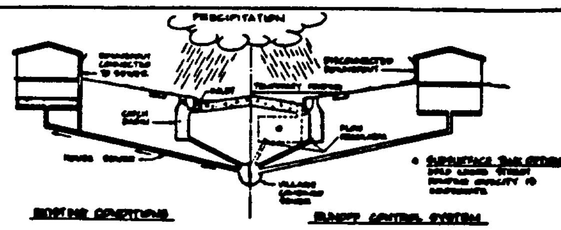

FIGURE 4 - Inlet Controlled System Under Different Conditions

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Temporary street ponding is still another method. Flow controllers can be placed in catchbasins to create temporary controlled street ponding. By preventing or slowing the overload, the sewage system is able to cope with the water, thus preventing overflows and basement backups. Figure 4 shows a schematic representation noting dry and wet weather conditions for street ponding considerations (Walesh and Schoeffman, 1985).

Flow restrictors placed within catchbasins are widely used to induce overland flow from sensitive areas to either outlet discharge points or more attractive capture/storage locations (Pisano, 1982, 1987, 1987; Smisson, 1987, 1985). The City of Laval , Canada is the process of "flow-slipping" waters from combined sewer laterals in hundreds of acres within the Marigot area down to the Riviere Des Prairies. These stormwaters would otherwise be captured and drained by existing combined sewers to a newly constructed tunnel with lift and future treatment. (Pisano, 1985)

Speed humps (asphalt) can also be placed to direct overland flow to storage or to maximize street storage potential. Systems of catchbasin flow controllers and speed humps can generate at low cost, controlled street storage. There are in excess of 80 such systems constructed in Parma , Ohio and in Skokie,Illinois (Walesh & Schoeffman, 1985; Pisano, 1982). Speed humps are gently contoured in contrast to speed "bumps". There has been no reporting of snow plow equipment problems.

Placed at specific points within the system, in-line flow controllers can also act as damming devices to utilize storage space that may be available in the existing sewers and/or to direct flow to off-line storage facilities.

Shallow underground off-line storage tanks/basins placed behind curbline/parkways/back alleys or in open park areas are other methods of "urbanized stormwater management ". These detention tanks are meant to temporarily store excess stormwater beyond street storage for controlled bleedback (vortex valves) into sewer system. Shallow new storm drains connected into existing and/or new catchbasins draining to storage tanks are often used to strategically locate underground storage in open areas (Pisano et al., 1982; Wisner, 1984; Walesh and Schoeffman, 1985; Pisano, 1982; Municipal Engineers Association of N.E. Ohio, 1987; Donohue Engineers, 1985; O'Brien & Gere, 1982; Matthews, 1982).

There are over 200 such off-line shallow detention storage installations in the greater Cleveland area (spilt between combined sewer systems and "over/under" sewerage systems). Figure 5 shows a typical installation in City of Parma , Ohio. Catchbasins are inputted into the 42" RCP tank with vortex flow throttle on underflow to relieve surcharge. Up until recently," Wet pit " type throttle chambers have generally been the rule in U.S. practice .

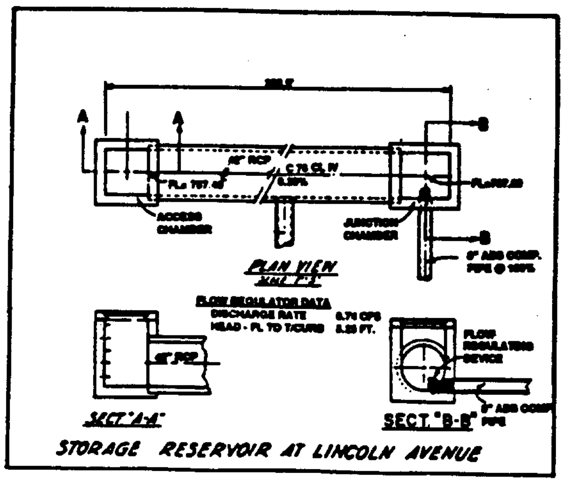

FIGURE 5 - Typical Underground Storage Tank
Parma, Ohio

1-3 BENEFITS AND DISADVANTAGES OF SWM

Benefits of using the "urbanized stormwater management " in local areas with combined sewers can generally be summarized as:

a) minimizes the need and degree for sewer separation and local relief sewers

b) provides immediate relief in areas with most severe basement flooding problems, leaving less critical areas until funds become available

c) lessens CSO and pollution loads since retained transient stormwater (and combined sewer stored in-line) drain back to sewers for treatment

d) provides an adaptive approach for control that can be applied in stages and then as time and funds permit, be integrated with more expensive structural control measures to provide ultimate protection.

SWM has a strong positive benefit for large complicated tunnel/lift station/conveyance/treatment systems. The net effect of applying SWM to a number of catchments tied into a major system is to "base-load" the system output , meaning that flow peaks would be smaller and less frequent , and that a higher system-wide base flow would result.

Disadvantages of SWM are as follows. First, the required degree of engineering support can be enormous for a large area. The analysis proceeds on a street by street basis. Precise topographic surveys are necessary and conditions of minor system piping and appurtenances must be known.

Second, the procedure will invariably release stormwater to the surface overland systems . Visual presence of released stormwater , if in the form of temporary ponding, is viewed as a negative by many inhabitants in urban areas , particularly in middle and high income communities . There seems to be little adverse reaction to overland curb flow.

Third, SWM will invariably require close observation and fine-tuning to ensure all elements are performing correctly. If the controlled areas are large , this task can take a number of years of close observation and attention. Such a long term commitment can be difficult for many communities.

Fourth, SWM may increase street maintenance either to clean up silt and debris from induced curbline flow, or to insure impervious and smooth street surfaces as to minimize subbase damage and micro "pockets" of street ponding.

Fifth, SWM is perceived by many to increase the liability of ice ponding and slippery conditions. In reality, this has not been a problem in the snowbelt areas of Illinois and Ohio, and even in the icebelt areas of Canada . This is probably the result of design flow controller release rates exceeding localized snowmelt conditions. Liability is nevertheless still a major determent of the catchbasin inlet control.

2 METHODS OF CATCHBASIN RESTRICTION

2.1 General Discussion of Methods

There are four different methods to regulate the inflow to piping system from catchbasins. The first entails grate geometry modification. The second consists of restricting the flow at or just below the grate. The third is modification of the outlet pipe (rarely used and not discussed). The fourth involves placement of flow control devices within the leader.

Catchbasin grating restriction has been frequently tried . The grating area may be reduced by mounting plates either on top or below the grating. See Figure 6. This option results in a lower flow capture efficiency. The disadvantage of this method is that the grating capture is reduced over the complete range of flows, meaning that for small events during which the piping system has adequate capacity, some flow reduction occurs. Debris can become packed in the closed grating and can be difficult to remove.

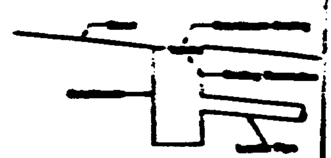

FIGURE 6 - Typical Catchbasin Grating Restriction

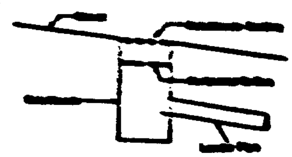

FIGURE 7 - Typical Horizontal Orifice Restriction

Still another type of control is the placement of horizontal orifice plates below the catchbasin grating. (See Figure 7). A variation is to slightly convex the plate to permit solids and leaves to slough toward the orifice . The size of the orifice in the plate restricts the flow to the desired level. Besides being inexpensive to fabricate, the head required for sizing the orifice is simply the expected street ponding depth. A disadvantage of this method is that the horizontal plate restricts access to the basin, as the plate must be removed before the catchbasin or inlet can be cleaned.

This technique is currently used to abate basement flooding in several large combined sewered areas in eastern Michigan. There are roughly 2300 such installations in the Township areas of Saginaw, Michigan (Pisano, 1987). A recent commercial product using this concept called , " "EZ-Flow " controller has emerged in the Canadian market. The device is a one piece molded hopper style plate made from polyethylene foamed plastic. Flow obstruction control is provided by a four "fin" design molded onto the restrictor plate surface about the orifice outlet. No U.S. experience has been noted.

The fourth class of controls for restricting flows are placement of devices in the catchbasin outlet to effectively reduce the leader pipe outlet area. An advantage of this class of controls is that for low flows , they do not interfere with the grating capture. Water is backed up in the catchbasin only during large flows that exceed the capacity top or below the grating. (See Figure 6). This option results in a lower flow capture efficiency . The disadvantage of this method is that the grating capture is reduced over the complete range of flows, meaning that for small events during which the piping system has adequate capacity, some flow reduction occurs. Debris can become packed in the closed grating and can be difficult to remove.

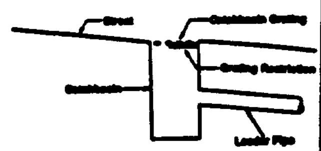

FIGURE 6 - Typical Catchbasin Grating Restriction

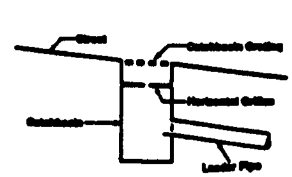

FIGURE 7 - Typical Horizontal Orifice Restrictor

Still another type of control is the placement of horizontal orifice plates below the catchbasin grating. (See Figure 7). A variation is to slightly convex the plate to permit solids and leaves to slough toward the orifice . The size of the orifice in the plate restricts the flow to the desired level. Besides being inexpensive to fabricate, the head required for sizing the orifice is simply the expected street ponding depth. A disadvantage of this method is that the horizontal plate restricts access to the basin, as the plate must be removed before the catchbasin or inlet can be cleaned.

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The fourth class of controls for restricting flows are placement of devices in the catchbasin outlet to effectively reduce the leader pipe outlet area. An advantage of this class of controls is that for low flows , they do not interfere with the grating capture. Water is backed up in the catchbasin only during large flows that exceed the capacity of the restricting unit. It is generally recognized that this class of controls is superior to the other three methods as the restricting orifice can be easily installed ,and with the orifice mounted flush (ideal) to the catchbasin wall, it does not interfere with catchbasin cleaning.

2.2 Discussion of Catchbasin Outlet Controllers

Four different types of restrictors are discussed. The general concept is shown in Figure 8. The first three types have the orifice placed in the outlet leader pipe . The last type has the orifice submerged in the catchbasin. The first two outlet orifice types are called, the "Scepter" and the "Cromac". The third type of orifice placed into the catchbasin leader causes the flow to vortex leaving the leader. The orifice is actually the outlet of a vessel with an intake which causes the flow pattern within the vessel to rotate and cause a vortex to form (creating resistance). The final type discussed is called the "Hanging Trap" in which the orifice is actually submerged within the basin.

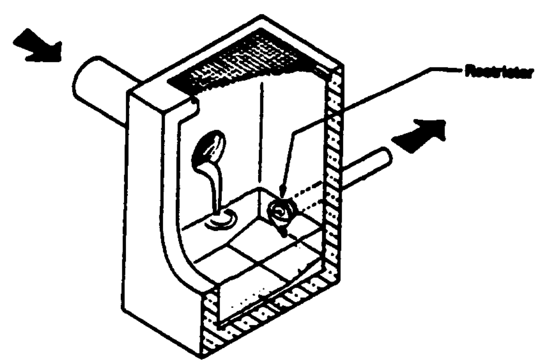

FIGURE 8 - Catchbasin with Restrictor on Leader

A. Scepter

The Scepter flow regulator is a PVC injection molded orifice that can be inserted in catchbasin leader or mounted on the catchbasin wall so as to cover the leader. The orifice has a diamond shape with a keyhole at the bottom. The purpose of the keyhole is to lower the sump level and keep the upper part of the orifice free of floating debris. During significant flow , the water level within the catchbasin rises and passes flow through the upper diamond shape portion of the device.The device was developed in Canada and has been extensively used in new SWM inlet control schemes with a lower flow restricting limit of about 0.5 cfs (Wisner, 1985).

B. Cromac

This orifice device is mounted over the leader pipe inside the catchbasin. It consists of a frame bolted to the catchbasin wall to encircle the leader pipe, and an orifice section which slides into the frame. The orifice section consists of two PVC sheets : one contains a trapezoidal opening 10" at the bottom and 3 1/2" at the top about 10" inches tall; the second plate, called the weir plate, is adjustable and can be fastened to the orifice plate with nylon bolts . The weir plate allows adjustment of the restricted area for flow passage. The orifice section is removeable to permit removal and cleaning(14).

C. Vortex Flow Throttling Devices

a) General Configuration

Figure 9 depicts a standard push-fit "O"-ring type device for catchbasins with suitable sumps. This device was developed in Denmark in the mid 70's. The inlet is the square - shaped hole in the upper foreground, while the discharge occurs through an internal orifice within the vortex drum . This square-shaped intake is well below the normal water level in the sump and is below the general region of floatables.

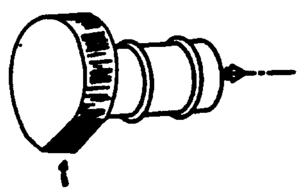

FIGURE 9 - Standard Configuration of Swedish - Type Catchbasin Vortex Valve.

The back portion of the device is simply the connection pipe with stop rings for "O-ring" rubber gaskets. A gas trap results due to the gasket connection and the intake being below the sump water level. Existing leader pipes in catchbasins are often "out-of-round" requiring a small segment of PVC or VCP to be grouted in before inserting the device. Another alternative is to segment the device and grout the device's outlet pipe into the leader, and then connect the "vortex drum" with a mechanical bolted collar connection.

Figure 10-A shows the layout for West German inlet with a "gully" screen for trapping and catching sticks, rocks and floatables . A vortex throttle controls the discharge from the inlet (Pisano, 1988). Shown in Figure 10-B is an advanced form of vortex throttle (German design). The device consists of two dish-heads welded together with a special flared intake and fitted with adjustable orifice inserts to permit changing the stage / discharge flow characteristic.

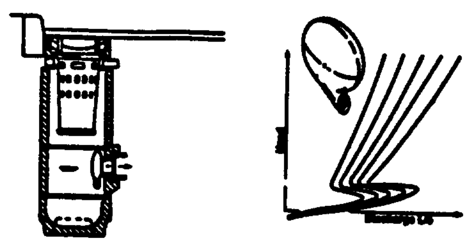

FIGURE 10 - Details for Standard German - Type Catchbasin Vortex Throttle.

b) Number of Vortex Throttle Installations

Several catchbasin type - flow controllers were first installed in the U.S. in 1976 on Puritas Ave. in the City of Euclid, Ohio for the purpose of de-pressurizing hydraulically overloaded storm sewers in "over/under" sewerage systems (over-storm and under-sanitary). As of 1989 there were over 2000 such installations in Euclid.

Overall, about 5000 such devices have been installed in the U.S., mostly in the Greater Metropolitan Cleveland area and in Portland, Maine. During the same time period, roughly 500 such devices have been installed in Canada, mostly in the provinces of Ontario , Quebec and British Columbia. In Europe there are roughly 500 catchbasin and inlet installations mostly in Denmark,England, Sweden, and Norway. Recently, a number have also been installed in West Germany.

c) Sizes and Applications

More than 75% of all U.S. applications have been in storm sewers which are part of "over and under" systems (where the objective is to minimize storm sewer surcharge resulting in less exfiltration and reduced sanitary sewer infiltration), or in strictly separated systems (where the objective is to provide upstream transient stormwater management). The balance of installations have been to limit flow entry into combined sewer systems for a wide variety of applications, ranging from mitigating localized sewer surcharging (basement flooding) to "flow slipping" street load from combined systems to nearby existing storm drain systems .
Generally, the design release rates on storm system applications have been, on the average, larger than those used for combined sewer applications .Almost all of the "over/under" applications have used devices with an orifice

diameter range of 3"-8" (0.25- 1.5 cfs release rate range). Most of the devices used on combined sewer systems have had lesser release rates resulting in orifice sizes of 3"-4".(0.25-0.5 cfs release rate range). For a few projects in Windsor, Ontario during the late 70's , several hundred devices with 2" orifices were used to restrict catchbasins discharging into small-diameter combined sewer pipes.

D. Hanging Traps

The final method discussed is the use of a hanging plastic tee grouted into the catchbasin leader. Tapped plastic insert sections (2- 3 ") create the flow control (Walesh and Schoeffman, 1985). Figure 11 shows the layout. Over 1000 such devices have been installed in Skokie , Illinois. This setup has also been used to control the outflow from shallow underground storage tanks.

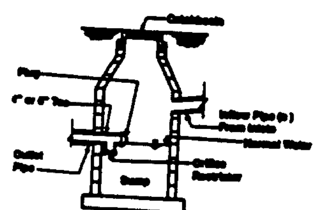

FIGURE 11 - Typical Flow Regulator in Catch Basin Installation Used in Skokie, Illinois

2-5 EXPERIENCE AND CLOGGING EVALUATIONS

The vortex throttle has probably received the greatest attention due to the commercial claim of "non-clogging" vortex flow action, and the high cost of the devices. Since 1976 when the device was first installed in Euclid, there have been a number of reportings of plastic cup and pop bottles lodging themselves in the square - shaped intake (presumably during rising and falling sequences during storm events). There have been few reported instances where the devices have clogged with sand and rocks. This problem has occurred where the devices were installed in catchbasins or in inlets with insufficient sump space.

One notable drawback of this technology is the inability to actually see by inspection whether the device is clogged (since the intake is submerged). In practice, the rate of observed street level drain down (where street ponding in intended) is generally used to detect such problems.

Catchbasin devices were installed and evaluated for the U.S. EPA 108 Program in Rochester, New York as part of a R&D SWM evaluation on a combined sewer system (O'Brien and Gere, 1982). Different tankage applications and catchoasin devices within combined systems were evaluated in Cleveland (Matthews, 1982) . It was concluded that fouling can occur in inlets (where no sumps are provided to catch debris), or where catchbasin sump depth is limited or not maintained. Minimum device size recommended is a unit having a minimum 3" orifice outlet .

It is interesting to note that there have been no reported new combined sewer applications using devices with an outlet orifice less than 3" since the late 70's. German experience with very small (less than 2" orifice units) has not been favorably due to cloggage (Pisano, 1988). From practice it seems that devices having orifice range of 3"-4" are about the practical lower limit.

As part of a SWM technology review and basis of design scheme for the Village of Skokie, Illinois , Donahue Engineers in 1984 conducted a one season (fall) evaluation of cloggage potential for various types of flow restrictors (release rate range of 0.12- 0.78 cfs) within a drainage area having large numbers of deciduous trees (Donahue Engineers, 1985) . Horizontal orifice plates, grating restrictions, Hanging Traps, Sceptors, Cromacs and Danish - type vortex valves were evaluated . This assessment was conducted to select the best flow control device for "inlet control" of the Howard Street District (roughly 800 acres) of combined sewer area impacted by basement flooding problems.

It was concluded that the Hanging Trap, the Scepter, and the vortex throttle were equal in performance . All other devices were adversely impacted by leaf cloggage. The Hanging Trap was chosen to be most cost effective since the first cost of the plastic Hanging Trap is about $25. It is fabricated of readily available materials, and is easily grouted in place (and reportedly easy to snap off and replace) .

In 1985 Hanging Trap flow throttles were installed in approximately 300 catchbasins and as the outlet control in 8 underground concrete tanks within the Howard Street District in Skokie, Illinois. A number of asphalt speed hump systems were also installed to create minor surface ponding areas with drainage back to nearby inlets .A post evaluation phase indicated no substantial problems. Design and implementation for a second area (1200 acres) is in progress . A higher density of underground tanks is envisioned as the area is more commercial in nature.

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Wisner conducted the most comprehensive set of clogging potential tests to date (Wisner, 1985). In the summer of 1985 he used a test facility consisting of a street section which can be hydraulically grade-adjusted with overhead sprinklers to create runoff to a full -scale plexiglass catchbasin . Solids were manually placed with controlled mixes of leaves, small twigs and sticks, leaf mixes , and paper inputs. The experimental setup also permitted storm inflow to be fed from curb line (creating maximal opportunity for splash turbulence and debris mix), or to be inputted directly into the middle of catchbasin sump, (and thereby creating minimum turbulence within the sump) .

Long-term controlled simulations using different types of catchbasin restrictors were conducted under both types of flow input regimes. It was generally concluded that cloggege potential for all devices was maximal during conditions of high basin turbulence (flow input to basin from curbline) as the likelihood of floatables being mixed within the basin and passing into and through the orifice aperture was greatest.

Wisner concluded that the Hanging Trap flow restrictor was acceptable at release rates down to 0.5 cfs provided the flow input was quiescent and was without turbulence. With normal curb line input, the Hanging Traps continually clogged for all flow release rates considered (0.5-1.3 cfs) . Figure 12 shows the typical catchbasin layout in Skokie . The flow input from inlets (typically 2-3) to the catchbasins were at mid sump level (meaning minimal turbulence) , explaining to a degree why the Hanging Trap flow throttle installations in Skokie performed acceptably.

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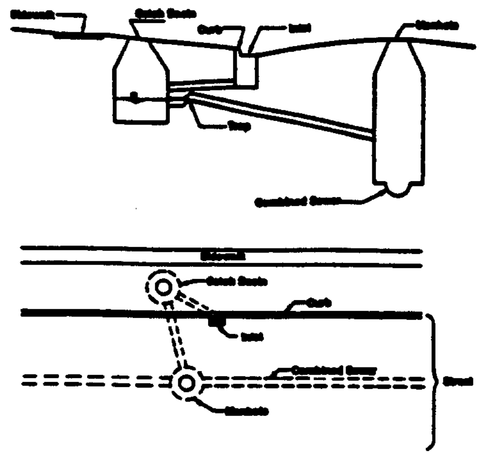

FIGURE 12 - Typical Street Drainage System Configuration for Skokie, IL.

The test results for the Scepter showed that the release rate of 0.5 cfs was the satisfactory lower limit. At lower flow rates it was concluded that the cloggage frequency would be unacceptable . The Cromac constantly clogged and a release rate of 1 cfs was deemed as the lower practical limit .

Wisner found that the vortex valves were nearly clog-free. He found that the German vortex throttle could not be clogged under any conditions . The German device was the only device tested for release rates under 0.2 cfs and was satisfactory for a release rate as low as 0.11 cfs. Wisner found that the intake of the Danish vortex valve could be clogged, but only under extremely adverse conditions such as high rate mixed transport of large twigs and leaves. The lowest release rate used for the Danish device was 0.23 cfs.

3 CASE STUDIES

3.1 Ridge Road Area , Parma Ohio

The "Ridge Road Program " was one of the three projects completed during the period of 1981- 1984 in Parma , Ohio (suburb of Cleveland) . This project best exemplifies inlet control concepts to mitigate difficult surface flooding and stormwater related basement flooding in a dense urban area. The project also reduced spring infiltration contributions to the sanitary sewer system and eventually to the WWTP.

The area known as the "Triangle " in Parma is a topographic "dished" shaped area (30 acres) situated within the lower portion of a 290 acre drainage system . The terrain in the watershed is hilly with deep valleys, and the land generally slopes to the "Triangle" (see Figure 13 for location). The sanitary sewer trunk system passing through the area carries input from 1200 acres upstream. The 290 acre area is highly developed with 1200 homes and many commercial establishments. The area is crossed by two major vehicular arteries and is served by an "over/under" storm/sanitary system (see Figure 1 for typical layout). This method is a common sewerage system configuration throughout the Cleveland area and in other metropolitan areas in the U.S.

Prior to this project, the "Triangle" endured severe basement flooding resulting from surcharging sanitary sewers during heavy rainstorms (at least 3-4 episodes per year) . The cause of surcharge stems from the undersized storm systems which cannot handle storms flows, pressurize, surcharge and leak significant amounts of clear water into the rock filled " french drain" trench section . Since the sewer joints in the sanitary sewer are invariably cracked or broken, the surcharge condition within the rock filled trench adversely affects the sanitary sewer piping, ultimately resulting in basement flooding.

Basement flooding in the "Triangle" is further exacerbated by the poor hydraulic outlet conditions of the local sanitary systems discharging to the trunk sanitary sewer .The trunk sanitary sewer passing through the study area receives significant upstream wet weather related inputs. It then becomes flow-constrained by a sudden flattening of grade just downstream of the study area.

Due to the rolling terrain , there are numerous "low valley pockets" throughout the entire 290 acre area. The storm drains are generally inadequate . Surface water which cannot escape via "major overland routes" at these low lying locations, accumulates and severe street flooding results. Prior to this project, both street and basement flooding frequently and simultaneously occurred in the "Triangle"

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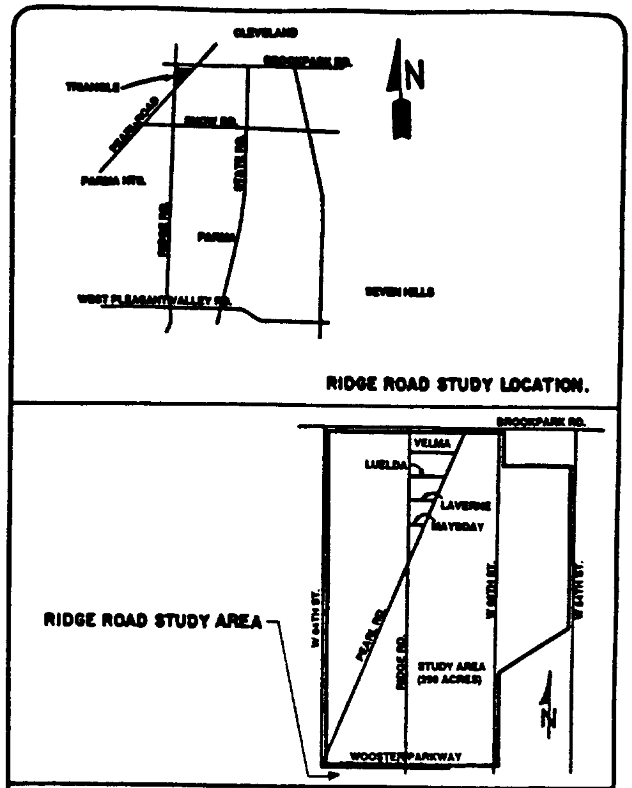
CLEVELAND
BROOKPARK RD.
TRIANGLE
PEARL ROAD
RIDGE RD.
STATE RD.
PARMA HTS.
PARMA
SEVEN HILLS
WEST PLEASANT VALLEY RD.
N
RIDGE ROAD STUDY LOCATION.
BROOKPARK RD.
VELMA
LUELDA
LAVERNE
MAYSDAY
W 64TH ST.
W 56TH ST.
W 54TH ST.
PEARL RD.
RIDGE RD.
STUDY AREA (250 ACRES)
WOOSTER PARKWAY
RIDGE ROAD STUDY AREA
N

FIGURE 13

during heavy summer thunder storms . Similar problems were experienced throughout the entire 290 acre area but were not as severe as in the" Triangle".

An solution contemplated earlier was to construct a large underground off-line detention basin for relieving the sanitary trunk sewer coming into the study area , and to construct sanitary relief sewers throughout the "Triangle ". Estimated cost of these improvements was $2.2 million. Only basement flooding in the homes within the "Triangle" would be affected . Surface water flooding would not be addressed.

The alternative (implemented) solution involved inlet controls on the storm sewer system within the entire (290 acre) catchment area to minimize sanitary relief sewer improvements. Dual concepts of both "inlet" and "outlet" controls were considered .

Under controlled conditions, experiments were conducted to relate the degree of storm sewer surcharge to sanitary sewer infiltration for different diameter storm pipes . These results were used to relate sanitary sewer infiltration as a function of storm sewer hydraulic control .

A hydrologic model was used (BRRL method), and different stormwater inlet control strategies were investigated for assumed levels of"full pipe or less" flow conditions . The aim was to determine whether sufficient storm sewer exfiltration reduction could either eliminate or minimize the need for sanitary system improvements . Cost effective analyses however indicated that inlet control could not reduce sanitary sewer surcharge to acceptable levels . Several relief sanitary sewer segments improvements were needed. The final solution entailed a "hybrid " of inlet (stormwater management of storm drains) and outlet (sanitary sewer relief) controls.

The following set of inlet controls were implemented as part of the storm sewer system improvement program. A schematic of a portion of the study area controlled is shown in Figure 14.

(a) Storm/sanitary manhole rehabilitation
(b) Re-grouting flow-constrained pipe segments
(c) Overland flow "training" berms
(d) Surface storage berms for surface storage
(e) Re-construction of low curbs to maximize surface storage
(f) Installation of catchbasin vortex throttles to induce street surface storage or overland flow to tanks
(g) New catchbasins to intercept overland flow
(h) New shallow drains to dewater low "trapped" street areas
(i) Underground storage tanks with outlet vortex throttles
(j) Disconnection of residential downspouts (front only).

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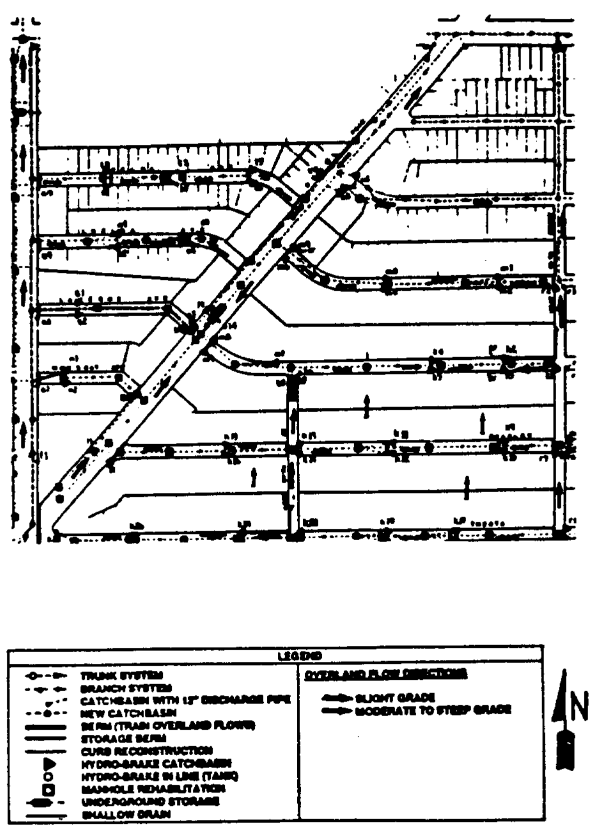

FIGURE 14 - Inlet Control Program Elements on Storm Drainage System

Construction costs in 1984 were $875,000 (SWM inlet controls = $600,000 and sanitary sewer segments = $275,000). Unit cost of underground storage ranged from $6.50 to $9.75/cubic foot (utility re-location, tanks, flow controllers, pavement replacement etc.) Installed catchbasin flow controllers ranged from $700-$900 per basin. (today , stainless steel vortex throttles would cost $500-$700 due to rises in raw material costs). Surface storage generated averaged about $4 per cubic foot. Total savings equalled about $1 million dollars (Pisano, 1982).

The project has mitigated surface water ponding and has provided basement flooding protection throughout the entire 290 acre area including the "Triangle". To date there has been only one reported instance of basement flooding in the "Triangle" (1985 during a 20 year storm) . Although not intended , spring sanitary sewer infiltration has been significantly reduced .

3.2 Lake Quinsigamond, Worcester, Mass.

Summary details of an extremely cost effective solution are presented for decreasing the nutrient loadings from an portion of the urbanized area impacting Lake Quinsigamond in Worchester, Mass. The Lake is a narrow mile-long recreational water body surrounded by dense urban patterns (residential and commercial). It is rapidly becoming eutrophic from stormwater discharges. Sewers within the study area are "over/under" systems .

In the 70's the greater metropolitan area of Worchester (2nd largest City in Mass.) was investigated in a 208 Areawide study, which then led to an intensive National Urban Runoff Program (NURP) program of the Lake Quinsigamond watershed in the early 80's. Extremely high bacterial loadings and high phosphorous emissions were noted from a 320 acre area , the Belmont Street Drain . In 1986, a study was initiated to develcp the "basis of design " details for specific stormwater storage/ treatment controls for this watershed.

The 1987-88 investigation commenced with a thorough physical survey of the sewerage system. Critical observations and measurements during dry and runoff periods indicated that the dominant nutrient source is contaminated storm drain base flow. It is believed that these emissions result from intermixing of contaminants within the "over " (sanitary sewer) with the "under" (storm sewer) during rainfall events (surcharge conditions) . During ensuing dry periods contaminated baseflow emanates from the rock filled trench systems .The service area is extremely steep , and the original storm drains were designed to handle about the 1 year storm . Surcharge levels in portions of the system are significant.

Recent summer dissolved oxygen profiles within the Lake indicated a deterioration since the NURP study in the early 80's . The City believes that immediate action to reduce nutrients to the Lake is needed. Due to extensive rocky soils and "ledge" throughout the area, piping system replacement will be exorbitant and is not feasible . Rehabilitation is probably the best solution, but funding is limited, and implementation is years away.

Instead, a number of system controls were found to immediately eliminate much of the total nutrient loading from this watershed. Construction will commence in 1990 to deflect (using vortex flow throttle) both storm system "first flush " and the highly contaminated baseflow to a nearby combined system (out of watershed and to regional WWTP). SWM concepts will be used in the upper portion of the combined system to delay and flatten street surface peak flows (within the combined sewer area) as to increase the transfer of peak storm system "first flush" flow from the over/under network into the combined sewer system .

Figure 15 highlights the proposed improvements. A new flow deflection chamber on Plantation Street at Tampa Street will permit contaminated upstream stormwater baseflow (about 1 cfs from 90 acres upstream) to be diverted into the combined sewer on Tampa Street. Initially a small vortex throttle valve is to be installed to deflect only dry weather baseflow. The chamber dimensions however will be sized to provide a larger flow deflection capacity.

In another phase of work ,8-9 catchbasin flow controllers and one small stormwater detention tank (with its own discharge flow controller) will be constructed on the combined sewer along backside of Tampa Street and Atlanta Street. The intent is to "free up" flow capacity along the Tampa Street combined sewer so that first flush stormwater flow from the upper Plantation Street catchment can be deflected to the Tampa Street combined sewer. The tank is to capture excess stormwater released from catchbasin restrictors along Tampa Street and Atlanta Street.

When the SWM element is completed on Atlanta Street and Tampa Street, an additional flow controller in the new diversion chamber would be installed . Approximately 12 cfs of stormwater "first flush" runoff (and "base flow") are to be diverted to the combined system . Total construction cost is estimated at $160,000 (Pisano, 1989). It is estimated that about 55% of the total annual nutrient loading to the Lake from this catchment will be eliminated. This "micro-control" , quick -action program is also estimated to reduce the total watershed nutrient loading to the Lake by about 11 % . This reduction in turn ,about equals the estimated nutrient increase basin-wide since 1981 due to rapid urbanization.

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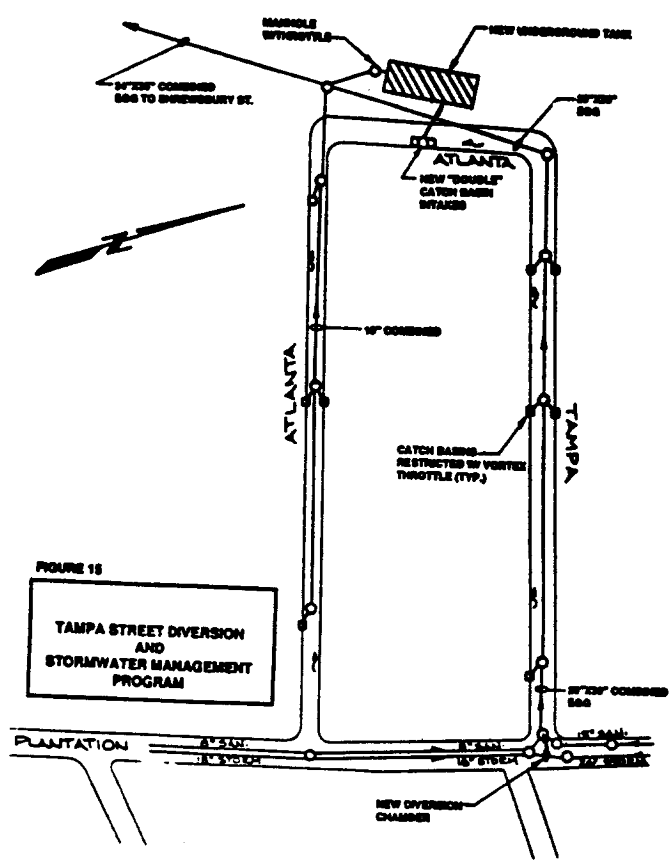

FIGURE 15

TAMPA STREET DIVERSION AND STORMWATER MANAGEMENT PROGRAM

3.3 SWM Considerations -1989 Boston CSO Facility Plan Study

In the late 70's , a CSO facility plan was prepared for the greater Boston area. The new agency created by court decree, the Mass. Water Resources Authority (MWRA), decided to re-investigate the concept of deep tunnels in view of the favorable tunneling costs experienced in Milwaukee. Satellite treatment, sewer separation , surface storage and deep tunnels were considered in the 1989 effort.

In addition, a Best Management Program (BMP) is to be developed for each of the 14 member neighborhoods and communities within the CSO area. Figure 16 shows the MWRA CSO service area. In-system storage , SWM , sewer flushing, street sweeping , and catchbasin cleaning were the major BMP concepts considered.

Production functions (level of scale versus pollutant removal) and cost functions were developed for each of the options considered for each area. These functions were then used in an optimization analysis to determine the best mix of controls for increasing levels of pollutant or overflow volume removal (19).

Three general SWM options were investigated.

(a) Partial Separation ("PS") : direct discoupling of small combined sewer segments directly to nearby separated systems.

(b) Flow Slipping ("FS") : restricting combined sewered catchbasins to move overland (usually not more than a block) street load with connection into existing separate system . Street ponding of released flows was not considered.

(c) Storage ("S"), Detaining combined sewer street load using small tanks with outlet flow throttle.

In order to develop adequate cross-sectional sample data for the production functions ,several large areas representing a broad spectrum of control possibilities were selected . Two major areas chosen are shown in Figure 16.

Area A (about 900 acres) is generally combined and its land mass is interior with few drainage outlets. Area B (about 800 acres) is mostly separated with small combined sewer " pockets". Since this area is situated near a major river and Boston Harbor, there are many drainage outlets. Area B is typical of old combined areas overlayed with relatively new sanitary systems. Land use in both areas is densely residential with mixed hilly and flat terrain. It was believed that these two areas represented a wide mix of

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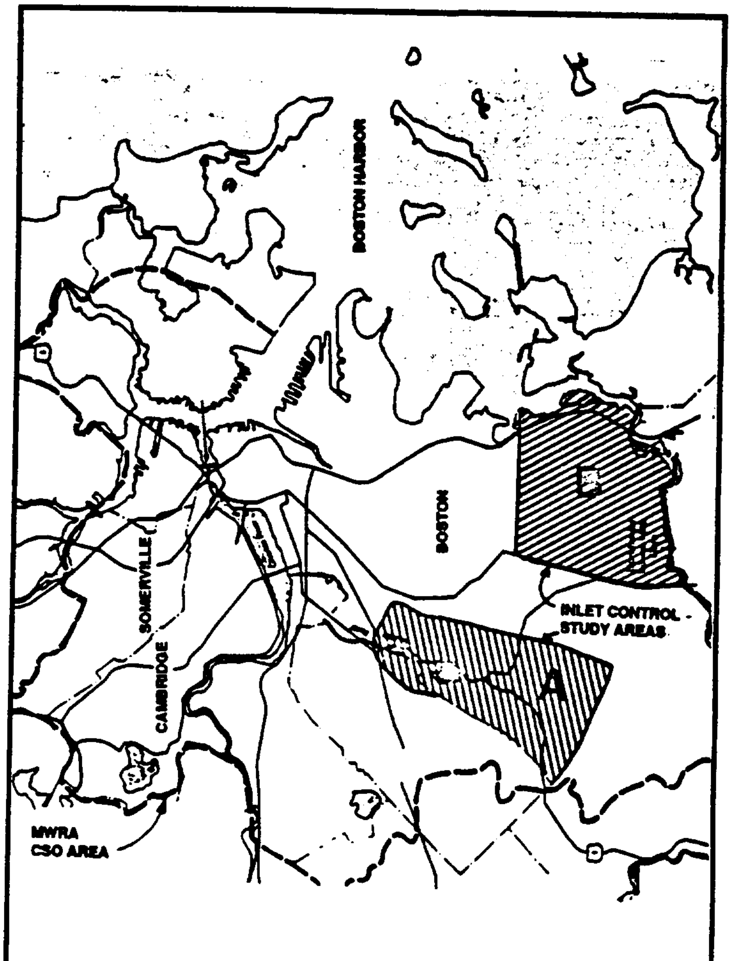

FIGURE 16 - Portion of Mass. Water Resources Authority (MWRA) CSO Service Area Considered for SWM Control

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piping systems so that costs and levels of achievable control could be extrapolated to the other subareas.

Maps were reviewed, street by street within the pilot areas to develop a large set of SWM possibilities. For most of the defined "desk-top" projects , the areas were then "windshield" inspected to ascertain general feasibility. Preliminary solutions and costs were developed .

A total of 56 individual small SWM projects were identified and costed for local conditions . Project areas ranged in size from 0.5 to 7 acres. There was about an equal distribution of the three SWM categories ("PS", "FS","S") . Using these projects as the data base , scaling factors (extent of feasibility and costs) were developed for all neighborhoods within the MWRA service area.

Complete separation construction costs (including engineering and contingency) for the two sample areas ranged from $90,000 to $120,00 per acre. Similar costs for the "FS" projects averaged $11,300 per acre . Average costs for the "PS" projects were $33,000. Costs for the "S" type projects were similar to complete separation due to the general lack of street siting opportunities (and achievable scale) to situate small curb-side underground tanks. Parks and green spaces were specifically excluded.

For area B , 57% of the combined sewered area could be impacted by SWM controls , and 48.6% of this area controllable by "PS" projects . The balance is spilt between "FS" and "S" projects .

The optimization procedure generally selected in-system storage as the least cost BMP option, and for some areas street sweeping and catchbasin cleaning were also attractive (CH2MHILL, 1989). SWM options were nevertheless competitive for several areas, particularly within pilot area B.

Since in-line storage was considered difficult to achieve as a BMP (much more study was perceived to be necessary for implementation) ,only a limited area was selected for in-line storage (value was obvious). Street sweeping and catchbasin cleaning at present levels were recommended as BMP controls. These conclusions are presently under review by the regulatory agencies and interested community groups (19).

CONCLUSIONS

The perceived value of SWM for CSO control is still in its infancy in the United States. In Canada , the practice is widespread, particularly in the Ontario provence. The concept is highly opportunistic , but can result in significant cost savings.

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A number of implemented case studies have shown that application of inlet control concepts to minimize the extent of outlet control relief systems , i.e. creating hybrid solution strategies, result in substantial cost reductions. Successful examples to date in the U.S. have been primarily for general drainage problems involving basement and street flooding .

Choice of the appropriate catchbasin flow controller for a given design application is difficult . Vortex throttles should be used when the intended release rates are less then 0.2 cfs. Other devices may be suitable for higher flow rates , provided there is minimal presence of deciduous leaves (i.e., large parking malls), and the likelihood of moderate levels of maintenance can be assumed. If these conditions cannot be satisfied , then vortex throttles should be used for design release rates of 0.2-0.5 cfs. Because of increasing size and cost, vortex throttles become less attractive than other options for design release rates exceeding 0.75 cfs.

Besides release rate, the most important determinant in flow control device selection is the presence of deciduous trees within the immediate catchment. Minimum catchbasin sump depths of at least 15 inches are recommended above the invert of the restricting device with catchbasin cleaning at least on an annual basis .

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ANALYSIS OF CROSS-CONNECTIONS AND STORM DRAINAGE

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Introduction

This paper is a preliminary summary of the first phase of a current EPA research project to:

- o develop investigative techniques to assist local governments in identifying the magnitude and sources of cross-connections in their storm drainage systems; and
- o present case studies of techniques used by selected municipalities in identifying cross-connections.

Discharges from storm drainage outfalls can be a combination of dry-weather base flows; stormwater runoff; snowmelt water; intermittent discharges of debris, wash-waters, and other waste materials into storm drains; and the relatively continuous discharges

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of sanitary and industrial cross-connected wastes. These discharges include stormwater that contains the washoff of pollutants from all land surfaces during rains, including washoff of pollutants from areas such as industrial material and waste storage areas, gas station service areas, parking lots, and other industrial and commercial areas, etc. Therefore, the quality of urban runoff can vary greatly with time (dry versus wet-weather, cold versus warm weather, etc.) and location.

The discharge of sanitary and industrial wastes into storm drainage (cross-connections) can lead to serious water pollution problems. In many cases, storm drain discharges are badly polluted by stormwatar alone, without the additional pollutant loadings associated with sanitary or industrial connections. The addition of sanitary wastes increases the concentrations of oxygen-demanding organic solids and nutrients, and increases the number of pathogenic microorganisms in the storm-induced discharge. Industrial wastes can be highly variable, but can substantially increase the concentrations of many filterable heavy metals in runoff, as an example. In many cases, annual discharge loadings from stormwater outfalls can be greatly affected by dry-weather discharges (Pitt and Shawley 1982; Pitt 1984; and Pitt and McLean 1986, as examples).

Dry-weather and wet-weather urban runoff flows have been monitored during many urban storm runoff studies that have found that discharges observed at outfalls during dry weather were significantly different from wet-weather runoff. Warm and cold weather runoff was also contrasted during some studies and was also found to be quite different. During the Castro Valley, California, Nationwide Urban Runoff Program (NURP) study, Pitt and Shawley (1982) found that the dry-weather flows were very hard and had very few nonfilterable pollutants, while the stormwater runoff was quite soft and had substantial nonfilterable metals. The dry-weather flows were found to contribute substantial quantities of many pollutants, even though the concentrations were not high. The long duration of baseflows in many areas of North America (about 95 percent of the time) off-set their lower concentrations and lower flow rates as compared to wet-weather (stormwater) flows.

The Bellevue, Washington, NURP project (Pitt and Bissonnette 1984) summarized the reported incidents of intermittent discharges and dumpings of pollutants into the local storm drainage system. During a three year period of time, about 50 citizen contacts were made to the Bellevue Storm and Surface Water Utility District concerning water quality problems. About 25 percent of the complaints concerned oil being discharged into storm drain inlets. Another important category of complaints was for aesthetic problems, such as turbid or colored water in the creeks. Various industrial and commercial discharges into the storm drainage system were detected. Concrete wastes flushed from concrete trucks at urban job sites were a frequently occurring problem. Cleaning establishment discharges into creeks were also a common problem. Vehicle accidents also resulted in discharges of gasoline, diesel fuel, hydraulic fluids, and lawn care chemicals into the storm drain inlets. Pitt (1984) also monitored both dry- and wet-weather discharges from stormwater outfalls in Bellevue and found significant pollutant yield contributions associated with dry-weather discharges from residential areas.

Dry-weather flows in a monitored Toronto residential area were found to have high pesticide concentrations, while a monitored industrial area had dry-weather flows that had high concentrations of organic and metallic toxicants (Pitt and McLean 1986). More than 50 percent of the annual discharges of water volume, total residue, chlorides, and bacteria, from the monitored industrial, residential, and commercial areas, were associated with dry-weather discharges. Substantial metal discharges, especially from the industrial area, were also found to be associated with dry-weather discharges.

Gartner Lee and Associates, Ltd. (GLA 1983) conducted an extensive survey of dry-weather flows in storm drainage systems in the Humber River watershed (Toronto) in an attempt to identify the most significant urban runoff pollutant sources. About 625 outfalls were sampled two times during dry-weather, with analyses conducted for many pollutants, including organics, solids, nutrients, metals, phenols, and bacteria. About 1/3 of the outfalls were discharging at rates greater than 1 L/sec. The dry-weather flows were found to contribute significant loadings of nutrients, phenols, and metals, compared to upstream conditions. About 10 percent of the outfalls were considered significant pollutant sources. Further investigations identified many industrial and sanitary sewage cross-connections into the storm drainage. An apartment building with the sanitary drains from eight units illegally connected to the storm drainage system was typical of the problems found. Other problem areas were found in industrial areas, including yard storage of animal hides and yard runoff from meat packing plants.

Methodology

A specific objective of this project is to identify the most promising techniques to identify, quantify, and

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locate cross-connections of sanitary and industrial wastes entering storm drainage systems.

As noted above, cross-connections can take multiple forms. Many cross-connection problems are associated with intermittent discharges. These intermittent discharges occur during wet-weather as runoff from storage areas, or as illegal dumping or washing operations that occur during dry or wet weather. Other cross-connection problems are caused by continuous connections that can occur during both wet and dry weather. These can be associated with "non-contact" cooling water discharges (which frequently contain a variety of chemicals, including algicides and corrosion inhibitors), other industrial wastewater connections, and sanitary sewage waste connections, for example.

This project is identifying procedures that can be used to identify the significance and type of either intermittent or continuous discharges occurring during dry weather. The pollutant contributions associated with cross-connections can be distinguished by unique characteristics based on water types and typical pollutants. As an example, the major water types (major ions) of the flow components could vary substantially: the water supply source could be either groundwater or surface water (this water type would represent many of the wastewater types), while an uncontaminated baseflow source could be from local springs, groundwater, or from regional surface flows. Knowing the specific water source for each flow component could enable the relative mixture of uncontaminated baseflow and the wastewater cross-connections to be calculated.

<u>Potential Dry-weather Discharge Sources</u>

The following list summarizes the potential contaminated residential area cross-connection sources being evaluated:

Sewage sources:
- raw sanitary sewage from leaky and directly connected sewerage
- septage from improperly operating septic tank systems

Household automobile maintenance:
- car washing runoff
- radiator flushing
- engine de-greasing
- improper oil disposal

Residential irrigation sources:

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- over-watering runoff
- direct spraying of impervious surfaces

Roadway and other accidents:
- fuel spills
- spills of truck contents
- pipeline spills

Other:
- washing of ready-mix trucks
- laundry wastes
- improper disposal of other household toxic substances
- dewatering of construction sites
- sump pump discharges
- contaminated surface and groundwaters

Commercial and industrial dry-weather discharges are being considered in a separate study conducted by Triad Engineering of Milwaukee. The results of the Triad study are being incorporated into the complete EPA manual. The commercial and industrial approach is stressing differentiating industrial categories used in the industrial discharge permit program.

The natural baseflow raw water source flows, along with the sewage related sources and many industrial sources, would be relatively continuous in flow duration. The other sources would be intermittent. As a drainage area increases in size, however, the probability also increases that dry-weather discharges associated with individual intermittent activities would appear continuous at the outfall. Most of the studies referenced previously found flows at the monitored outfalls most of the time during dry weather, even though the flows were very low at times. The quality of the flows also changed dramatically at different times of the day for the monitored Toronto industrial outfall (Pitt and McLean 1986). Some trends were also noted for dry-weather outfall flows for different times of the year (especially in the colder areas).

This study is identifying unique physical, biological, or chemical characteristics that would distinguish the different flow sources. After the potential source categories are identified, additional investigations would proceed upstream in the sewerage to identify the specific sources.

<u>Monitoring Approach</u>

The purpose of the monitoring procedures is to separate the outfalls into three general categories (with a known level of confidence) to identify which outfalls need further analyses and investigations. These categories are: (1) pathogenic or toxic pollutant sources, (2) nuisance and aquatic life threatening pollutant sources, and (3) unpolluted water sources. The pathogenic and toxic pollutant source category would be considered the most severe and could cause disease upon water contact or consumption and significant impacts on receiving water organisms. They may also cause significant water treatment problems for downstream consumers, especially for soluble metal and organic toxicants. These pollutants may originate from sanitary, commercial, and industrial wastewater cross-connections. Other residential area sources (besides sanitary wastewater), such as inappropriate household toxicant disposal, automobile engine de-greasing, vehicle accident clean-up, and irrigation runoff from landscaped areas excessively treated with chemicals (fertilizers and pesticides) may also be considered in this most critical category.

Nuisance and aquatic life threatening pollutant sources can originate from residential areas and may include laundry wastes, landscaping irrigation runoff, automobile washing, construction site dewatering, and washing of ready-mix trucks. These pollutants can cause excessive algal growths, tastes and odors in downstream water supplies, offensive coarse solids and floatables, and highly colored, turbid or odorous waters.

Clean water discharged through stormwater outfalls can originate from natural springs feeding urban creeks that have been converted to storm drains, infiltrating groundwater, infiltrating domestic water from water line leaks, etc.

The proposed monitoring approach is separated into three phases:

- initial mapping effort
- initial field surveys
- confirmatory chemical analyses.

These three initial phases will be followed by detailed storm drainage and site investigations to identify specific pollutant contributors and control options, as appropriate.

An important requirement of the methodology is that an initial field screening effort would require minimal effort and would have little chance of missing a seriously contaminated outfall. This screening program would then be followed by a more in-depth analysis to more accurately determine the significance and source of the dry-weather pollutent discharges.

Mapping. The most important step in a cross-connection investigation is in preparing and studying drainage and land use maps. In addition to mapping, aerial photographs and general site investigations may be very useful. An important objective of the mapping activities would be to identify the locations of all of the stormwater outfalls. Finding the outfalls is not trivial. In the case studies examined, repeated trips typically uncovered additional outfalls that could not be located during earlier excursions. In Toronto (GLA 1983), for example, most outfalls were located during the first field trip, but two more trips were needed before all of the outfalls were located. Similarly, additional outfalls were periodically found that were not identified on the city storm drainage maps. It is very difficult for communities to maintain up-to-date mapping of drainage facilities.

Another important objective of the initial mapping activities is to outline the drainage areas discharging to the outfalls. These drainage maps should identify the predevelopment streams that may have been converted to storm drains (indicating the likelihood of natural uncontaminated baseflows) and the current and past land uses. Specific land use categories to be indicated should include commercial and industrial land uses (identified by Standard Industrial Categories, SIC), plus other activities that may contribute runoff problems (such as land fills). Any industrial activities having significant potential of contributing flows to the storm drainage system, as indicated by Triad's analyses, need to be specifically identified and located.

Initial field surveys. The initial field surveys are to be used as a screening effort: to identify the outfalls needing more detailed investigations which would identify pollutant sources and control options. These initial surveys would include physical and limited chemical evaluations of outfall conditions and would be conducted to minimize "false negatives" (outfalls actually having important discharges, but falsely classified as not needing further investigation).

Different flow and pollutant characteristics of the potential discharge sources can be used to identify and quantify cross-connection problems. The initial surveys to obtain this key information should be repeated at all outfalls over several seasons. Many of the dry-weather discharges are intermittent and may not be noted during any one investigation. Various physical characteristics

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near the outfall can provide evidence that inappropriate discharges periodically occur. However, repeated trips to the outfalls significantly increase the probability of identifying problem outfalls. It is also important to time outfall investigations during the times of day when possible activities may be contributing cross-connection discharges.

It is difficult to develop a procedure that will separate the outfalls into clear "problem" and "no problem" categories. In some of the case studies investigated, only correcting problems at the most critical outfalls resulted in insufficient receiving water quality improvements. It may be important to eventually correct all cross-connection problems throughout a city, not just the most severe problems. This screening procedure should therefore be considered as just an initial effort that needs to be followed-up with more detailed confirmatory investigations at the outfalls and receiving water monitoring to document improvements after different stages of the control program.

Candidate parameters. Many different analytical methods are being evaluated as part of this project. The initial screening effort should include the following:

- placement of outfall identification number;
- outfall discharge flow estimate;
- floatables, coarse solids, color, oil sheen, and odor characteristics of water;
- other outfall area characteristics, such as stains, debris, damage to concrete, corrosion, unusual plant growth, or absence of plants;
- water temperature;
- conductivity;
- fluoride concentration;
- ammonia and/or potassium concentrations; and
- surfactant concentration.

These characteristics can be relatively easy to obtain at the outfall location, depending on the needed detection limits for the chemical analyses and potential interferences. The selection of the procedures to use to obtain the tracer concentrations will depend on many conditions, most notably the expected tracer concentrations in the uncontaminated base flows and in the potential cross-connection source flows, along with the needed probabilities of detection at the minimum contamination level. A description of the techniques being developed as part of this study to help in the selection of the analytical procedures is given later in this paper. Other factors affecting procedure selection include ease of use, analytical interferences, cost of

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equipment, training requirements, and time requirements to conduct the analyses.

Simple outfall estimates of discharge, and noting the presence of oil sheens, floatables, coarse solids, color, odors, etc. will probably be the most useful indicators of outfall problems. These observations will need to be repeated several times, especially if non-continuous discharges are likely. The presence of stains and structural damage will greatly assist in identifying significant non-continuous discharges, in addition to continuous discharges.

Notably absent from the above list are pH and dissolved oxygen. These have been included in several previous cross-connection studies, but with limited value. These two parameters have not been found to be extremely useful in identifying or categorizing cross-connection sources. However, in areas having known industrial sources, pH may be an important parameter that would have to be added to this list.

Specific conductance and temperature can be quickly and easily measured using a dual dedicated meter. Water color can be quantified using a comparative colorimetric meter or spectrophotometer in the field.

Fluorides can be detected using a variety of methods in the field, including field colorimetric kits having detection limits of less than 0.15 mg/L. This detection limit may not be sufficient to detect low dilutions of contaminants with adequate precision. Dedicated specific ion meters for fluorides are available having very low detection limits (2 ug/L) that would be quite capable of detecting very small dilutions. Neither of these methods are "direct reading" and require some time at the site to conduct the analysis and/or calibrate the meter.

Ammonium forms of nitrogen can be measured in the field using indicator paper, with detection limits of about 10 mg/L. Field colorimetric kits having detection limits of about 0.1 mg/L are available for total ammonia. Ion selective electrodes can be used in the field, with detection limits of about 0.01 mg/L for ammonia. Only the indicator paper method is a direct measurement procedure, but it probably does not have a low enough detection limit to permit the detect of low dilutions of cross-connection contaminants. The other methods require some sample preparation, but would be much more useful.

Potassium can be measured in the field using ion selective electrodes having detection limits as low as 0.01 mg/L. Portable spectrophotometers can also be used,

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with detection limits of about 0.1 mg/L. Either of these methods can be useful in a cross-connection study.

Detergents (or surfactants) can be detected in the field using a comparative colorimetric method (having a detection limit of 50 ug/L) or with a recently developed auto titration method having very few interferences and much lower detection limits.

In addition, the following optional characteristics may also be obtained at each outfall, depending on probable pollutant sources:

- o hardness;
- o toxicity screening; and
- o specific metals.

Hardness can be easily determined in the field using field titrimetric kits or even indicator papers, with varying sensitivities and interferences. Toxicity screening tests require laboratory analyses and some can be conducted in several hours. The toxicity tests would be useful in areas known to have commercial or industrial activities. Some individual metals (especially copper and chromium) could also be used in areas having these land uses. In most cases, it will probably be necessary to conduct a variety of carefully selected tests because of the large number of potential pollutant sources that probably occur in most drainage areas.

This scheme should allow an efficient determination of the general category (toxic/pathogenic, nuisance, or uncontaminated) of the water being discharged. In many cases, fluorides can be used to separate untreated water from treated water sources. Untreated water sources may include discharges from natural waters or untreated industrial waters. If the treated water has no fluoride added, or if the natural water has fluoride concentrations close to treated water fluoride concentrations, then fluoride may not be an appropriate indicator. Hardness can be used as an indicator if the clean water source is likely groundwater, while the treated water source is from surface supplies. Specific major ions could also be used to separate groundwater and surface water sources. Specific conductance may also serve as a rough indicator of major water source.

Water from treated water supplies (that test positive for fluorides, or other suitable tracer) can be relatively uncontaminated (domestic water line leakage or irrigation runoff), or it may be heavily contaminated. In areas having no industrial or commercial sources, sanitary wastewater is probably the

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most important cross-connection source. Surfactants may be useful in determining the presence of sanitary wastewaters. However, surfactants in water from treated water sources could indicate sanitary wastewaters, laundry wastes, car washing water, or other waters having detergents. Fabric whiteners (as measured by fluorescence using a fluorimeter in the laboratory or in the field) may also be a useful test for laundry and sanitary wastes.

If the surfactants were not present, then the treated water could be relatively uncontaminated (such as from domestic water line leaks or irrigation runoff), or it may be from rinsing ready-mix trucks or other rinsing activities (such as accident scenes). Sanitary wastewater would have the most consistent characteristics (volume and characteristic) compared to most of the other potential sources. Ammonia (or ammonium) nitrogen and potassium have been studied in several previous studies as an indicator of sanitery wastewaters. If the surfactant concentrations were high, but the ammonia and potassium concentrations were low, then the cross-connection contamination is likely laundry water. If they were all high, then sanitary wastewater is the likely source. Obviously, odor and other physical appearances (such as turbidity, foaming, color, and temperature) would also be very useful in separating major sanitary wastewater flows from rinse water or laundry water sources.

Toxicity screening methods would be very useful in areas known to have commercial or industrial activity, or to check for intermittent residential area discharges of toxicants.

Several confirmatory outfall analyses could be conducted to verify the more significant sources of cross-connection waters. These analyses require highly trained personnel and specialized equipment that would not be available in most laboratories. It may not be feasible to analyze samples from each of several hundreds of outfalls several times a year for these materials. These analyses can be very useful to check for false negatives and for more specific results on a random basis. These confirmatory analyses may include:

- o trihalomethanes
- o specific bacteria
- o coprostanol

Trihalomethanes (THMs) are formed when chlorine reacts with certain natural organics present in waters. The detection of these compounds in groundwaters has been used as a positive indication of treated city water

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leakage (Hargesheimer 1985). Chloroform and dichlorobromethane are the THMs most frequently used because of their very low detection limits and specific indicators of treated domestic water.

Bacteria are usually poor indicators of the source of cross-connection water. Past use of fecal strep. to fecal coliform ratios to indicate human versus nonhuman bacteria sources in mixed and old wastewaters (such as most nonpoint waters) has not been very successful. There may be some value in investigating specific bacteria types, such as fecal strep. biotypes, but much care needs to be taken in the analysis and interpretation of the results. A more certain indicator of human wastes may be the use of certain human-specific molecular markers, specifically the linear alkylbenzenes and fecal sterols, such as coprostanol and epicoprostanol (Eganhouse, et al. 1988).

Detailed outfall analyses. After the initial outfall surveys indicate the presence of serious contamination, additional pollutants associated with local commercial and industrial activities need to be monitored. This monitoring will assist in identifying the classes of commercial or industrial activities responsible for the contamination.

Watershed analyses to locate specific sources. In order to identify the specific contaminant sources in the drainage system, further detailed analyses are needed. These may include:

- drainage system surveys (tests for specific pollutants, visual inspections, and smoke and dye tests)
- in-depth watershed evaluation (including aerial photographs)
- industrial and commercial site studies

Follow-up Site Investigations. Further drainage area investigations upstream of the outfall would be conducted after the outfall studies have indicated dry-weather discharge problems. These would include drainage system and industrial and commercial site studies (such as dye and smoke studies) to locate specific cross-connections. Additionally, aerial photography can be very useful during later phases of cross-connection control projects. As an example, aerial photography can be very useful in identifying areas having failing septic systems located in residential areas served by storm drainage systems. Aerial photography can also be used to identify continuous discharges to surface drainages, such as sump discharges, and to identify

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storage areas that may be contributing significant amounts of pollutants during rains.

<u>Additional Project Activities</u>

In order to identify potential cross-connection sources, it is necessary to have a certain knowledge about each potential source flow component. Specifically, the probable range of concentrations of the alternative tracers in each flow component (including the "clean" background) is needed. As noted above, the watershed survey to identify the presence of specific industrial and commercial activities is crucial.

This project is therefore collecting typical quality data for different cross-connection sources as a guide in helping to design the initial field investigations. Obviously, local information for potential flow sources will be needed. The variations of the characteristics is especially needed in order to select the field procedures needed. Statistical tests are being used in conjunction with the potential cross-connection source concentration information and the capabilities of existing relatively simple tests to help in the selection of the appropriate field and laboratory tests.

Monte Carlo tests (using the microcomputer program PRISM, version 2.01, from Palisade Corporation, Newfield, NY) are being used to examine the sensitivity of different analyses in identifying and quantifying different mixtures of cross-connections. Typical situations representing a broad range of potential runoff mixtures are being examined to identify the most robust analytical methodology. As an example, the concentration variations of individual components can be used to select the required minimum detection limit of the analytical method in order to determine the mixing portion of two sources.

In Figure 1, it is assumed that an uncontaminated component has a 10 to 90 percentile concentration range of 1 to 50 ug/L for a specific tracer and a contaminating component has a comparable concentration range of 10 to 500 ug/L for the same tracer. If a detection probability of at least 90 percent was needed for a contamination percentage of 10 percent, the Monte Carlo tests indicate that a methodology detection limit of at least 5 ug/L would be needed. If the detection limit was only 25 ug/L, the probability of detection of this mixture would be only about 55 percent. Many additional figures are currently being prepared to assist in the selection of detection limits, for a wide variety of concentration ranges and mixing ratios.

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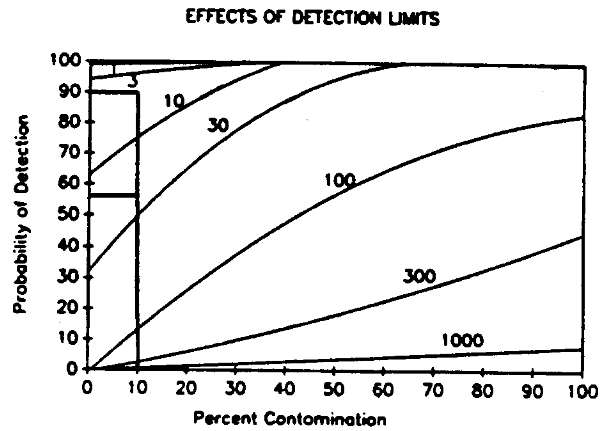

Figure 1. Effects of Detection Limits on Probability of Detection

The continuation of this project will involve field investigations to test the procedures and candidate equipment, and revisions to the draft manual.

Conclusions

Many urban runoff projects have found that dry-weather discharges from stormwater outfalls can contribute significant pollutant loadings. Ignoring these loadings can lead to improper conclusions concerning stormwater control requirements.

Municipalities that have recognized the importance of dry-weather flows have investigated their sources using various methods. Unfortunately, most municipalities have very large numbers of outfalls and an efficient method is needed to separate the outfalls creating the most severe problems. This project is examining three categories of outfalls: pathogenic/toxicant, nuisance and aquatic life threatening, and clean water. The most important category is for outfalls contributing pathogens or toxicants. These are most likely originating from sanitary wastewater or industrial cross-connections. An initial screening analysis at all outfalls should have a high probability of identifying all outfalls in this category.

The first step of this procedure is an extensive mapping effort to identify the locations of all outfalls for sampling and to outline the drainage areas contributing to each outfall. The screening analyses at the outfalls include several visual measures (color, turbidity, oil sheens, floatables, coarse solids, etc.) along with measurements for fluorides and surfactants. Fluorides can be used to indicate if the water originated as treated domestic water (instead of infiltrating untreated groundwater). This may indicate sanitary sewage cross-connections or other waste waters. Surfactants can help in identifying sanitary sewage connections, in contrast to landscaping irrigation runoff or rinse waters, or industrial waters. The drainage area maps need to be studied to determine the presence of potential industrial or commercial cross-connection sources.

More sophisticated analyses are available to confirm the potential sources, but they most likely cannot be employed for all outfall samples because of the required highly skilled analysts and expensive equipment.

Future project phases will evaluate these outfall procedures in test conditions and will result in manual refinements. Procedures to identify and correct specific cross-connections will also be summarized in these future project phases.

Acknowledgements

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A "LIVING MASTER PLAN" FOR COMBINED SEWER SYSTEMS

by Larry A. Roesner, F. ASCE[1], John A. Aldrich, A.M. ASCE[2], and Edward H. Burgess, M. ASCE[3]

INTRODUCTION

Cincinnati, Ohio, celebrated its bicentennial in 1988. Like many of the nation's older and well-established cities, Cincinnati is coping with problems of infrastructure stressed beyond capacity. Chronic flooding occurs in some areas where trunk sewers have insufficient capacity or adequate drainage facilities are not provided. Deteriorated sanitary sewers are overloaded by infiltration and inflow. The combined sewer system that serves much of Cincinnati often overflows during storms, washing pollutants into local waterways.

To solve these wastewater and drainage problems, the City of Cincinnati StormWater Management Utility and the Metropolitan Sewer District of Greater Cincinnati have joined forces to develop a Stormwater Wastewater Integrated Management (SWIM) Master Plan with a 100-year planning horizon. The major objectives of the master plan are:

- To eliminate flooding caused by backups from sewers
- To eliminate all discharges of untreated wastewater into waters of the State
- To develop an operations and construction coordination program
- To eliminate building moratoriums due to sewer problems
- To develop a comprehensive drainage and flood-control system for the City of Cincinnati
- To develop a 100-year stormwater and wastewater master plan to protect and enhance the quality of life in Cincinnati and Hamilton County

Based upon these objectives, the SWIM Master Plan Program is designed to accomplish three primary goals:

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- A Wastewater Master Plan, which will provide adequate conveyance and treatment facilities for projected future wastewater flows and/or reduce or convey excessive infiltration/inflow (I/I) which enters the sewerage system;
- A Stormwater Master Plan, which will safely manage flooding caused by backups of the storm drainage system within the City of Cincinnati; and
- A Combined Sewer Overflow Master Plan, which will adequately control combined sewer overflows (CSOs) during high-river stages and rainfall events.

It is unclear at the present time what level of control will ultimately be required for CSOs. For this reason, a key element of the CSO-control plan is to develop a "building block" approach, which will allow sequential construction of facilities to achieve increasingly higher levels of control as the need for these facilities is demonstrated based upon monitoring and analysis of receiving water. Thus, the plan is a "living plan," providing a road map that identifies the location and type of facilities that are to be constructed but not specifying the ultimate size of those facilities. However, space is reserved to build facilities that will control the one-year storm in case that level of control is finally required in any given area.

For the purposes of the SWIM Program, the study area, which comprises the 414-square-mile area of Hamilton County, Ohio, was divided into nine major drainage areas. This paper describes how this approach to master-planning is being applied in one of these, the Duck Creek Drainage Area (3).

PHYSICAL SETTING

The Duck Creek Drainage Area is located in the southeast quadrant of Hamilton County in southwestern Ohio adjacent to the Ohio River and immediately west of the Little Miami River (Figure 1). The Ohio River is a large, muddy, fast-flowing tributary to the Mississippi River. The drainage area of the Ohio River at Cincinnati is 76,580 square miles (198,257 square kilometers). The Little Miami River, to the east of the drainage area, has a watershed of 1,757 square miles (4,549 square kilometers) and has been classified as a Scenic River over much of its length, including the portions adjacent to the Duck Creek Drainage Area. About 5,100 acres (2,070 hectares) of the total of 17,581 acres (7,115 hectares) in the drainage area drain to these two major rivers, while the remaining 70 percent is drained by Duck Creek and its tributaries.

Over 80 percent of the drainage area is sewered, with combined sewers comprising 60 percent of the sewered area and separate sewers comprising 40 percent of the sewered area. More than half of the sewers were built before 1940, and both structural and hydraulic deficiencies have been reported. Figure 2 show the areas served by combined sewers and by separate sewers. It also shows the eighteen watersheds into which the drainage area was divided for the purposes of this study.

The interceptor sewer system, which is shown on **Figure 3**, diverts dry-weather sanitary flows and a portion of the wet-weather flow to the Little Miami WWTP. Wastewater flows from the remainder of the drainage area are intercepted by the Delta Avenue Pump Station, located along the Ohio River. The existing capacity of this pump station, which pumps flows into the Little Miami WWTP, is 9,000 gallons per minute (570 liters per second).

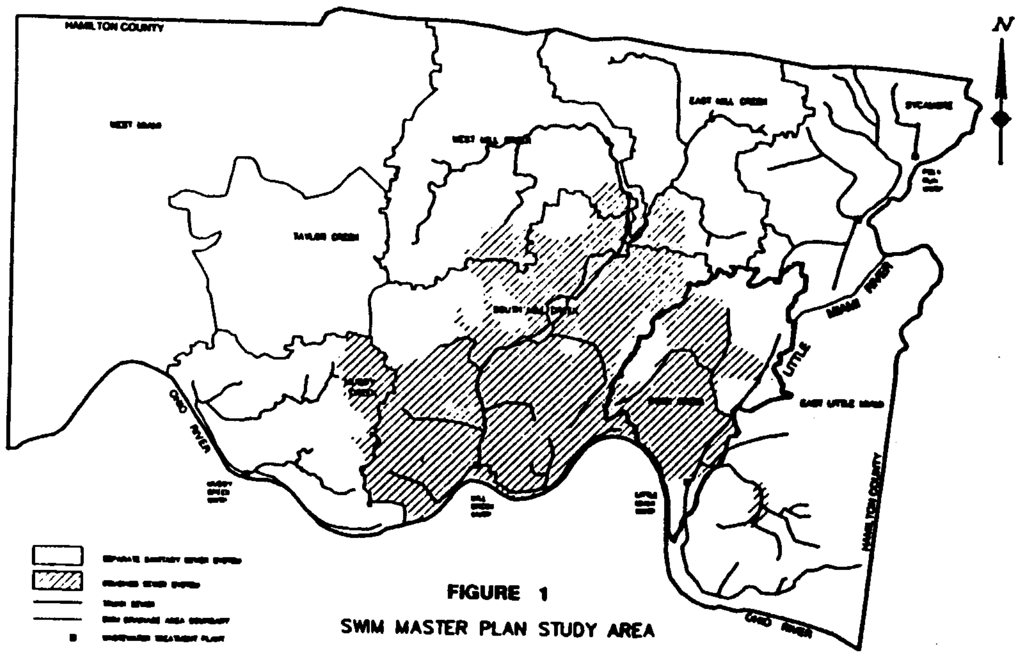
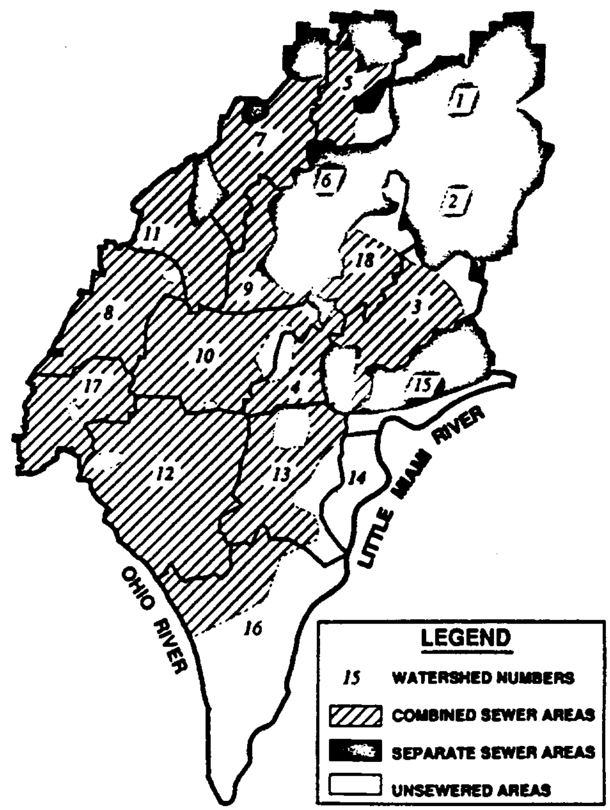
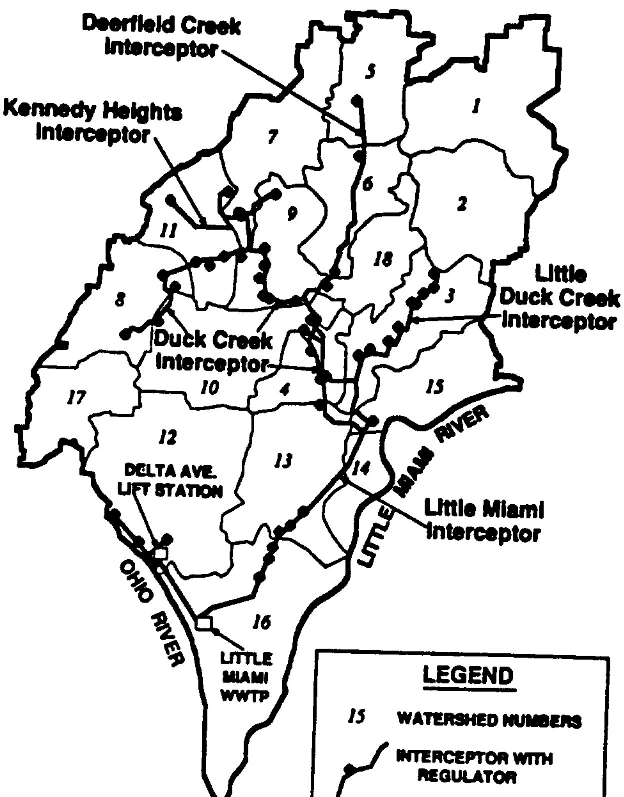


FIGURE 1
SWIM MASTER PLAN STUDY AREA



WATERSHEDS AND SEWERED AREAS IN DUCK CREEK DRAINAGE AREA | FIGURE 2



COMBINED SEWER INTERCEPTOR SYSTEM IN DUCK CREEK DRAINAGE AREA	FIGURE 3

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The combined sewer interceptor system in the Duck Creek Drainage Area contains 52 regulators. A regulator is defined as any structure which diverts dry-weather wastewater flows from combined sewers into interceptor sewers. Virtually all of these regulators are static regulators, typically consisting of a grate with a drop inlet (with or without a diversion dam) and containing no moving parts. Figure 3 also shows the location of the regulators in the Duck Creek Drainage Area.

The Duck Creek Drainage Area comprises about 20 percent of the City of Cincinnati, plus all or part of seven other communities. The drainage area is about two-thirds residential, one-fourth open (parks, public land, and steeply sloped areas), and less than 10 percent commercial/industrial. Less than 5 percent of the drainage area is available for new development, and population/employment/dwelling unit projections call for negligible growth over the 100-year planning horizon (2).

RECOMMENDED STORMWATER CONVEYANCE IMPROVEMENTS

Analysis of the storm drainage system consisted of applying the RUNOFF module of the USEPA StormWater Management Model (SWMM) (5) to all storm drainage pipes and channels greater than or equal to 36-inch (0.91 meters) equivalent diameter. This included separate storm drains as well as combined sewer trunks. The objectives of this analysis were:

- Ensure that the trunk sewer can convey runoff from the 2-year storm; where possible, develop facility plans to provide 10-year protection.
- For all new development (or re-development), require runoff controls so that post-development runoff peaks do not exceed pre-development peaks for the 1-, 2-, 5-, and 10-year storms.
- For stormwater quality management, use CSO-control facilities in combined sewer areas and regional facilities in separate sewered areas.

Improvements to stormwater management facilities were proposed to provide adequate drainage for nearly 100 locations. These improvements address both local drainage problems identified by the SWIM team and conveyance problems discovered during simulation of 10-year design storms.

Near-surface storage facilities were generally determined to be more cost-effective for controling severe instances of flooding than replacing existing pipes with larger pipes. Nineteen near-surface storage facilities of various sizes were recommended to detain peak flows during 10-year flooding events. Where adequate sites for near-surface storage facilities were not available, replacement or relief sewers were recommended. The analysis showed that about 4.5 miles (7.2 kilometers) of storm/combined sewer needed to be either replaced or relieved depending on the structural integrity of the existing sewer and constructability problems along the alignment of the existing sewer.

Many of the problems identified by the SWIM team involved surface flooding in areas which are not currently served by storm sewers. Control measures were designed to resolve each of these problems; most of these measures can be implemented immediately (within the available funding levels of the City), while a few measures will significantly increase the volume of CSOs and should not be implemented until CSO control measures adequate to prevent increases in CSOs are in place.

ANALYSIS OF THE LITTLE MIAMI WASTEWATER TREATMENT PLANT

The Little Miami Wastewater Treatment Plant (WWTP) has an average daily secondary treatment capacity of about 36 million gallons per day (mgd, or 1.6 cubic meters per second, m^3/s) and a hydraulic capacity of 96 mgd (4.2 m^3/s). About 66 percent of its average dry-weather flow comes from the Duck Creek Drainage Area, which is predominantly served by combined sewers. The remainder of the flow is generated within the East Little Miami Drainage Area, to the east, which is predominantly served by separate sewers. The WWTP receives an existing average daily dry-weather flow of 25 mgd (1.1 m^3/s), which represents 70 percent of secondary capacity, and an existing dry-weather peak flow of 40 mgd (1.8 m^3/s), which exceeds the plant's secondary capacity by 11 percent. Flow projections for the year 2010 indicate that the average daily dry-weather flow will reach 35 mgd (1.5 m^3/s), representing 97 percent of the plant's secondary capacity. The estimated peak dry-weather flow in 2010, is 56 mgd (2.5 m^3/s), 155 percent of secondary treatment capacity. Therefore, about 20 mgd (0.9 m^3/s) of additional treatment capacity will be required at the Little Miami WWTP by 2010 to enable it to handle projected peak daily dry-weather flows.

Additional treatment capacity is required at the Little Miami WWTP to handle wet-weather flows. Currently, there is only about 11 mgd (0.5 m^3/s) of wet-weather capacity at the plant, which is well below the capacity of the interceptor to convey wet-weather flows to the plant; thus, CSOs are expected to occur at the plant virtually every time it rains. There is no projected wet-weather capacity at the plant by 2010.

ESTIMATE OF COMBINED SEWER OVERFLOWS

Estimates of combined sewer overflow frequency, volume, and pollutant loads were performed with the Storage, Treatment, Overflow, Runoff Model (STORM) (6), based on the hydraulic performance of the combined sewer interceptor and regulator system. STORM continuously simulates overflow quantity and quality, using surface runoff and land-use/pollutant relationships. About forty years of hourly rainfall data from the Greater Cincinnati International Airport were continuously simulated with STORM to determine average annual CSO statistics.

Overflow quantities are calculated from the interaction between the in-system storage capacity, the interceptor transport capacities of the sewer network, and the volume of runoff entering the system. Interceptor capacities were determined from simulations of the hydraulic performance of the combined sewer interceptor system using the EXTRAN model of SWMM (7), as discussed below.

A lumped rational formula coefficient of 0.5 was applied for each watershed; average evaporation of 0.1 inches (2.5 milimeters) per day was used, and surface depression storage was set at 0.06 inches(1.5 mm). A volume of 0.04 inches (1.0 mm) represents the approximate existing capacity available for storage of wet-weather flows in the combined sewer system.

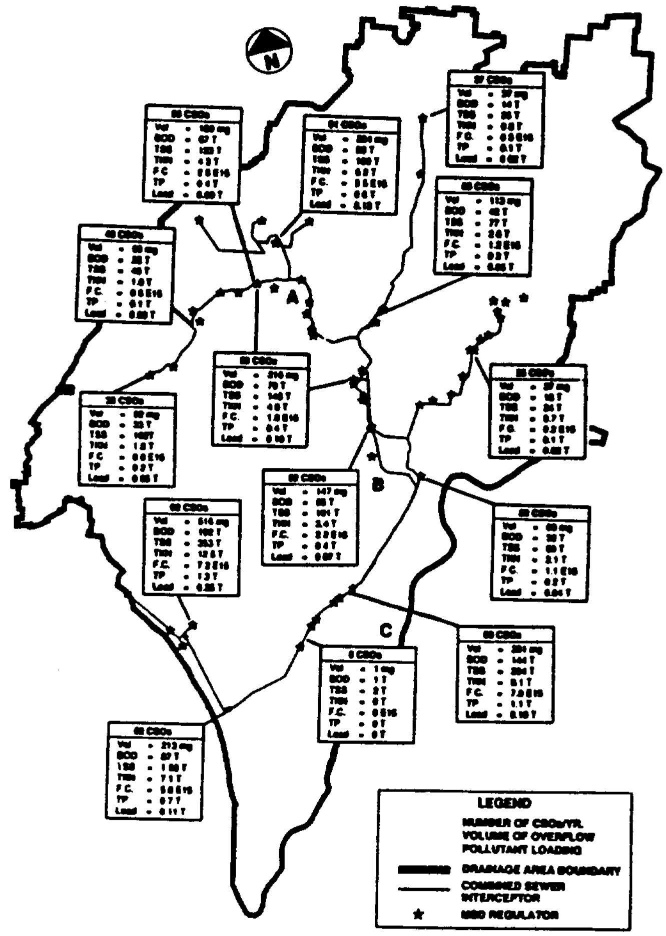
Existing overflow volumes can be projected based on unit treatment rates (expressed in cfs per acre or inches per hour) determined from hydraulic simulations with the SWMM-EXTRAN model. The hydraulic simulation defines the interceptor capacity, indicates the locations of CSOs where interceptor capacity is less than regulator capacity, and locates portions of the interceptor where additional capacity is available. Therefore, this procedure pinpoints wet-weather hydraulic deficiencies--those points where an interceptor is incapable of conveying flows contributed by regulators, thus causing an overflow.

In general, the capacity of the combined sewer interceptor system is significantly less than the total capacity of the regulators. The combined sewer interceptor system has sufficient capacity for existing and projected future dry-weather flows. However, during wet-weather conditions, the interceptor can only capture the runoff from rainfalls of between 0.02 and 0.05 in/hr (0.5 to 1.3 mm/hr). For larger rainfall events, interceptor surcharging prevents flow captured by the regulators from entering the interceptor. CSOs resulting from insufficient interceptor capacity occur throughout the system but are most pronounced along the lower reaches of the interceptor, where the capacity decreases as the interceptor slope flattens along the Little Miami River floodplain. These CSOs are particularly serious since they flow into the Little Miami, which has been designed a Scenic River by the State of Ohio and is therefore subject to stricter water-quality standards.

The CSO frequency and annual overflow volume projections developed with STORM can be applied to determine the severity of CSOs resulting from surcharging and flooding of the interceptor. Dry-weather flows in the interceptor are subtracted from the maximum hydraulic capacity of the interceptor segment which flows out of each watershed to determine the wet-weather capacity of the interceptor and/or the regulators. Figure 4 indicates the average annual overflow frequency, volume, and pollutant loads at key locations along the interceptor system. Based on interceptor capacity, an average of about 50 to 60 overflows per year occur in the Duck Creek Drainage Area. Insufficient interceptor capacity results in approximately twice the number of overflows as are caused by insufficient regulator capacity.

CSOs cause the greatest impacts where high pollutant loads enter into small streams. This is most pronounced at the outlets of the combined sewers draining Watersheds 7, 8, and 17, (shown as the area upstream of A on Figure 4) where about 25% of the total CSO pollution from the Duck Creek drainage area enters the most upstream portion of the free-flowing Duck Creek. In addition, almost all the CSO pollution in lower Duck Creek enters upstream of B on Figure 4; this location is near a residential area which includes parks where water contact occurs. CSO loadings to other tributary streams are not as high but are still of concern due to the close proximity of these CSOs to residential neighborhoods.

Other CSOs enter larger streams but are of equal concern. For example, about a 1-3/4-mile (2.8 km) stretch of the Little Miami River near the confluence with Duck Creek (shown as C on Figure 4) is contaminated by the CSOs which occur at the diversion structure located at the junction of the Duck Creek and Little Duck Creek interceptors. Water-quality impacts from CSOs into the Ohio River at the Delta Avenue Pump Station and the Little Miami WWTP (both located in the southern portion of the drainage area, constitute about 30% of the total CSO pollution load generated in the Duck Creek Drainage Area but are somewhat less serious than those in the rest of the drainage area because of the higher assimilative capacity of the Ohio River. In the Ohio, the most serious water-quality problem is coliform pollution due to potential public health impacts on near-shore recreation and water contact while boating.



Annual Overflow Frequency, Volume, and Pollutant Loads at Key Locations | Figure 4

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DETAILED EVALUATION OF CSO CONTROL ALTERNATIVES

A detailed evaluation of alternatives for abatement of CSOs in the Duck Creek Drainage Area was performed. Wastewater facility improvements as described below focused on expansion of the Little Miami WWTP to handle projected increases in dry-weather flows and to provide treatment for wet-weather flows captured by various CSO control alternatives. Several CSO abatement alternatives were then sized to provide various levels of control based on the recommended WWTP expansion. The alternatives are listed below; the following sections discuss first the WWTP expansion and then each of the alternatives in turn.

A. **Combined Interceptor System Optimization** — Limited adjustments and/or replacements of regulators, overflows, manholes, and sewer segments, yielding relatively inexpensive methods to significantly reduce CSOs;

B. **Distributed Storage/Treatment Within Sub-Areas** — Storage/treatment facilities (in-line or off-line) sited within most sub-areas of the combined sewer system;

C. **Regional Storage/Treatment Facilities** — Larger storage/treatment facilities serving one or more watersheds in conjunction with regulator improvements and/or consolidation sewers upstream of the regional facility;

D. **Deep Tunnel** — Storage provided by a hard-rock tunnel about 200 to 300 feet underground, which is emptied after the storm by pumping into the interceptor system; and

E. **Sanitary/Storm Sewer Separation** — Installation of separate sewer systems to reduce the contributions of stormwater to the combined sewer system.

REQUIRED IMPROVEMENTS AT THE LITTLE MIAMI WWTP

Peak dry-weather flows at the Little Miami WWTP are expected to exceed plant capacity by 20 mgd (0.9 m^3/s) by 2010, as discussed above. In addition, treatment capacity is required for wet-weather flows captured by all CSO control methods other than sewer separation. The STORM model was used to explore trade-offs between treatment and storage requirements. In general, secondary treatment costs (both capital and operations/maintenance) are significantly higher than storage costs, and thus maximizing storage is preferable. Storage must be supplemented with enough treatment capacity to ensure that space will be made available to store flows from subsequent rain events.

Based on rainfall statistics and STORM simulations, storage facilities designed to capture the one-year storm (*i.e.*, a CSO frequency of one per year) must be completely drained within four days to provide sufficient storage for subsequent events and to prevent anaerobic conditions within the storage facility. STORM simulations showed that a wet-weather treatment rate of about 0.01 in/hr (0.25 mm/hr) coupled with a total of about 0.96 inches (24.4 mm) of storage would capture the one-year storm and be emptied in the recommended four days. For the Little Miami WWTP, this translates to a wet-weather treatment rate of 54 mgd (2.4 m^3/s) coupled with a total storage volume within the Duck Creek Drainage Area of 210 million gallons (800,000 m^3). An additional 35 mgd (1.5 m^3/s) is required to treat the average dry-weather flow predicted for 2010, bringing total required expansion to 89 mgd (3.9 m^3/s).

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Expansion of the Little Miami WWTP is included as an integral part of all other CSO control alternatives discussed in the following sections.

SMALL SCALE CSO CONTROL MEASURES

Combined sewers are less extensive in areas of Watersheds 8 and 11. In Watershed 11, stormwater runoff from over half the watershed is contaminated by CSOs which are produced within a combined sewer area of less than 50 acres (20 hectares). Separation of a few combined sewers and construction of a small storage facility in Watershed 11 will eliminate CSO contamination of stormwater runoff which otherwise must be treated with regional CSO control measures.

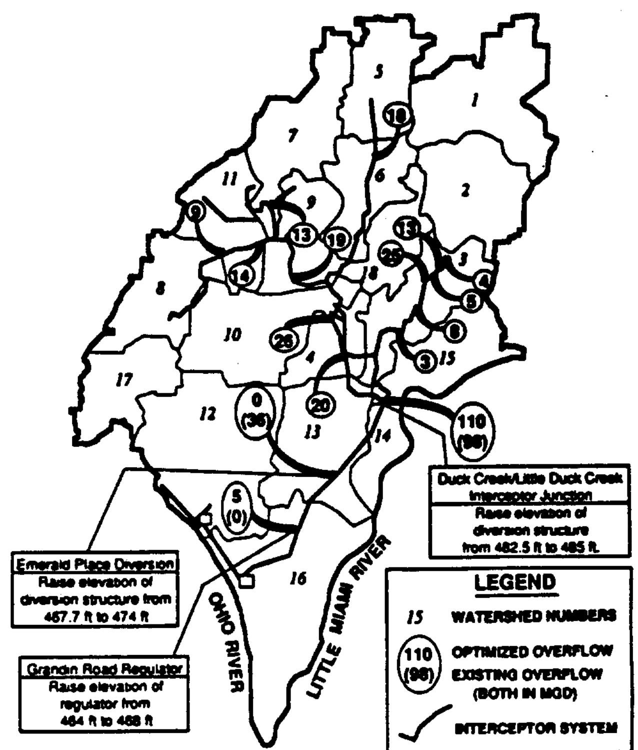
In Watershed 8, numerous connections of sanitary sewers to storm sewers exist. The Master Plan recommends that dry-weather flows from these sanitary connections be intercepted and CSO control facilities be provided for the wet-weather flows. CSO control in this watershed is provided partially by converting a large box-culvert system into a CSO consolidation sewer. This culvert system can be used as an in-line storage device to provide control in the short term and can be integrated into a long-term CSO control plan.

Alternative A: Combined Sewer Interceptor/Regulator Optimization to Reduce Wet-Weather CSOs

As described earlier, the overall performance of the existing combined sewer interceptor system in the Duck Creek Drainage Area is limited during wet-weather conditions by low overflow elevations at key regulators. Alternative A provides for raising of overflow elevations of regulators which obviously limit interceptor system performance to increase the driving head through the system. Figure 5 shows sites where reductions in interceptor overflow rates would be achieved if the following system optimization measures are implemented (shown in boxes on Figure 5):

- Junction of Duck Creek/Little Duck Creek interceptors: The high-level overflow weir located adjacent to the existing sluice gate on the old Duck Creek interceptor outfall can be raised by about 5 feet (1.5 meters) without major modification to the existing diversion structure.
- Emerald Place diversion: Permanently closing this gate will serve to prevent any overflows at this location. Maintenance measures needed to ensure that the gate is properly sealed should be performed. No capital costs are envisioned.
- Grandin Road regulator: This regulator can be relocated upstream in the combined sewer, and the diversion dam can be raised to achieve an overflow elevation of 468.0 feet (142.6 meters). The estimated capital cost of this improvement is less than $50,000.

In general, system optimization results in a 20 percent to 40 percent increase in conveyance in the Little Miami Interceptor. Optimizing interceptor conveyance reduces overall Duck Creek Drainage Area overflows from an average of about 60 per year to about 55 per year, except at the Little Miami WWTP. Across the drainage area, CSO volume and pollutant loads are only reduced about 2 percent under the system optimization scheme. However, it is important to note that about 7 percent of the total CSO volume and pollutant loads generated within the drainage area are diverted from the environmentally sensitive Little Miami River into the Ohio River, which possesses a greater assimilative capacity. In addition, overflows would occur at the Little Miami



COMBINED SEWER OPTIMIZATION ALTERNATIVE IN DUCK CREEK DRAINAGE AREA — FIGURE 5

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WWTP, where it is more efficient to screen, disinfect, or provide primary treatment for CSOs.

In summary, optimizing the existing Duck Creek Interceptor system increases conveyance between 20% and 40%, but such an improvement is not sufficient by itself to reduce CSOs to 1, 3, 6, or 12 per year. However, in conjunction with alternatives for combined sewer storage and/or local interceptor replacement, modification of specific regulators could lower the overall cost to reduce overflow events. In addition, short-term benefits achieved by optimization is the baseline CSO control level under the U.S.EPA CSO-control strategy. Therefore, system optimization is used here as the baseline for evaluation of other CSO control schemes.

Alternative B: Distributed Storage/Treatment Within Sub-Areas

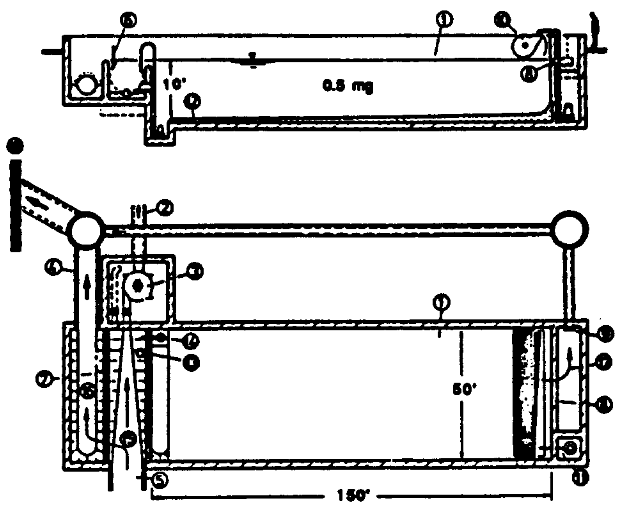
Small storage/treatment facilities can be distributed throughout the drainage area to hold "first-flush" wet-weather flows until after the rainfall has ceased. Such facilities usually are placed at a combined sewer regulator and/or at the outlet of a 20- to 200-acre (8- to 81-hectare) sub-area of the combined sewer service area. The storage volume required to reduce the frequency of CSOs within each watershed was determined from the STORM simulations, based on the existing wet-weather capacity of the interceptor segment flowing out of each watershed.

Figure 6 presents the conceptual design of a 0.5-mg (1,900 m^3) storage/-sedimentation facility typical of those being implemented in West Germany for CSO control (1) and which is recommended for installation in Cincinnati. Among the unique aspects of this facility which make it ideal for CSO control are that it:

- Captures the "first flush": The facility uses a vortex regulator to capture the portion of the first flush in excess of the interceptor capacity. Following the rainfall event, the pollutants captured are bled back into the interceptor for secondary treatment at the WWTP.
- Provides sedimentation: The dimensions of the facility are established to promote settling at the design hydraulic loading rate.
- Bypasses less frequent large storms: Storm flows in excess of the design capacity are bypassed from the facility, preventing re-suspension of solids captured in the first flush.
- Requires low maintenance: The facility is designed to be self-cleaning, reducing the maintenance required after a storm event.

Providing distributed storage facilities within sub-areas reduces CSO frequency volumes, and pollutant loads sufficiently to achieve the goals of the CSO-control plan. However, this approach has several major disadvantages:

- A large number of facilities is required, over 400 in Duck Creek alone. The unit cost for each facility is higher than for other types of facilities since no economies of scale are realized.
- Many of these facilities would need to be located in residential neighborhoods. Resulting site limitations would restrict construction of many facilities to existing roadway right-of-ways or would result in construction problems (utility interference, traffic disruptions, pavement removal/replacement, etc.) which would in all probability lead to increases in construction costs above those mentioned in the previous sub-section.



1 settling tank
2 outlet to plant
3 flow control, vortex valve
4 bypass
5 incoming combined sewer
6 scum-board
7 storm overflow
8 clarifier overflow
9 clarifier orifice
10 tipping flusher
11 flushing water tank
12 flush way
13 check valve
14 pump
15 dry-weather-flow
16 storm runoff
17 clarified storm runoff
18 receiving water

Figure 6

TYPICAL STORAGE FACILITY "TANK"
(FROM BROMBACH, 1989)

- Operational problems would be distributed throughout the drainage area rather than being concentrated in a few areas. Among these are the impact of odors on residential neighborhoods and of corrosive sewage stored in these facilities. In addition, all facilities would operate during every rainfall event and potentially could require maintenance once or twice during an event. Also, access to facilities would probably be within roadway right-of-ways, potentially causing traffic disruption.

Alternative C: Regional Storage/Treatment Facilities

Regional storage facilities have distinct advantages where space is available. A typical regional facility is shown in **Figure 7**. The regional storage facility is essentially a set of distributed storage facilities grouped at a single location where space is available, a large drainage area is served, and few consolidation sewers are required to convey flow to the facility. Regional facilities are preferred over distributed storage because the former provide several advantages:

- Economies of scale will reduce construction and operations and maintenance (O & M) costs.
- Sites can be selected which minimize disruption to the community.
- Multiple-use opportunities are greater.
- Storms smaller than the design capacity can be captured in a few of the available tanks, minimizing O & M effort for frequent storms.
- Facility operation can be varied to facilitate O & M activities. For example, some tanks can be taken out of service for repair without decreasing the capture efficiency of the facility for all events except those at or near the design capacity.

In the Duck Creek Drainage Area, sites were selected for regional storage based on considerations such as the availability of vacant and/or under-utilized land or land in an industrial/commercial area, or the possibility of locating a site near combined sewer regulators and/or bottlenecks in the interceptor system.

Using these criteria, ten sites were selected; these are shown as small squares in **Figure 8** and are labeled with the names of neighborhoods or nearby geographical landmarks. For each of these sites, the number of 500,000-gallon (1,900 m^3) storage tanks (shown in Figure 6) required to reach specified overflow levels is given. The largest regional storage facilities would be located near the junction of the Duck Creek and Kennedy Heights interceptors (the Norwood and the Kennedy Heights facilities), near the junction of the Duck Creek and Little Duck Creek interceptors (the Little Miami Floodplain facility), at the Delta Avenue Pump Station (the Delta Avenue facility), and at the Little Miami WWTP.

The regional storage facilities should be designed in the following manner:

- Each individual tank should operate as shown in Figure 6.
- During storm events, flow should be diverted to the tanks sequentially. Thus, during small storms, only a few tanks would be used and require post-storm maintenance; the entire facility would be full only during the design event.

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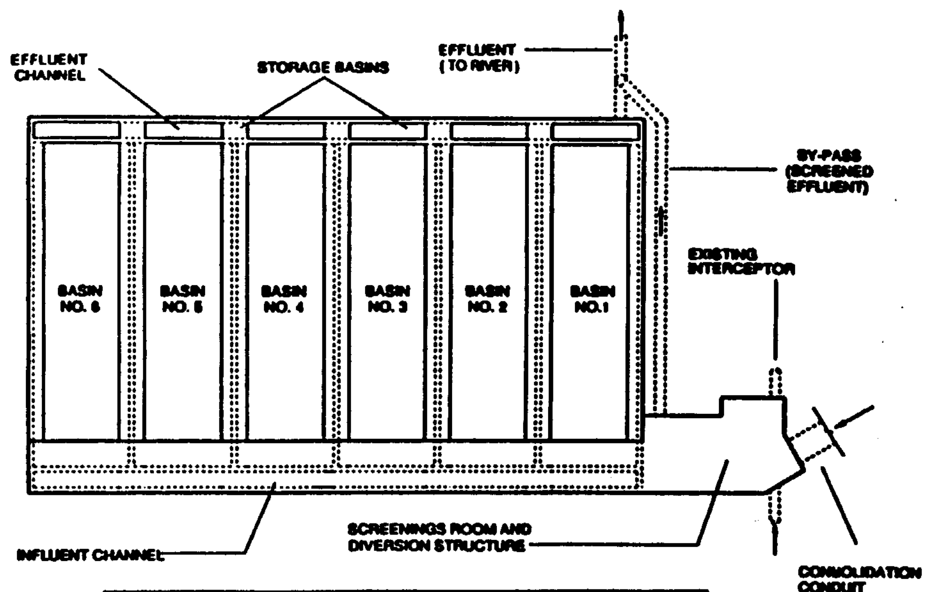
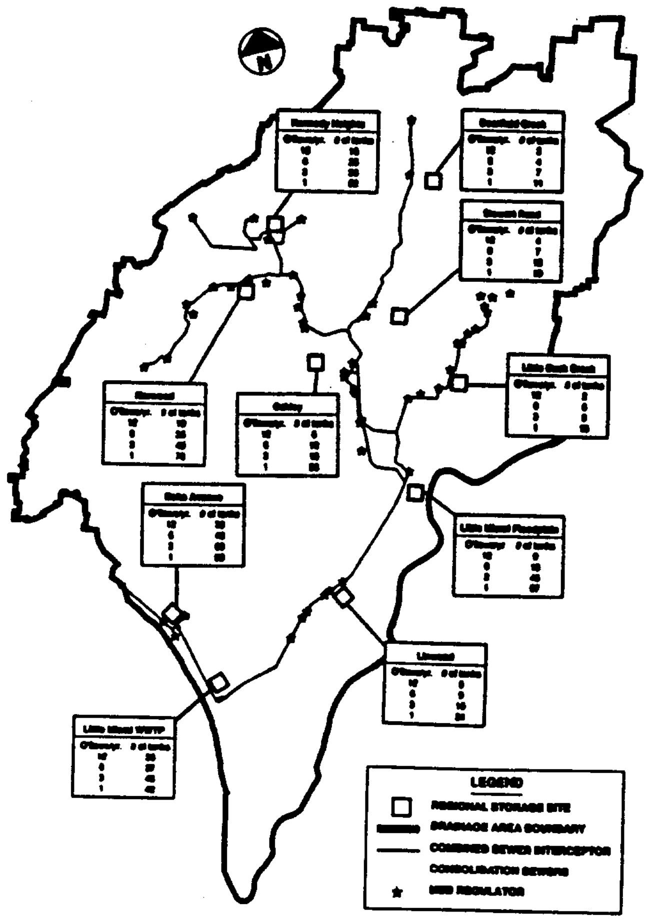


Typical Regional Storage Facility (Gravity Drained)	Figure 7



Regional Storage Alternatives in the Duck Creek Drainage Area | Figure 6

- The diversion sequence should be varied periodically so that the same tanks would not be used all the time and tanks could be taken out of service occasionally for maintenance.

Alternative D: Deep Tunnel

Where limited sites are available for regional storage facilities, storage can be provided in a deep tunnel. Design considerations for a deep tunnel would include the following:

- The tunnel should be 36 feet (11 m)in diameter, constructed in hard rock 200 to 400 feet (61 to 122 m) below the ground.
- The number of drop shafts into the tunnel should be minimized, since each costs about $5 million to construct.
- Whenever appropriate, consolidation sewers should be built in preference to additional tunneling and drop shafts, since the latter are more expensive.
- Regional storage facilities should be constructed wherever the cost of additional consolidation sewers, tunnel segments, and drop shafts exceeds the cost of regional storage.
- A pump station is required to empty the tunnel and should be sized to equal the capacity of the Little Miami WWTP expansion for wet-weather treatment (54 mgd or 2.4 m^3/s). The pump station would discharge into the existing interceptor system.

Figure 9 shows the location and extent of deep tunnel construction which would be required to reduce overflows in the Duck Creek Drainage Area to one per year. This was the only level of control considered for the deep tunnel, for two reasons:

1) If storage in the tunnel were decreased by changing the alignment shown in Figure 9 (*i.e.*, by significantly shortening it), the tunnel would not capture enough of the combined sewage to be effective.
2) It is not cost-effective to decrease the storage in the tunnel by reducing the tunnel diameter, since the incremental cost of drilling a smaller tunnel is not significantly less than the cost to drill a 36-foot (11m) diameter tunnel as proposed.

The major advantage of a deep tunnel is that most of the facilities are located below ground, minimizing problems in several areas, including potential utility obstructions, land requirements, and odor. Before selecting this alternative, however, further investigation of the tunnel is necessary to ensure that geological conditions are appropriate for its construction (e.g., to locate the hard-rock layer and any fault lines which could impact the tunnel during an earthquake). Storage at the Little Miami WWTP is provided by a 13-mg (0.6 m^3) equalization basin as described above.

Alternative E: Sanitary/Storm Sewer Separation

Sewer separation is defined as the division of an existing combined sewer system into non-interconnected sanitary and storm sewer systems. Theoretically, complete sewer separation is the only measure which can completely eliminate combined sewer overflows. There are several major disadvantages involved in separating the two systems:

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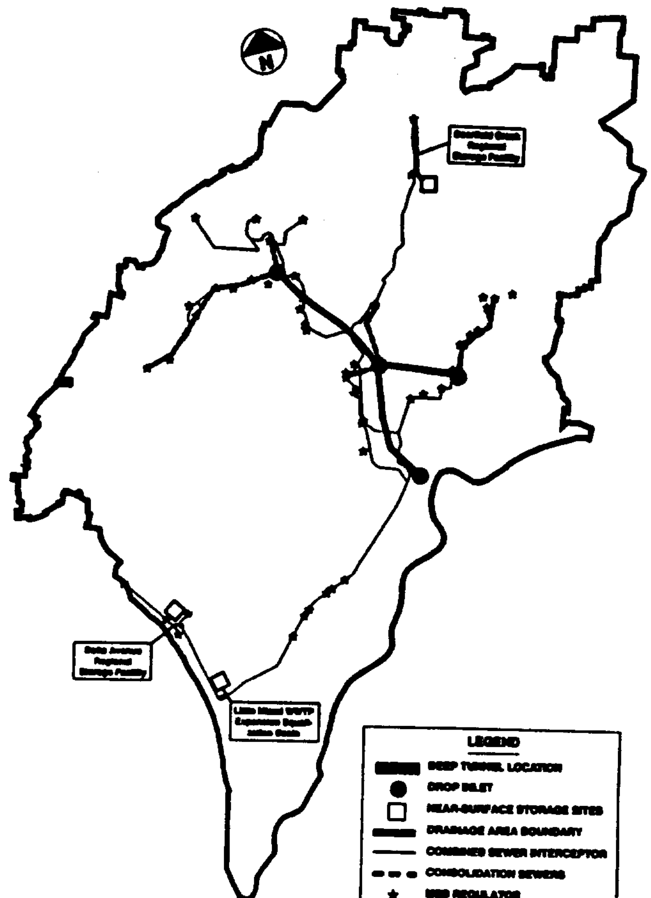

Location of Deep Tunnel Construction Duck Creek Drainage Area	Figure 9

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- Stormwater runoff from heavily urbanized areas often becomes contaminated by excrement from domestic animals and by illegal sanitary cross-connections to the storm drain system. CSO discharges also contain a substantial amount of so-called floatable pollutants, such as oils from motor vehicles, paper, and other debris from roadways and parking areas, which are flushed into the system during the early stages of a storm event. When sanitary and storm sewer systems are combined, a portion of these "first-flush" pollutants in the stormwater runoff can be captured by the interceptor and treated at the WWTP. However, when the sewers are separated, these first-flush pollutants are not captured and treated: all runoff is discharged into the receiving water.
- Separation of all or portions of the system would result in substantial construction-related problems. Separation of the service connections from buildings in combined sewer areas would require modifications to existing structural plumbing, which is generally very difficult and often entails extensive renovation. Full-separation projects directly affect large numbers of people due to the need to excavate in virtually every street having a combined sewer, resulting in high costs, extensive time requirements, and disruptions to both traffic and utilities.

Because of these major disadvantages, system-wide sewer separation was not considered to be a viable alternative for CSO control in the Duck Creek Drainage Area. Sewer separation is viable in those locations where the area tributary to a regulator is small (less than 20 acres or 8.1 hectares) and/or where providing other control measures is not cost-effective.

IMMEDIATE-ACTION PLAN

Figure 10 presents a graphic summary of short-term alternatives for CSO control involving facilities which meet a clear, immediate need and are common to several of the alternative control plans. These facilities also play an integral part in long-term CSO management. Important considerations about these facilities include the following:

- A 20-mgd (0.9 m^3) expansion of the Little Miami WWTP (or construction of a new plant elsewhere) is recommended to meet projected increases in dry-weather wastewater flows. Implementation of the 20-mgd (0.9 m^3) expansion will prevent CSOs from increasing as development occurs. In order to meet design goals for other CSO-control facilities, additional treatment capacity at the WWTP is required. Therefore, a total increase in treatment capacity of 34 mgd (1.5 m^3/s) is required for wet-weather flows captured under alternative CSO control plans designed to reduce CSOs to one per year. Without this capacity, storage facilities would not be emptied fast enough to capture flows in combined sewers from subsequent storms to meet the objectives of the long-term plan.
- The wet-weather conveyance capacity of the Little Miami interceptor can be increased by about 20 percent to 40 percent by raising the overflow elevations of three regulators. These modifications reduce total CSO pollution by about 2 percent but also divert about 7 percent of the remaining CSO pollution from the environmentally sensitive Little Miami River to the Ohio River.

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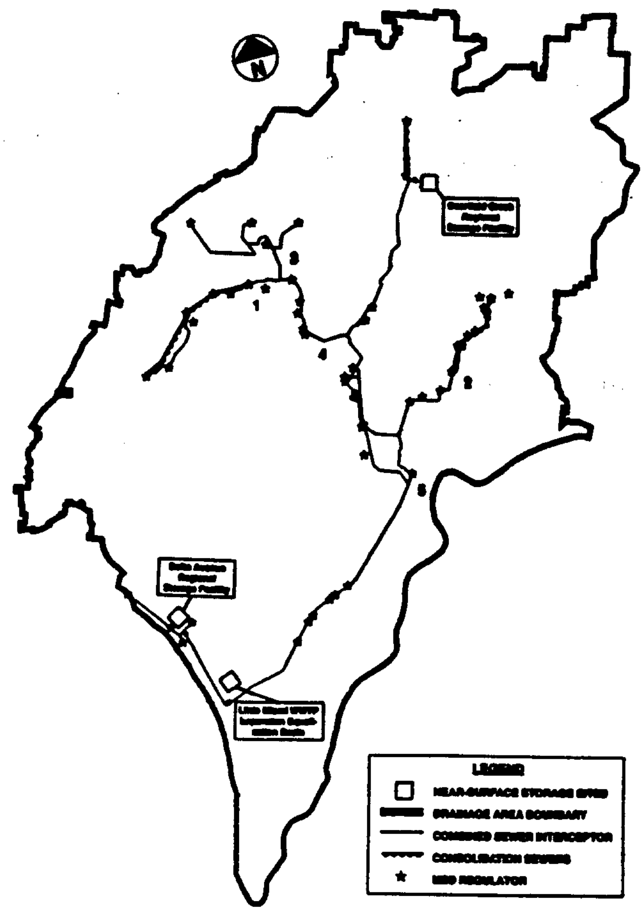

Location of Elements Common to Recommended CSO Facilities Plans	Figure 10

- About 8,700 feet (2,650 m) of consolidation sewer should be installed along Deerfield and Little Duck Creeks. A regional storage facility can be placed at the outlet of the Deerfield Creek consolidation sewer to reduce overflows to one per year.
- Implementation of the Delta Avenue regional storage facility is recommended, sized to reduce overflows to between one per month and one per year.
- Either vortex separators or swirl concentrators will provide additional short-term control of CSOs, but have relatively short service lives and will likely require replacement under a long-term control plan. These facilities should be placed at the following locations, shown on Figure 10:
  - Outlets of proposed consolidation sewers (Norwood, shown as point 1, Little Duck Creek, shown as point 2)
  - At locations where CSO volumes are large (the outlet of the Kennedy Heights combined sewer into Yononte Creek, shown as point 3; the outlet of the Oakley relief sewer, shown as point 4; and the diversion at the junction of the Duck Creek, Little Duck Creek, and Little Miami interceptors, shown as point 5)

LONG-TERM PLAN

The long term CSO control measures presented under Alternatives A through E build upon the facilities which are recommended under the short-term plan. The ultimate decision of the alternative methodology selected for long-term CSO control depends on evolving technological, regulatory, and financial criteria.

An important element of the long-term plan is that no explicit level of control is defined, although the capability ultimately to control to one overflow per year is provided. The approach is first to build storage facilities to control overflows to twelve per year, then monitor the effectiveness of this level of control on improving receiving water quality. Where further improvement is required, additional facilities can be built using the Master Plan as a blueprint or guide. It is important to note that, under this plan, transport facilities such as consolidation conduits are sized for the ultimate level of control, *i.e.*, the one-year storm, so that these facilities do not have to be replaced if it is determined that CSOs must be reduced to fewer than twelve per year.

The deep tunnel plan, however, is not flexible in terms of level of control. It is an "all-or-nothing" proposition (meaning that a certain level of control must be committed to at the inception of the project) while other alternatives can be phased in over time (meaning that additional levels of control can be provided over time if they are needed).

SUMMARY

Combined sewers serve about half of the Duck Creek Drainage Area and collect both stormwater and wastewater. On average, each of these combined sewers overflows approximately 55-60 times each year, severely impacting the water quality of Duck Creek and its tributaries, which then carry this pollution into the Little Miami and Ohio Rivers.

The objective of the CSO master plan for the Duck Creek Drainage Area was to locate and quantify CSOs in the drainage area, to develop alternative schemes to

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alleviate them in the long term, and to propose short-term measures which will control, eliminate, or consolidate those CSOs having the greatest impact. Basic findings obtained as a result of this study can be summarized as follows:

- CSOs occur at the Delta Avenue pump station and the Little Miami WWTP over 60 times each year. These two facilities have the lowest wet-weather capacity in the drainage area.
- The Little Miami WWTP has a treatment capacity adequate for existing dry-weather flows but cannot handle the projected 20-mgd (0.9 m^3/s) increase in peak dry-weather flow or the additional wet-weather flows which the combined sewer interceptor is capable of conveying. To reduce overflows into the Ohio River, therefore, a 54-mgd (2.4 m^3/s) expansion of the plant's wet-weather treatment facilities is required, along with a 13-mg (0.6 m^3/s) equalization basin.
- Annually, about 55 CSOs are caused by insufficient wet-weather capacity in the gravity-combined sewer interceptor as a whole, with this capacity generally decreasing as flows move downstream in the interceptor. In certain watersheds within the drainage area, between 25 and 60 CSOs per year result from this inadequate interceptor capacity.
- CSOs also occur due to insufficient regulator capacity, although, in general, regulators can convey more wet-weather flow to the gravity-combined sewer interceptor than the interceptor can accept.
- Schemes to optimize the performance of the combined sewer interceptor will only cost about $50,000, but they do not significantly increase the wet-weather interceptor capacity except in the Little Miami interceptor, where wet-weather interceptor capacity increases by about 20% to 40% but CSOs are only reduced by about 2%. Since optimization of the interceptor performance will increase flows to the Little Miami WWTP, additional overflows to the Ohio River will occur unless interceptor optimization is accompanied by the construction of additional storage/treatment facilities at the plant.
- Over 400 distributed storage facilities with a volume of 0.5 million gallons (1,900 m^3) are required within the Duck Creek Drainage Area to reduce CSOs to one per year. Construction of these facilities would disrupt many neighborhoods, and the facilities themselves, once operational, are likely to cause odor problems. Unit capital and O & M costs are significantly higher than for other storage alternatives since virtually no economies of scale are present. The total capital cost required to implement Alternative B, which is based on wide-scale use of distributed storage facilities, is about $431.5 million.
- Alternative C, regional storage/treatment facilities, concentrates the storage required to control CSOs to ten strategically-located facilities within the drainage area. These regional facilities involve about the same amount of storage as is required under Alternative B but are large enough to achieve significant economies of scale. Three consolidation sewers are also required under this alternative in order to convey combined sewerage to the strategic sites.
- Storage requirements for CSO control can also be provided by a deep hard-rock tunnel. In Duck Creek, two segments of 36-foot diameter tunnel are required: The tunnel would be drained with a 54-mgd (2.4 m^3/s) pump

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station located at the junction of the Duck Creek/Little Duck Creek/Little Miami Interceptors.

- Separation of all combined sewers in the Duck Creek Drainage Area would eliminate all CSOs but would cause severe disruptions to the community during implementation, would not provide treatment for any stormwater runoff as is now being provided by the existing combined sewer system, and would likely result in a separate sewer system with high levels of inflow/infiltration, many cross-connections, and numerous illicit connections. Therefore, separation is not recommended unless other methods are not cost-effective.
- Short-term alternatives for CSO control and adequate wastewater conveyance and treatment involve facilities which meet a clear, immediate need and which are common to several of the alternative control plans. Facilities which are recommended for implementation during the next twenty years will also play an integral part in long-term wastewater/CSO management. Installing vortex separators or swirl concentrators will provide further short-term control of CSOs, but such facilities have relatively short service lives and will likely require replacement under a long-term control plan.

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SWEDISH TRENDS IN CSO PLANNING AND CONTROL

Johan Larsson[1] and Jan Falk[2]

Introduction

Urban drainage is a conservative business where trends and policies are not easily established or abandoned. Seen in a 50-year perspective, one can observe that every major shift in Sweden is preceeded by a decade of discussion and a decade of transition. When consensus among engineers is finally reached, it seems to be the starting point for a re-evaluation by a new generation of engineers.

In this paper, we will describe Swedish sewer system policies in a 50-year perspective, focusing on the transition to a new policy during the 1980's. In many respects, these policy changes have been parallel with international trends. Of special interest, however, is the persistent and in the 1970's even mandatory policy of separating all existing combined sewer systems.

Key figures for the Swedish severage system are:

Population	8.5 million
Urban population	7.3 million
Water production for municipal use	975 million m³
Sewers, total length	80,500 km

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Total value of the sewerage system	100 billion SEK
Annual costs of operation and maintenance	3 billion SEK
Annual investments	1.3 billion SEK
Per cent of severed areas which are combined	25
Average price for drinking water incl. sewage services	10 SEK per m³

The period 1940-1970

In the early 1940's there was a consensus among Swedish engineers of the merits of the combined sewer system, as illustrated by a quotation from an official study in 1941 (Bäckman, 1984):

"The combined system is the oldest, most common and from many aspects the most attractive. It is simple, complete and efficient as all water can be transported in one sewer system. It does require careful calculations so that the extent of basement flooding is not unacceptable. The total pollution may be larger from the combined system, but polluted storm water is also a problem in the case of a separate sewer system."

This official favouring of the combined system was merely a recognition of the established practice during the 1930's. In the period 1900-1920, when most cities made their first sewer plans, no general trend can be observed. Depending on local conditions, separate or combined system policies were preferred when the sanitary, pollutional and economic objectives were considered.

Thus, the combined system can be regarded as the established practice in Sweden from around 1930, although a number of cities continued their original separate sewer policy. The combined sewer policy was finally abandoned first in the late 1950's.

Already in the 1940's, however, the combined system was again questioned. The increase in urban population, general standard of living and the resulting increase in water pollutional effects were the driving forces. It was argued that a separation of waste water from storm water was the only rational choice for an efficient waste water treatment. Furthermore, basement flooding from combined sewers could not be accepted in the future.

The first attempts to adapt the new sewer policy were made in the late 1940's. The resistance to this novelty was large however, primarily from the constructors. In the 1950's, a massive housing development scheme was initiated. An epidemic of paratyfus in Sweden in 1953 was also the detonator of an explosive building of interceptor sewers and treatment plants. The rush of development made design inflows a matter of guessing with many surprises as a result.

At the end of the 1950's, there was a consensus on the merits of the separate system. Plans for new developments had even been changed in the last minute. During this period of transition, emphasis was laid on making the policy shift happen and having everyone walking in the same direction.

The 1960's can be characterized as an escalated 1950's. The basic choices were made. The treatment plants were localized and the interceptor structure was determined. The separate sewer system was the only possible alternative if the continuous improvement of treatment plants should give full effect.

At the end of the 1960's the typical sewer structure was a central core of pre-war combined system surrounded by a post-war separate system connected to the central core. The official policy from the new Environmental Protection Board to cope with this problem was separation of the existing combined sewers. This formidable task was initiated in most cities, mostly on a piecemal basis however, and certainly not with any enthusiasm when facing the practical problems.

Summarizing the period 1940-1970, we can identify a final concensus of the merits of the combined system in the late 1930's, an intense discussion and questioning of these merits during the 1940's, a transition period and lining-up for the separate system during the 1950's and a non-reflecting continuation during the 1960's.

The 1970's - a period of discussion

Research on urban hydrology started in Sweden in the beginning of the 1970's. The reason for this was that it now had become obvious that storm water in no way was as unpolluted as earlier expected and that you needed new and more accurate methods for the dimensioning of pipes (Falk, 1979 and 1983). Applied research focused on local infiltration of storm water and mostly financed by the

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Swedish Building Research Council (BFR) gave some promising results.

For the formulation of a new policy, the Swedish Environmental Protection Board (SNV) set up a committee who reported in 1972. The proposal stated that the efforts still should be concentrated on the re-building of old combined systems for separate systems. However, the proposal was turned down due to the promising research results on local management of storm water, i.e. infiltration, the large content of pollutants in storm water from downtown areas and last but not least the enormous costs for re-building.

During the late 1970's research was initiated at several universities with the objective to develop methods for the managing and upgrading of the combined sewer system. Examples of these projets are: Flow equalization and combined sewer overflows at the Royal Institute of Technology (KTH) in Stockholm and water budget for the city of Lund at the University of Lund, see Falk 1979 and 1983. Backed up by these and severel other projects, SNV made another attempt to form a new policy for storm water management.

Up to the late 1970's practically all permits given for the discharge of treated waste water contained a paragraph saying that combined systems should be replaced without further delay. In December 1978, SNV wrote a letter to all municipalities, saying that separation was no longer the only solution considering the management of storm water. All municipalities having mandatory demands of separation were urged to apply to the Franchise Board to have that paragraph changed, if they wanted to. Several municipalities did so and instead they had to make a so-called rehabilitation plan for their sewerage system, which had to be approved of by the environmental unit at the county administration. However, many of these early plans were merely a paper product and did not reflect the actual conditions of the sewerage system and thus were of small practical use. Those municipalities made the plans, not because they wanted to, but only to fulfil the demands of the authorities. Many municipalities thought that they had done enough on environmental protection when they upgraded their sewage treatment plants during the 1960's and 1970's and now wanted to allocate their resources to other areas.

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The 1980's - a period of transition

During the 1960's and 1970's the so-called "million programme" was carried through. New buildings for one million people were erected. In 1980 this programme was finalized. This also meant that new exploitation in the areas of water supply and severage decreased remarkably. A new era of management instead of exploitation started. There were no longer different opinions between the authorities and the municipalities on whether measures had to be taken on the severage system. What still differed was more the priority of undertaking certain tasks. The change in the opinion of the municipalities may be explained by the fact that the costs for running the existing severage systems were steadily increasing and that personnel now unoccupied by exploitation were there.

The rehablitation plan concept launched by SNV and reported on in guidelines (SNV 1983a and 1983b) had its focus on the environmental aspects. In 1987 (VAV, 1987) the Swedish Water and Wastewater Works Association published guidelines for how to make priorities when planning maintenance, renewal and improvements of the water supply and severage networks. This strategy may be looked upon as a continuation of and complement to the work carried out by SNV and where the economical aspects are more in focus.

The aim of storm water management was fourmulated by SNV (SNV, 1983a) as:

"... to manage stormwater in a way that minimizes nuisances for buildings and environment and that minimizes the costs of investments, operation and maintenance."

This aim may be reached if the following means are regarded:

- the prevailing water budget conditions should be considered when planning an urban area,
- storm water should be managed at the source when possible,
- measures should be taken to prevent a deterioration of the quality of storm water,
- the risks of surcharges and overflows should be minimized by using all possible means of flow equalization,

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- o heavily polluted storm water and combined sewer overflow should be purified before it is discharged in a receiving water.

Research during the 1980's has made available sets of new tools which are as of today ready for use, making it easier to achieve the aim set above, for example:

- o Database for key information on the severage network - easier planning.
- o Mathematical modelling of the urban runoff process - better decision making.
- o CCTV-inspections - malfunctions discovered.
- o Renovation instead of rebuilding - cost effective.
- o Swirl concentrators at combined sewer overflows - less pollution.

Trends of the 1990's and conclusions

Summarizing the period 1970-1990 we can identify a total consensus of the merits of the separate system in the late 1960's, an intense discussion and questioning of these merits during 1970's and a transition period and a lining-up for flow equalization during the 1980's.

Trying to predict the future, it is tempting to make a comparison with the characteristice of the 1960's during the policy shift in the period 1940-1970. Will the 1990's then be a non-reflecting and amplified continuation of the 1980's?

What are then the trends of the late 1980's to be extrapolated?

There is a consensus among most engineers that flow equalization and sewer renovation must be the key elements of rehabilitation and that source-control of storm water is the natural choice for new developments.

There is a wide-spread use of computerized tools for the description, monitoring and simulation of the dynamic system. The logical next step is real time control.

There is a consensus among most decision makers that financial resources must be allocated to the improvement and renewal of sewer systems.

Thus, the necessary requirements seem to be there. The engineers know what to do, they have control of the system and the financial resources will be there. What is needed is only the official goals formulated as performance criteria for flooding and pollution.

In the case of basement flooding, the necessary performance criteria are there, recommended by VAV in 1985 as a return period of 10 years (VAV, 1985).

In the case of pollution, no such recommendation has been given by SNV. In the absence of official guidelines, however, more unofficial performance criteria tend to be used. The most common is an overflow frequency in the range of 1-10 events per year, depending on receiving water conditions.

The trend of the 1990's will probably be determined by the attitude taken by SNV.

A recommendation by SNV, formulated as allowable overflow frequences, would probably be the detonator of an explosive building of storage volumes.

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MANAGEMENT STRATEGIES TO CONTROL INDUSTRIAL DISCHARGES TO COMBINED SEWER OVERFLOWS AND SEPARATE STORM SEWERS

by Kevin Weiss[1] and Harry Thron[2]

The United States Environmental Protection Agency (EPA) is in the process of developing and implementing comprehensive National Strategies to coordinate National Pollutant Discharge Elimination System (NPDES) permitting efforts for discharges from combined sewer overflows (CSOs) and discharges from separate storm sewers. Important components of both of these control strategies address reducing pollutants from industrial sites to separate and combined drainage systems.

INTRODUCTION

Control options and the regulatory framework developed under the Clean Water Act (CWA) for the following four types of discharges are discussed:

- o Process discharges to combined sewers with CSOs;
- o Industrial site runoff to combined sewers with CSOs;
- o Non-storm water to separate storm sewers[3]; and

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[3] In many situations, NPDES permits have been written for discharges of industrial process waste waters to separate storm sewers. EPA has proposed regulation that will generally allow these discharges as long as they are in compliance with permit conditions at the

o Industrial site runoff to separate storm sewers.

REGULATORY PROGRAM FOR INDUSTRIAL DISCHARGES TO COMBINED SEWERS

A. NATIONAL COMBINED SEWER OVERFLOW STRATEGY

EPA estimates that there are approximately 1,200 communities with combined sewer systems, and these systems operate 15,000 to 20,000 CSOs. Many of these CSOs are clustered in 'older' developed areas in the Eastern United States, the Great Lakes Region and scattered areas of the West Coast. In a relatively few municipalities, major efforts to control CSOs have already been undertaken. Varied control strategies have emerged, such as: Chicago's underground tunnel system; San Francisco's major interceptor system; a 400 million gallon per day swirl concentrator coupled with in-line storage controls in Washington DC; and the sewer separation projects undertaken by a number of cities. However, the majority of communities have not adequately addressed CSOs. As a result, EPA issued the "National Combined Sewer Overflow Strategy" on August 10, 1989. The National CSO Strategy establishes a framework for controlling CSOs which includes the following minimum technology based requirements for all CSO discharges:

- o Proper operation and regular maintenance programs for sewer systems and CSOs;
- o Maximum use of collection system for storage;
- o Review and modification of pretreatment programs to assure CSO impacts are minimized;
- o Maximization of flow to sewage treatment plant
- o Prohibition of dry-weather flows; and
- o Controls of solid and floatable materials in discharges.

Most combined sewer systems have multiple CSO discharge points. Controls in various parts of the combined system will usually differ. Priorities for

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point of discharge into the separate storm sewer. (see December 7, 1988 (53 FR 49443)). This paper only addresses the identification and control of non-storm storm water discharges to separate storm sewers that currently are without a NPDES permit.

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developing specific practices to meet the minimum technology based requirements should be based on a number of considerations, including pollutant loads from the various CSO discharges in the combined system, the nature of receiving waters, the location of CSO discharge points, and existing design features of the combined sewer collection system. When evaluating priorities for controls to meet the requirements numbered 1, 2 and 4 above, the contribution of pollutants in discharges from industrial sites to pollutant loads should be considered. Since pollutant loads associated with discharges from industrial sites are generally higher than pollutant loads from other types of land uses, it is expected that in many cases, the development and implementation of practices under requirements 1, 2 and 4 will focus on portions of the combined sewer system serving industrial lands.

B. PRETREATMENT REQUIREMENTS

The third component of the minimum technology based requirements listed above, review and modification of pretreatment programs to assure CSO impacts are minimized, directly addresses controls on discharges from industrial sites to combined sewer systems.

The CWA establishes a dual regulatory program for discharges (including both industrial process wastewaters and storm water discharges associated with industrial activity) to surface waters. Facilities which discharge directly to surface waters must obtain an NPDES permit. NPDES permits will specify limits on the amount of pollutant discharged or other controls. Requirements in a permit are technology based, or where necessary to assure compliance with State water-quality standards, more stringent water quality based requirements. Facilities with a NPDES permit are solely responsible for providing the treatment necessary to meet the conditions in the permit issued for the discharge.

Discharges of industrial process wastewater to publicly owned treatment works (POTWs), referred to as indirect discharges, are exempt from NPDES permitting requirements, but rather are subject to pretreatment requirements. These facilities are only responsible for providing the treatment necessary to meet appropriate pretreatment conditions. The POTW receiving the discharge from the industrial site is responsible for providing additional treatment and may be required to establish additional pretreatment requirements for the industrial dischargers to its system to enable the POTW to comply with its NPDES permit.

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Pretreatment requirements include both national technology based pretreatment standards, the so-called categorical pretreatment standards, and local limits which are established on a case-by-case basis by the POTW receiving the discharge. In theory, the technology based requirements established in NPDES permits for direct discharges should be roughly equivalent to the combined treatment required by the pretreatment program and provided by the POTW. However, a discharge of industrial waste water to a combined sewer with CSOs does not receive the treatment provided by the POTW for the portion of the discharge that is discharged from the CSO. In such cases, the level of pretreatment provided to the discharge prior to its discharge to the combined sewer can be increased to ensure that the combined treatment provided by the industrial facility and the POTW is roughly equivalent to the treatment provided by direct dischargers.

There are a number of ways that pretreatment requirements can be adjusted to account for the additional release of pollutants associated with CSOs. One court case, NRDC v. EPA, 790 F.2d 289 (3rd. Cir. 1986), provides some guidance on adjusting pretreatment requirements for indirect discharges to POTWs. In NRDC v. EPA, the court reviewed, and ultimately rejected, EPA's regulations for allowing national pretreatment standards for indirect dischargers to be made less stringent by granting removal credits for the amount of waste removed by the POTW. The removal credit provision was intended to equate the amount of treatment provided by the POTW and the pretreatment of the indirect discharge to the amount of treatment provided by direct discharges subject to national technology-based pretreatment requirements.

In 1978, EPA promulgated regulations that provided that removal credits could be granted by a POTW that experienced CSO discharges at least once a year only if that POTW was implementing an approved plan to treat and control such overflows (June 26, 1978, (43 FR 27765)). This requirement was amended in 1981 in response to complaints from indirect dischargers that removal credits could not be granted by many POTWs because plans to treat and control CSOs had not been developed or approved for the majority of POTWs (January 28, 1981 (46 FR 9427)). The 1981 regulatory amendments provided that a removal credit could be reduced by a percentage equal to the percentage of overflow time during a year where the POTW could estimate the number of hours per year during which overflows occur. In 1984, EPA eliminated the regulatory

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provision that required the consideration of CSOs when granting removal credits (August 3, 1984 (49 FR 31212)).

While discussing the 1981 removal credit regulations, the court commented that adjusting the removal credit granted to an indirect discharger by the percentage of time that overflows occur does not take into account the fact that CSOs cause sudden increases in pollutant discharges into navigable waters. The court stated that a strict interpretation of the CWA would need to take into account the POTW's performance during an overflow.[4] The court went on to reject the 1984 regulations which allowed POTWs to grant removal credits without consideration of CSOs. The court held that EPA cannot ignore CSOs when establishing removal credits and noted that NRDC had estimated that CSOs discharge 560,000 pounds of toxics from indirect industrial discharges annually. The court also held that EPA could not use national average estimates on the frequency of CSOs to establish removal credits, because this would ignore the great variability among combined sewer systems in the number and duration of CSO events and in the amount of discharge that occurs during an event.

C. OPTIONS FOR CONTROLS

Both on-site controls and controls which adjust the performance of the collection system can be used to reduce pollutant discharges associated with industrial discharges (both industrial site runoff and process discharges) to combined sewers. Under the NPDES program, on-site controls are referred to as pretreatment requirements. Options for controls can be grouped in the following classes:

1. On-site Controls

- On-site storage with discharge to the combined sewer during dry weather conditions;

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[4] This can be viewed as non-binding dicta from the court, since the court in NRDC v. EPA was hearing challenges to the 1984 regulations, and not the 1981 removal credit regulations which had been upheld in National Association of Metal Finishers v. EPA, 719 F.2d 624 (3d Cir.1983), reversed in part sub nom. Chemical Manufacturers Ass'n v. NRDC, 105 S.Ct. 1102, 84 L.Ed.2d 90 (1985).

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- o Wet weather or more stringent all weather limitations on the levels of pollutants discharged; and
- o Source controls directed at reducing pollutants in runoff and spills discharged to the combine sewer system[5].

2. **Collection System Controls**

- o End-of-pipe treatment of CSO discharges;
- o Proper operation and regular maintenance programs for sewer systems and CSOs;
- o Maximum use of collection system for storage;
- o Maximization of flow to sewage treatment plant; and
- o Sewer separation[6].

In addition to considering industrial discharges when developing control strategies, operators of combined systems may consider using high volume discharges from industrial facilities to flush sewers during periods of dry weather. For example, many relatively clean discharges, such as non-contact cooling waters are often either discharged to separate storm sewers or discharged directly to surface waters. These discharges may serve as inexpensive sources of water for periodic sewer line flushing.

CONTROLS FOR INDUSTRIAL DISCHARGES TO SEPARATE STORM SEWERS

On December 7, 1988, (53 FR 49416), EPA proposed NPDES permit application requirements for discharges from certain types of separate storm sewers, including storm water discharges associated with industrial activity and discharges from municipal separate storm sewer systems serving a population of 100,000 or more.

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[5] Source controls directed at reducing pollutants in runoff and spills discharged to combined sewer systems are similar to those for runoff and spills to separate storm sewer systems, and are discussed in more detail later in this paper.

[6] Sewer separation should only be used as a means to improve water quality where the net pollutant load discharged to surface waters is decreased or other environmental benefits result (such as avoiding discharges to sensitive receiving streams). When evaluating a sewer separation strategy, the pollutant loads associated with storm water discharges which will be taken out of the combined system should be considered.

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A. REGULATORY FRAMEWORK FOR STORM WATER DISCHARGES ASSOCIATED WITH INDUSTRIAL ACTIVITY

In the December 7, 1988 notice, EPA proposed different regulatory requirements for facilities which discharge storm water associated with industrial activity via separate storm sewers depending upon whether or not the facility discharges storm water to a municipal separate storm sewer system.

Under EPA's proposed regulatory framework, facilities which discharge storm water associated with industrial activity to waters of the United States, but not through municipal separate storm sewer systems are required to obtain a NPDES permit. Controls for these facilities will be developed by EPA or an NPDES approved State during the permit issuance process. Facilities that discharge storm water associated with industrial activity to municipal separate storm sewer systems serving a population of 100,000 or more generally would not need an NPDES permit if they notify the municipality operating the system of the discharge and comply with requirements of municipal storm water management programs written into the NPDES permit for the municipal system discharge. EPA has proposed to postponed a regulatory decision on addressing storm water discharges associated with industrial activity which discharge to other municipal separate storm sewer systems until after completion of two studies of storm water discharges.

B. STORM WATER MANAGEMENT PROGRAMS FOR DISCHARGES FROM MUNICIPAL SEPARATE STORM SEWER SYSTEMS SERVING A POPULATION OF 100,000 OR MORE

At the heart of the proposed regulatory program for discharges from municipal separate storm sewer systems serving a population of 100,000 or more is the requirement that municipal applicants develop municipal storm water management programs. The framework for municipal storm water management programs proposed by EPA addresses four major components:

- identifying and controlling non-storm water discharges to municipal separate storm sewer systems;
- reducing pollutants in construction site runoff to municipal separate storm sewers;
- reducing pollutants in industrial site runoff to municipal separate storm sewers; and

- reducing pollutants in runoff from residential and commercial areas to municipal separate storm sewers.

Programs to reduce pollutants in industrial site runoff to a municipal separate storm sewer systems specifically address industrial facilities. In addition, programs to identify and control non-storm water discharges to municipal separate storm sewer systems will in many cases focus heavily on industrial areas because of a higher potential for illicit connections, spills or improper dumping.

At a minimum, municipal storm water management programs to reduce pollutants in runoff from industrial sites discharging to municipal separate storm sewer systems serving a population of 100,000 or more should address the following:

- Identification of Facilities - Procedures should be developed to identify facilities which discharge storm water associated with industrial activity to the municipal separate storm sewer system. The identification should include the facility name, address, location and a description (such as SIC codes) which best reflects the principal products or services provided. The location of facilities should be correlated with receiving waters, with special attention being given to facilities which discharge storm water to receiving waters with known water quality problems.

- Evaluation of Program - Municipal agencies and departments with a role in controlling storm water discharges from industrial areas should be identified. Existing spill control/response programs and fire inspection/chemical control programs should be identified. Sewer use ordinances should be evaluated to insure illicit connections are prohibited and programs and procedures for ensuring that sewer use ordinances are implemented should be identified. Legal authorities for requiring industrial facilities to monitor discharges, develop BMPs and/or provide end-of-pipe treatment should be evaluated. Finally, staffing and funding needs for these activities should be estimated.

- Methods for Developing Priorities and Investigative Monitoring - Priorities for investigative monitoring and developing controls should be based on a number of factors, including the facility location within

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the watershed and the nature of activities occurring at the facility. Facilities that generally will be high priority include those that: are stationary sources of particulate or lead air emissions that are classified as a major emitting facility under the Clean Air Act[7]; store large amount of toxic chemicals[8]; operate on-site land disposal units; or are located in drainage basins with impacted or sensitive receiving waters or widespread industrial activity. Priorities can be based on a combination of several sources of information, including discharge monitoring data (provided by either the municipality or the industry), data describing the quality of the receiving water, and other non-quantitative data describing the nature of industrial activity or the receiving water.

- <u>Methods to Develop Controls</u> - A management program should include procedures and methods for developing controls for non-storm water discharges as well as for reducing pollutants in storm water discharges from industrial sites. The process of developing controls should include adequate public participation. Options for these controls are discussed below.

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[7] EPA regulations at 40 CFR 52.21(b)(1) define "major stationary source" as a facility which is a member of a class of industries which is specifically listed in the regulation which emits, or has the potential to emit, 100 tons per year or more of certain pollutants including elemental lead and particulates. Other major sources include sources were the industry type is not specifically listed and that emit, or have the potential to emit, 250 tons per year or more of certain pollutants including elemental lead and particulates.

[8] Section 313 of Title III of the Superfund Amendments and Reauthorization Act requires operators of certain facilities that manufacture, import, process, or otherwise use certain toxic chemicals report annually their releases of those chemicals to any environmental media. Listed chemical include 329 toxic chemicals listed at 40 CFR 372.45. After 1989, the threshold quantities of listed chemicals that the facility must manufacture, import or process in order to be required to submit a release report is 25,000 pounds per year. The threshold for a use other than manufacturing importing or processing of listed toxic chemicals is 10,000 pounds per year. EPA promulgated a final regulation clarifying these reporting requirements on February 16, 1988 (53 FR 4500).

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o <u>Compliance Monitoring and Procedures to Enforce Requirements</u> - A compliance program should include reporting and appropriate monitoring requirements. Plans for when and how to conduct inspections should be developed. Provisions for penalties and sanctions for failure to comply should be developed.

C. NON-STORM WATER DISCHARGES TO SEPARATE STORM SEWERS

Non-storm water discharges to separate storm sewers include a wide variety of sources, including illicit connections[1], improper dumping, spills, leakage from malfunctioning or leaking sanitary sewer lines, contaminated ground water or leakage from storage tanks and transfer areas. Measures to control spills and visible leakage can be incorporated into best management practices (BMP) plans (see below).

In many cases, operators of industrial facilities may be unaware of illicit discharges or leakage from underground storage tanks or other non-visible systems. In some cases, illicit connections to storm sewers were installed before their legal prohibition, and have since been forgotten about. For example, illicit connections are often associated with floor drains that are connected to separate storm sewers. Rinse waters used to clean or cool objects, and other process wastewaters may be discharged to the separate storm sewer via the improperly connected floor drain. These non-storm water discharges to a storm sewer may be inadvertent with the operator unaware that the floor drain is connected to the storm sewer. In this case, the key to controlling these discharges is to identify them.

D. METHODS TO IDENTIFY NON-STORM WATER DISCHARGES TO SEPARATE STORM SEWERS

Several methods for identifying the presence of non-storm water discharges are discussed below. A comprehensive evaluation to non-storm water discharges at a facility may incorporate several methods.

o <u>Schematics</u> - Where they exist, accurate piping schematics can be inspected as a first step in

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[1] Illicit discharges are point source discharges of pollutants that are not composed entirely of storm water and that are not identified in an NPDES permit which are discharged to separate storm sewers that result in discharges to waters of the United States.

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evaluating the integrity of the separate storm sewer system. The use of schematics is limited because schematics usually reflect the design of the piping system and may not reflect the actual configuration constructed. Schematics should be updated or corrected based on additional information found during inspections.

- <u>Evaluation of drainage map and inspections</u> - Drainage maps should be prepared to identify the key features of the drainage system, including: each of the inlet and discharge structures; the drainage area of each inlet structure; and units such as storage or disposal units or material loading areas, which may be the source of an illicit discharge or improper dumping. In addition, floor drains and other water disposal inlets that are thought to be connected to the sanitary sewer should be identified. A site inspection should be used to augment and verify map development. These inspections, along with the use of the drainage map, can be coordinated with other best management practices discussed below.

- <u>End-of-pipe screening</u> - Discharge points or other access points such as manhole covers can be inspected for the presence of dry weather discharges and other signs of non-storm water discharges. Dry weather flows can be screened by a variety of methods. Inexpensive on-site tests include: measuring pH; observing for oil sheens, scums and discoloration of pipes and other structures; as well as colormetric detection tests for chlorine, detergents, metals and other parameters. Where appropriate samples can be collected and returned to a laboratory for more expensive testing, such as analysis for fecal coliform, fecal streptococcus, conventional pollutants, and volatile organic carbon.

- <u>Water balance</u> - Many sewage treatment plants require that industrial discharges measure the volume of effluent discharged to the sanitary sewer system. Similarly, the volume of water supplied to a facility is generally measured. A significantly higher volume of water supplied to the facility relative to that discharged to the sanitary sewer and other consumptive uses may be an indication of illicit connections. This method is limited by the accuracy of the flow meters used.

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- Dye testing - Dye testing involves dropping fluorometric or other types of dyes into floor drains, toilets and other points where non-storm water discharges are collected. Storm drain outlets are then observed for possible discharges.

- Manhole and Internal TV Inspection - Physical inspection of manholes and internal inspection of storm sewers either physicaly or by television are used to identiy potential entry point for illicit connections. Dry weather flows, material deposits and stains are often indicators of illicit connections. TV inspections is relatively expensive and generally should be used only after a storm sewer has been identified as having illicit connections.

E. OPTIONS FOR CONTROLLING POLLUTANTS IN STORM WATER DISCHARGES

Options for reducing pollutants in storm water discharges from industrial plants can be described in terms of the following five categories:

- Providing end-of-pipe treetment;
- Implementing Best Management Practices (BMPs);
- Diverting storm water discharge to sewage treatment plant;
- Traditional storm water management practices;
- Elimination of pollution sources.

A comprehensive storm water management program for a given plant may include controls from each of these categories. Development of comprehenaive control strategies should be based on a consideration of the characteristics of the plant.

1. End-of-Pipe Treatment

At many types of industrial facilities, it may be appropriate to impose requirements to collect and treat the runoff from targeted areas of the facility. One source of guidance for developing end-of-pipe treatment controls are the technology-based effluent guideline limitations for storm water discharges which EPA promulgated for the following ten categories of industrial discharges:

- Cement Manufacturing
- Feedlots
- Fertilizer Manufacturing
- Petroleum Refining

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- Phosphate Manufacturing
- Steam Electric
- Coal Mining
- Ore Mining and Dressing
- Mineral Mining and Processing
- Asphalt Emulsion

Table 1 provides a brief description of the effluent guideline limitations for these industries. Several basic principles regarding the national effluent guideline limitations include:

- treatment standards require that runoff from targeted areas of the plant be collected and temporarily stored on-site;

- The effluent guideline limitations do not apply to discharges whenever rainfall events, either chronic or catastrophic, cause an overflow of storage devices designed, constructed and operated to contain a design storm, with the 10-year, 24 hour storm, or a 25-year, 24 hour storm commonly being used in the effluent guideline limitations as the design storm; and

- Most technology-based treatment standards are based on a consideration of relatively simple technologies such as settling of solids, neutralization, and drum filtration.

The effluent guideline limitations can provide guidance where technology transfer is appropriate for developing case-by-case technology-based requirements for an industry that is not covered by a guideline. Various parameters such as the type of plant activities targeted for controls, the design storm, the pollutants limited, or the concentrations of pollutants in a discharge can be adjusted to account for site and industry specific factors when developing case-by-case effluent limitations for an industry that is not covered by a national limitation. Potential ground water impacts should also be considered when requiring and designing storage devices.

2. Best Management Practices

The term best management practices (BMPs) can describe a wide range of management procedures, schedules of activities, prohibitions on practices, and other management practices to prevent or reduce the pollution of waters of the United States. BMPs also include operating procedures, treatment requirements and

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Table 1: Effluent Guideline Limitations that Address Storm Water

EFFLUENT GUIDELINE CATEGORY	AREA COVERED	POLLUTANTS LIMITED[1]	DESIGN STORM
Cement Manufacturing (40 CFR 411)	Material storage pile runoff	TSS, pH	10-year, 24-hour
Animal Feedlots (40 CFR 412)	any precipitation which comes into contact with any manure, litter or bedding, or any other raw material or product used in production of animals or poultry or direct products	no discharge	25-year, 24-hour
Fertilizer Manufacturing (40 CFR 418)	runoff which comes into contact with any raw material, intermediate product, finished product, by-product or waste product	total phosphorus fluoride TSS, pH, BOD5 organic nitrogen ammonia	25-year, 24-hour
Petroleum Refinery (40 CFR 419)	runoff which comes into contact with any raw material, intermediate product, finished product, by-product or waste product	oil and grease total organic carbon TSS, BOD5, COD, pH phenolic compounds total chromium hexavalent chromium	
Phosphate Manufacturing (40 CFR 422)	runoff which comes into contact with any raw material, intermediate product, finished product. by-product or waste procuct	total phophorus flouride pH	25-year, 24-hour
Steam Electric (40 CFR 423)	runoff from or through any coal storage pile	TSS	10-year, 24-hour
Coal Mining (40 CFR 434)	drainage from coal preparation plant water circuit and coal storage, and ancillary areas related to the cleaning or beneficiation or coal of any rank; drainage from active	iron, TSS, pH manganese	10-year, 24-hour

[1] A given subcategory within the category may be subject to a subset of the pollutants listed.

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Table 1: Effluent Guideline Limitations that Address Storm Water

EFFLUENT GUIDELINE CATEGORY	AREA COVERED	POLLUTANTS LIMITED[2]	DESIGN STORM
Coal Mining (cont'd)	mining areas[3]; and drainage from post-mining areas[4]		
Mineral Mining and Processing (40 CFR 436)	Any drainage from the mine site	pH, TSS, total fluoride	10-year, 24-hour
Ore Mining and Dressing (40 CFR 440)	Drainage from specified mineral mines[5], beneficiating mills and extraction mills	TSS, Fe, pH, Al, TSS, COD, Zn, Ra226, U, As, Cu Ni, Hg, Cd, As Pb,	10-year, 24-hour
Asphalt Emulsion (40 CFR 443)	Runoff from process areas	oil and grease, pH, TSS	

[2] A given subcategory within the category may be subject to a subset of the pollutants listed.

[3] active mining areas include the area on and beneath land, used or disturbed in activity related to the extraction, removal, or recovery of coal from its natural deposits.

[4] post mining area means: (1) reclamation areas (the surface are of a coal mine which has been returned to required contour and on which revegetation work has commenced) or (2) the underground workings of an underground coal mine after the extraction, removal , or recovery of coal from its natural deposit has ceased and prior to SMCRA bond release.

[5] Mines include active mining areas, (a place where work or other activity related to the extraction, removal, or recovery of metal ore is being conducted, except, with respect to surface mines, any are of land on or in which grading has been completed to return the earth to desired contour and reclamation work has begun) including all land and property placed under, or above the surface of such land, used in or resulting form the work of extracting metal ore or minerals from their natrual deposits by any means or method, including secondary recovery of metal ore from refuse or other storage piles, wastes, or rock dumps and mill tailings derived from the mining, cleaning, or concentation or metal ores.

practices to control plant site runoff, drainage from raw materials storage, spills or leaks. BMPs can be established in two basic ways: BMP plans and site or pollutant-specific BMPs.

Best Management Practices Plans

EPA has worked with industry to identify the generic BMPs which most well-operated facilities use for pollution control, fire prevention, occupational safety and health, or product loss prevention. Many of these BMPs involve planning reporting, training, preventive maintenance and good housekeeping. Many industrial facilities currently employ BMPs as part of normal plant operation. For example, preventive maintenance and good housekeeping are routinely used in chemical and related industries to reduce equipment downtime and to promote a safe work environment for employees. Good housekeeping BMPs generally are aimed at preventing spills and similar environmental incidents by stressing the importance of proper management and employee awareness. Experience has shown that many spills of hazardous chemicals can be attributed, in one way or another, to human error. Improper procedures, lack of training and poor engineering are among the major causes of spills. Experience has shown that BMPs can be appropriately used and BMP plans can effectively reduce pollutant discharges in a cost-effective manner. BMP plans should reflect requirements for Spill Prevention Control and Countermeasure (SPCC) plans required under section 311 of the CWA, and may incorporate any part of the SPCC plan into the BMP plan by reference. BMP plans should also assure that solid and hazardous waste is managed in accordance with requirements established under the Resource Conservation and Recovery Act (RCRA). Management practices required under RCRA should be expressly incorporated into the BMP plan.

In addition, each of the following 9 specific requirements should be addressed in the BMP plan to reduce pollutants in runoff from the plant:

- BMP Committee
- Risk Identification and Assessment
- Materials compatibility
- Employee training
- Preventive maintenance
- Reporting and notification procedures
- Good housekeeping
- Visual Inspections
- Security

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A brief description of these requirements follows[14]:

BMP Committee

The BMP committee identifies specific individuals within the plant organization which are responsible for developing the BMP plan and assisting the plant manager in its implementation, maintenance and revision. The activities and responsibilities of the BMP committee should address all aspects of the facility's BMP plan. However, it is preferred that plant management, not the committee, has overall responsibility and accountability for the quality of the BMP plan.

Risk Identification and Assessment

The BMP plan should reflect an assessment of the pollution potential of runoff generated from specific areas of the plant. The plan should inventory the types of materials handled, the location of material management activities and types of material management activities.

The BMP Committee should assesses the layout and activities at the plant identified as high priority areas with a significant potential for contributing pollutants to the drainage system. Factors to consider when evaluating the pollution potential of runoff from various portions of an industrial plant include:

- loading and unloading operations;
- outdoor storage activities;
- outdoor manufacturing or processing activities;
- dust or particulate generating processes; and
- waste disposal practices

Factors such as the toxicity of chemicals, quantity of chemical used, produced, or discharges, history of NPDES permit violations, history of significant leaks or spills of toxic or hazardous pollutants, nature and uses of the receiving waters should be considered.

Materials compatibility

Incompatibility of materials can cause equipment failure resulting from corrosion, fire or explosion. Equipment failure can be prevented by ensuring that the

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[14] Additional technical information on BMPs and the elements of a BMP plan is contained in the publication entitled "NPDES Best Management Practices Guidance Document", USEPA, June 1981.

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materials of construction for containers handling hazardous substances or toxic pollutants are compatible with the container's contents and surrounding environment.

Employee Training

Employee training programs are necessary to inform personnel at all levels of responsibility of the components and goals of the BMP plan. Training should address topics such as spill response, good housekeeping and material management practices.

Preventive maintenance

A preventive maintenance program involves inspection and testing of plant equipment and systems to uncover conditions which could cause breakdowns or failures which can result in discharges of chemicals to surface waters. A good preventive maintenance program includes identification of equipment or systems to which the program applies, periodic inspections or tests of identified equipment and systems; appropriate adjustment, repair, or replacement of items; and maintenance of complete records on the equipment and systems.

Reporting and notification procedures

A system to keep records of incidents such as spills, leaks and improper dumping, along with other information describing the quality and quantity of storm water discharges should be established and maintained.

Good Housekeeping

Good housekeeping requires the maintenance of a clean, orderly facility. Training of employees in housekeeping techniques and establishing housekeeping protocols reduces the possibility of mishandling of chemicals or equipment.

Visual Inspection and records

Qualified plant personnel should be identified to inspect designated equipment and plant areas. Typical inspections should include examination of pipes, pumps, tanks, supports, foundations, dikes, and drainage ditches. Material handling areas should be inspected for evidence of, or the potential for, potential impacts on runoff quality. A tracking or follow-up procedure should be instituted to assure that adequate response and corrective action have been taken.

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Security

A security system prevents accidental or intentional entry onto a plant which might result in vandalism, theft or other improper use of plant facilities. The BMP plan should describe the existing security system and identify necessary improvements.

Site or Pollutant-Specific Best Management Practices

In addition to the requirements of BMP plans discussed above, more advanced site or pollutant-specific BMP requirements can be developed. These site or pollutant-specific BMPs can be described in terms of the following four categories:

- Prevention
- Containment
- Mitigation
- Ultimate Disposition

Table 2 provides a more complete listing of the types of BMPs associated with each category.

3. Diversion of discharge to Sewage Treatment Plant

Where storm water discharges contain significant amounts of pollutants that can be removed by a sewage treatment plant, the storm water discharge can be discharged to the sanitary sewage system. Such diversions must be coordinated with the operators of the sewage treatment plant and the collection system to avoid worsening problems with either CSOs, basement flooding or wet weather operation of the treatment plant. Where CSO discharges, flooding or plant operation problems can result, on-site storage followed by a controlled release during dry weather conditions can be considered.

4. Traditional Storm Water Management Practices

In some situations, traditional storm water management practices such as infiltration devices, unlined on-site retention and detention basins, regional controls (off-site retention or detention basins) and oil and grit separators can be applied to an industrial setting. However, care must be taken to evaluate the potential of many of these traditional devices for ground water contamination. In some cases, it is appropriate to limit traditional storm water management practices to those areas of the drainage system that generate storm water with relatively low levels of pollutants (e.g. many rooftops, parking lots, etc.). In addition, other types

Table 2: Advanced BMP Alternatives

		Mitigation		
Prevention	Containment	Cleanup	Treatment	Waste Disposal
Monitoring	Secondary Containment	Physical	Liquid-Solids Separation	Landfill
Nondestructive Testing	Flow Diversion to Secondary Containment	Mechanical	Volatilization	Land treatment
Labeling	Vapor Control	Chemical	Coagulation/ Precipitation	Surface Impoundments
Covering	Dust Control		Neutralization	Reclamation
Pneumatic and Vacuum Conveying	Sealing		Ion exchange	Discharge to Surface Water
Vehicle Positioning			Chemical Oxidation	Deepwell Injection
Dry Cleanup			Biological Treatment	Discharge to POTW
			Thermal Oxidation	Offsite Disposal

of controls such as spill prevention measures, can be considered to prevent catastrophic events that can lead to surface or ground water contamination.

5. Elimination of Pollution Sources

In some cases, the elimination of a pollution source may be the most cost effective way to control pollutants in storm water discharges associated with industrial activity. Options for eliminating pollution sources include reducing on-site air emissions affecting runoff quality, changing chemicals used at the facility and modification of material management practices such as moving storage areas into buildings. An example of source elimination is that many wood preserving facilities which have used pentachlorophenol as a preservative in the past have switched to other preservatives. An example of source elimination at wood preserving plants using inorganic preservatives such as chromated copper arsenate (CCA), is the use of runoff from drip pads as a water supply in making aqueous preserving solutions.

Appendix I: REFERENCES

1. National Combined Sewer Overflow Strategy, USEPA, August 10, 1989.

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REAL-TIME CONTROL OF COMBINED SEWER SYSTEMS FROM THE USER'S PERSPECTIVE

By Jean Marie Delattre[1]

1. INTRODUCTION

Real Time Control (RTC) systems are generally considered as a new complementary alternative to civil engineering works, when a sewer network has reached an advanced stage of complexity over a long period of intensive urbanization. Recently, it has also become an attractive support for extensive data collection and knowledge accumulation.

Over the last few decades, the response to urban drainage and runoff pollution problems was mostly oriented towards civil engineering works and legal policies that were supposed to provide definite solutions to the problems. Construction of treatment plants created a significant quality improvement in receiving waters, but made more obvious to the public the sudden impacts of overflows during precipitation events on a partially-recovered aquatic environment.

The new large sewers and detention facilities that were designed for an extreme synthetic rainfall event did not completely solve the flooding problems, but sometimes simply moved the flooding damages to other locations, and produced new unexpected flows. The need for understanding the unsteady flow behavior in combined sewer networks has generated implementation of measurements and simulations. Furthermore, necessary adaptations to a constantly evolving urban process led to improved operation of existing facilities, and ultimately to some large scale RTC systems.

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Although research people and an increasing number of practitioners are convinced that we should "live with" the drainage and pollution problems, many politicians still would rather find easy solutions to "get rid of" the sewer problems through a series of short term actions. As a result RTC alternatives should not only respond to a long term needs but also provide short term results to gain steady and substantial financial support.

On the other hand, the public is very much aware of sudden environmental impacts, which forces technicians towards sort of regulated systems. The engineering response is how far it is feasible to manage peak effects of urban drainage and pollution overflows within a dynamic urban environment.

The exponential improvements of electronics and the availability of computers at relatively low cost, in conjunction with a more cautious attitude on the part of decision makers toward the construction of new large sewers, have provided more support for the implementation of reliable RTC alternatives. More than strictly implementing a conceptual approach of flow control, the design of RTC systems is now oriented toward gaining the acceptance of both decision makers and sewer personnel, thereby avoiding disruptions to the existing organization and threats to long term RTC performance.

2. DESIGN OBJECTIVES AND OPERATING FUNCTIONS

The first condition for implementing a RTC system and achieving short term results is to check the potential capabilities for control within the sewer network (e.g. volume and location of storage capacities), then to get the water authorities defining common objectives for planning, design, construction, maintenance and management of the sewers.

Monitoring a sewer network (raingage and water level sensors, runoff and flow simulations) usually is the first step toward a more accurate understanding of existing flow patterns, on the way to a more complex RTC system.

The decision to start an overall RTC project needs a political agreement and a willingness of sewer managers to integrate existing independent local controls and to update existing organization schemes.

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2.1. Global objectives from the design perspective

The 2 main global objectives generally turn out to be:

(a) Reduction of magnitude and frequency of damages caused by floods from sewers

(b) Reduction of annual and peak pollutant discharges to the receiving waters, measured in terms of observed environmental impacts

The public response

Urban communities desire an unconstrained way of life, specially regarding freedom from dangerous environmental impacts. They strongly respond to instantaneous thresholds and generally do not accept the concept of the probability that they will be flooded, especially when flooding had not occurred previously.

Even though sewer authorities cannot expect a high acceptance of sewer constraints, the public in general tends to understand limited negative impacts if adequate information is provided before, during and after the causing event, and if it is consistent with adverse physical conditions in the affected area.

The sewer personnel response

Operating personnel of a RTC system can be scared by discovering that floods or overflows in some way depend upon their action, when previously they could blame an improper design or complain about the 10-year event. Some lag time between installation and routine operation may arise from this concern.

Operators need a strong collective backing from the sewer organization to start on-line control decisions, especially to move gates during precipitation events. This situation causes some RTC projects to remain static supervised sewer systems rather than controlled systems.

RTC or real time supervision (RTS) ?

Before implementing a RTC system, a detailed evaluation of existing and planned detention and diversion facilities should be carried out, to define the nature, dimension and frequency of use of control schemes as well as the level of interdependence of operator RTC decisions. In fact, one may ask the following question: did we design a RTC system but wind up with a RTS system? Was the reaction time available with the RTC system long enough to allow some action from an operator during the hydrologic response time of controlled sewer sub-networks?

Economic limitations

At the decision stage of a project, the economic evaluation of RTC systems to obtain the necessary financial support is a tough and biased task. This is because there usually is no significant short-term benefit to be expected from dynamic control.

This situation leads RTC projects to find immediate benefits, such as reduction of maintenance and energy costs at pumping stations, local control at detention basins, and higher removal of total pollution load at treatment plants.

2.2 Expected functions from the operation perspective

Considering the intuitive expectations of people who have been conducting a manual and static operation of sewers for many years before a RTC system is implemented, the first obvious requirement is to help workers solve their routine tasks. The logic of improvement from an organizational perspective would claim that only after achieving a satisfactory level of this basic goal can RTC introduce new techniques to progress to a dynamic control that will be validated by cumulated experience.

Information on failures and malfunctions obtained through a monitoring system is a familiar task that is performed for many automatized pumping stations or treatment plants, but its integration into an RTC system can provide higher performance and understanding during rainfall events, and help to define proposals for future improvements. The goal of RTC is not to replace all manual operations, and "during event dynamic control" should be implemented on a limited number of selected sites, at least at the outset.

Operational objectives can be defined as follows:

(a) Better protection and assistance for workers during their daily inspection and maintenance activities

(b) Provide information about flow measurements and malfunctioning sewer equipment

(c) Update and improve guidelines for anticipated manual operation where local control is not conducted automatically

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The sewer physical configuration is not static.

Buried sewers are still inspected (more frequent but shorter inspections), and all workers are conscious that they move within a dangerous environment (indeed they get extra salary because of sanitary hazards), and their first objective is to be safe when they stay within or walk along a sewer.

Unfortunately, RTC adds new hazards since gates and transient flows can be activated from sensor signals through control algorithms. Consequently, gates and actuators should be set back on manual operation when workers move downstream, otherwise RTC would not be accepted from a security standpoint. When hydrological assistance and locking facilities are provided to workers, dynamic control schemes are more easily accepted. Figure 1 provides a diagram showing RTC coordination procedures.

So, the initial state of the network before a rainfall event cannot be considered as a fixed static configuration from one day to another. The control center enforces coordination to get an acceptable configuration for RTC at each day of the year, depending on expected rainfall pattern (dry weather, low rain, moderate rain, high rain, convective instability).

Coexisting manual and automatic operation

Sewer personnel will not accept RTC as a "spy system" which does not allow manual operation of gates and weirs (movable beams), just because some RTC assumption requires that any flow variation should be originated by an automatic device. RTC operation should find a compromise in which experienced workers retain the initiative in sites where adjustment of gate position is not very dependent upon rainfall intensity, and dynamic control of unsteady stormwater flows at detention basins or combined sewer overflows along interceptors is conducted exclusively by trained people at a control center.

Such an approach requires active coordination and good communication support within the RTC system, to save time and prepare decisions before, during and immediately after precipitation events. In this context, "before" is related to assistance, "during" to action, and "after" to evaluation. One may therefore guess the benefit of knowing in advance the precipitation patterns, and even more so the predicting of the magnitude and distribution through time and space of rainfall intensity (e.g. starting time, duration and mean rainfall intensity).

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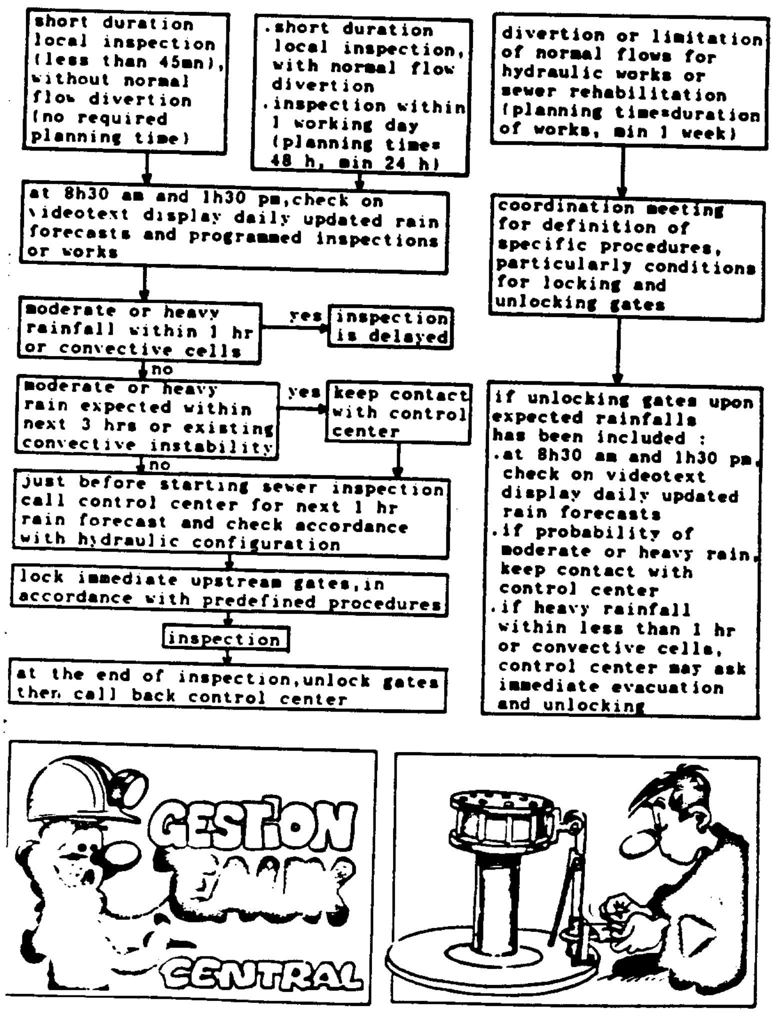

Figure 1. Coordination Procedures for Sewer Inspections of Works Upon Direct Influence of Local RTC Actuation

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2.3 Correcting and complementary functions

Let us go through some additional considerations for implementing a RTC system. Many cities started building combined sewers, then decided to promote separate systems (sanitary sewers for sewage and stormwater sewers for runoff). Unfortunately, sanitary sewers carry clean water (infiltration or accumulated runoff from local inlets which result in exceeding capacity), and stormwater sewers receive illegal wastewater discharges, for which no short term action can be expected for political and economical reasons. Sewer authorities have no choice, and should improve this situation and operate dynamic controlled transfers at selected sites. A RTC correcting function will be to reestablish some sort of separate sewer systems. Also, RTC systems can provide some support for non-structural alternatives through warning procedures, such as traffic diversion in case of local street flooding, or activation of people on duty during high intensity rainfalls.

2.4 Long term potential objectives

The state of the art of RTC does not allow too much confidence in managing complex pollution problems along a sewer network, because continuous measurement and on line simulation of quality parameters is still unsatisfactory for large scale operation. Also, RTC has difficulty integrating long term behavior, e.g. weekly, monthly and seasonal accumulation, deposit and washout processes. Prediction of suspended solids depends strongly on phenomena between precipitation events and is very correlated with urban aggregated production of pollutants. One next step in RTC development might be to include some mechanical approach to transportation and deposition of suspended solids in sewers where cleaning constraints are critical, through a supervision of measured, calculated or simulated velocities.

This overview of design objectives and operation functions shows that we should not dream about a perfectly integrated RTC system. It is necessary to make a compromise with the existing organization and to carefully manage development steps, otherwise RTC operation will be time consuming and ineffective.

3. IMPLEMENTATION OF SUPERVISION AND CONTROL SCHEMES

The main question from the users perspective is the effectiveness of RTC systems, in terms of sewer situations being improved, of sewer personnel using outputs of the system, of information requirements being satisfied on time, etc. Operational results should be relevant more than very accurate, and should be consistent from one situation to the next. Therefore, similarly designed control schemes may differentiate in the long run, depending on the specific operational approach and organizational strategy. Since the first RTC systems in the 70's, we moved from monitoring centralized systems with almost no intelligent local control, to a conceptual supervisory control of a few intelligent local controls, and more recently to some integrated supervision of a broader range of sewer operational tasks. That means that a flexible and adaptive design of RTC systems is now a fundamental requirement from the users perspective.

The actual trend can be summarised as follows:

(a) A careful approach of dynamic control

(b) An extension of supervision functions

(c) A need for anticipation of precipitation events

Integration of industrial technology, experimental research, validated knowledge of the sewers, along with a close on-site collaboration, is now the usual approach for RTC projects.

3.1 Control levels

Most of the existing RTC systems have been developed under similar control schemes:

(a) A basic level: sensors and actuators

(b) A local control (on-site control)

(c) A supervisory control (control center)

Levels a and b are generally connected with wired-hardware, levels b and b mainly communicate through phone lines, and level c includes computer interfaces. Depending on the network configuration, transmissions to major local controls are supported by private lines (particularly along interceptors) or public dedicated lines.

The greatest diversity of RTC implementation comes in the design and operation of the control center, though some kind of implicit agreement may exist for sensors, actuators and local control. We will not go through an extensive description or comparison of all RTC components but rather focus on required performance, constraints and limitations in a sewer environment.

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3.2 Sensors and actuators

3.2.1 Rainfall,water level and velocity sensors

Rainfall gages

Reliable rainfall measurement is a usual basic requirement for any RTC system. The mechanical tipping bucket technology is widely used, probably because it has been extensively used by weather services. Its precision is 0.1 mm. Measurements of rainfall intensities over 240 mm/hour are not accurate, and measurements over 100 mm/hour are usually underestimated. An optimal location is not easily available in urban environment because of vandalism and casual obstruction. A density of 1 raingage/10 km^2 seems to be a normal reference for urban drainage, but it is still insufficient for very convective precipitation. Neither statistical analysis nor predefined estimates of rainfall reduction with area can be used for RTC operation, since RTC deals with real, rather than synthetic, rainfall events.

Meteorological radar

The first hydrological application of meteorological radar was for river flood warning. Radar is now being used in sewer RTC operation, where response times of urban sub-catchments are very short, oftan less than 1 hour. A rough anticipation of rainfall intensity and space distribution is helpful for simple operational decision schemes and for preliminary warnings, through linear wind velocity and steady direction translation. Research is in progress to get 1 hour forecasts and on-line calibration of precipitation estimates from radar. The benefit of meteorological radar for a RTC approach is illustrated through the Seine Saint-Denis experience (see Figure 2).

Water level sensors

Most RTC decisions still rely on water level data, some of which are stored locally on graphic recorders, magnetic tape or RAM, for periodical validation and statistical analysis. Piezoresistive and ultrasonic sensors are extensively used in RTC systems. Ultrasonics are more attractive for sites with open access, while piezoresistive sensors provide a satisfactory response for buried sewers that sometimes flow under pressure. Most problems come from reference level calibration and amplitude drifts through time, and from failures caused by electrical overload or lightning. Duplication of sensors is limited to a small number of strategic control sites, such as flow through detention basins. An aggregate elevation error of

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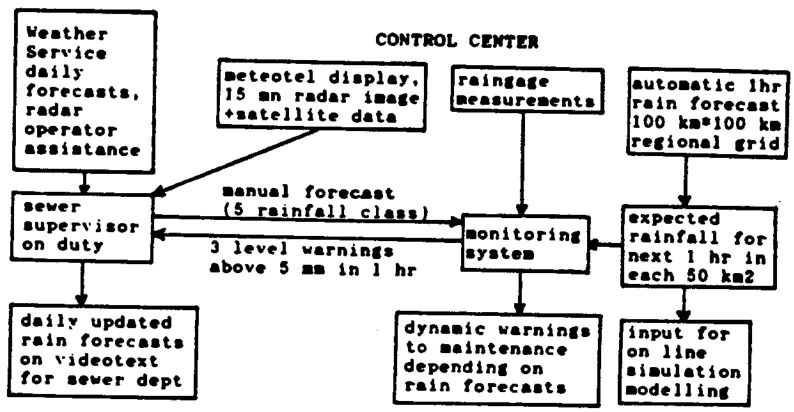

Forecast Based on Radar Imagery for 7/8/89 (1540 and 1600)

Average Speed = 33.1 km/h
Direction = 52.9° or NE

(Previous Values 23.8km/h and 70.3° or ENE)

Forecast for the Next Hour

Zone	Cumulative Rainfall (mm)	% Surface Rain>5mm in 1 hr
Seine-Saint-Denis	2.2	1.4
Croult-Moree-Vieille Mer	2.2	0.9
Bords de Seine	1.0	0.0
Bords de Marne	3.0	3.3
Reseau Unitaire	2.2	1.4

(Source: Seine Saint-Denis County)

Figure 2. Operational Use of Meteorological Radar and Raingage Information for a Sewer RTC System

+5 cm, from the sensor signal down to the final value on a display, is acceptable for a supervisory operation, and is feasible with no advanced maintenance. An aggregate precision of +10cm should be supported by any local control scheme with no significant impact. A significant effort beyond the filtering techniques will be necessary to get reliable on-line validations of water level data. Figure 3 shows an example of maintenance criteria for water level sensors in a large scale RTC system.

Velocity sensors

Installation of velocity sensors for RTC mainly responds to requirements for knowledge about flows, and RTC operation does not still fully integrate these data within dynamic CSO control schemes. Ultrasonic sensors for measuring horizontal velocities at one or two selected water levels are commonly used, and accuracy is dependent on absence of bubble phenomena and hydraulic re-suspension of solids during high flows. Combining velocity measurements with rainfall and water level data, then checking their consistency with calculated or simulated flows, may provide some basis for a first on-line validation.

No large scale experience is available in operating water quality sensors for RTC sewer systems. As a first step, it seems reasonable to utilize trend analysis applications for a preliminary control of combined sewer overflows, combining velocity and suspended solids data.

3.2.2 Actuators

Most of the actuators are pumps and gates, but there is an increasing interest in experimenting with new hydraulic configurations, mainly due to maintenance considerations.

Gates

A common approach is to use waterproof electrical drives for position controlled gates and hydraulic devices for regulating gates, including a predefined safe position in case of a major regulation failure. Most gate operation problems come from leakage associated with improper gate seating during construction, and from corrosion or deposit problems associated with insufficient use. Common types of gates used for sewer flow control are sluice gates, radial gates, flap gates and, increasingly, adjustable sharp crested weirs.

river level conditions	activation of pumping stations: river is high		C/A	river is low
rainfall forecast	> 5 mm in 1 hr		< 5 mm in 1 hr (B/A)	
criteria	class A		class B	class C
local control priority	.waste water pumping stations .high impact dynamic control		local control with low impact in dry weather or low rainfall	no control activation
deadline for (*) replacement	24 hrs		3 days	10 days
consequence on usual maintenance planning	dry weather, low rain forecast	within working day	function of daily planning	function of week planning
	moderate or heavy rain forecast	immediate interruption of present task, ask for help if > 2 workers required on-site	within working day	within working day if no level sensor in class A or B
priority for maintenance	1. predefined sequence ordering			
	2. < 2 workers on-site and short time travel		no local intelligence available	preference for usual routes
	3. back return control schemes are inadequate for heavy rainfalls		easy planning routes	

* time between detection at the control center and back return to normal operation

(Source: Seine Saint-Denis County)

Figure 3. Maintenance Criteria for Water Level Sensors in a Large-Scale RTC System

Specific hydraulic configurations for flow control

Inflatable dams - this hydraulic device was first implemented on rivers in the USA. The control is based on filling and emptying volumes of air or fresh water within a low pressure recirculating system. All hydraulic and electric equipment are installed in a separate room disconnected from the sewer, and maintenance constrainte are lower. The main limitation for regulation of combined sewer overflows is the lack of reliable device to measure accurately the height of the dam, whether water is flowing over it or not.

Vortex flow control (hydrovex)

This static device is extensively used in Germany to control combined sewer inflows being carried to the treatment plant during a precipitation event. Its performance is insured through a standard design, and maintenance is minimal since there is no moving component.

Air-regulated priming siphons

The use of siphons instead of gates for stormwater flow control in sewers resulted from construction and maintenance considerations. Much of this hydraulic structure is concrete without moving parts, and negative pressure inside the siphon is controlled through an air entrance regulation. Corrosion is a smaller problem, maintenance access is easier and less costly, and regulation components are standard industrial products (see Figure 4). The use of regulated siphons looks promising, but regulator performance still can be improved through more research and on-site operational evaluation.

3.3 Local control

3.3.1 Local control functions

Local control is carried out at pumping stations, detention basins, diversion of combined sewer overflows, hydraulic measurement sites, etc. When control schemes are complex or very dependent upon supervisory conditions, there is a widespread tendency to use a local computer to perform a flow control strategy, and to activate safety control schemes depending on failure configurations.

During precipitation events, an operator at a control center may take a decision to select new set points for flow control, or to give priority to a predefined gate position, or to start selected pumps. Local set point values are assumed to handle, independently at each site,

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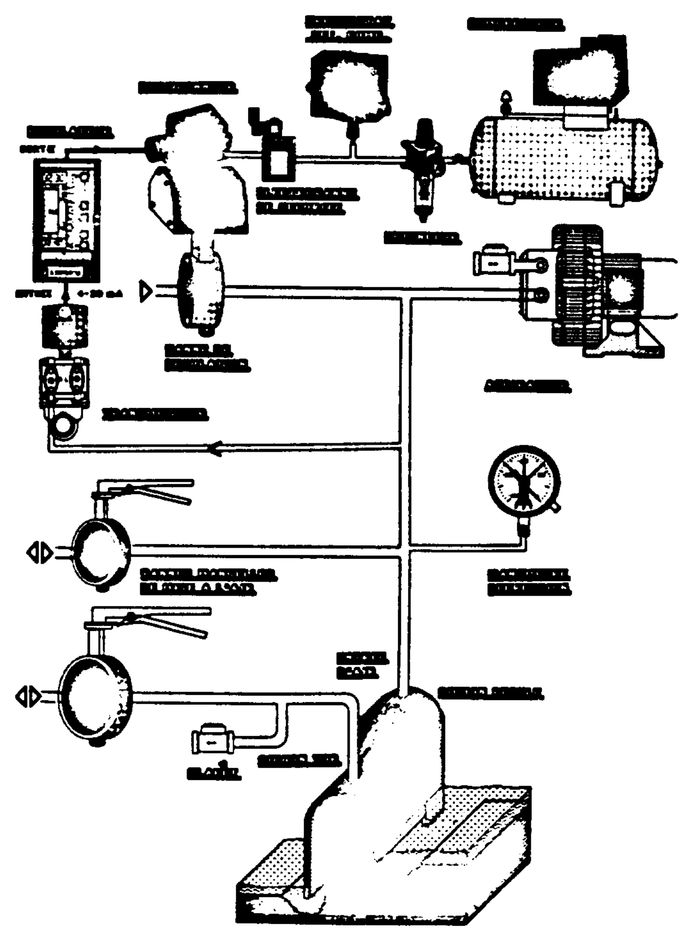

Source: Seine Saint-Denis County

Figure 4. Configuration of an Air-Regulated Priming Siphon

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a high percentage of significant events, and usually they will be changed only after validation by an experienced operator, or through a supervisory analysis and some guidance from simulations. From the user's perspective, allocation of new set points is considered a constrained deviation from a known reference, which is local control.

Depending on the type and duration of failures, flow control performance will be lowered progressively from an excellent supervisory control down to an ultimate static control, if no manual operation is available at this critical moment. Though duplication of controller components might be attractive, it is not obvious that such a design would be more efficient for extreme situations, because of maintenance constraints and random environmental hazards in sewers. Back-return strategies, including activation of separate electromechanical components, are often preferred by practitioners, who find it cheaper and closer to the traditional attitude of sewer personnel.
At a first stage of operation,it is not very productive, from a security standpoint, to implement complex regulation schemes to control actuators that should work on a low frequency basis, and proportional integral derivative (PID) regulation should be used restrictively and checked with simulator tools.

3.3.2 Operation constraints

Some RTC operation teams try to be actively present from the very beginning at the design stage. Under such conditions, lag time before operation has been significantly reduced and more reliable control schemes have resulted.

Specifications for local control should respond to environmental constraints (namely humidity and corrosion), and include stainless steel components, heating, easy access for maintenance, standard industrial components, adequate location for wire connecting plastic pipes within the concrete works, enforced control of electrical installation (adequate connections, reliable quality of components, protection against current fluctuations, exhaustive on-site tests, etc. Then, for maintenance, electrical wiring diagrams need to be periodically checked and updated, and a proper and logical identification of sensors and actuators should be agreed upon at the beginning and used at all levels of the RTC system.

Maintenance of local control equipment requires a medical care type of approach. Periodic exercising of actuators and control schemes, as well as guidelines for identifying probable failure causes, are necessary to increase the overall reliability of large scale RTC systems during rainfall events.

3.4 Supervisory control

The control center configuration is largely dependent upon the RTC organization scheme. The actual trend is to implement flexible separate communicating systems that may support future extension or renewal. Moreover, it may be convenient to implement separate compatible hardware subsystems for RTC tasks, and for off-line evaluations or new developments.

RTC operators ask for time saving facilities and visual comfort. This means shorter response times (less than 3 sec), user-friendly operations, and better quality of graphics, perticularly for trend analysis and boundary estimations. Even though computer performance steadily increases, operational adjustments of computer applications should be managed stepwise to minimize the disturbing effects on RTC operators.

The tendency of new RTC systems is to collect, process and visualize physical data with a minimum validation from the operator, in order to provide him dynamically at the right time the relevant information he needs to take decisions. Rainfall anticipation provides an operator extra time to prepare supervisory tasks (check present network configuration and controller status) and work a first guess on expected control scheme (where, when).

These criteria require extended functions of the control center that will be dynamically activated upon a combination of significant changes in telemetered data, in precipitation conditions or from an external action of an operator.

Figure 5 presents a large scale control center configuration, including on-duty operation.

Monitoring systems

Monitoring systems are expected to run simultaneous on-line operations, and they are generally built on multi-processor and multi-bus hardware. They should control scanning periods, data transfers from and to local controls, on-line parametering of a data base, and handle alarms, graphical displays, daily printouts, computer interfaces. The manufacturing industry has accumulated a large experience in building reliable monitoring systems that have been working successfully within an industrial environment. However, some performance problems in processing velocity

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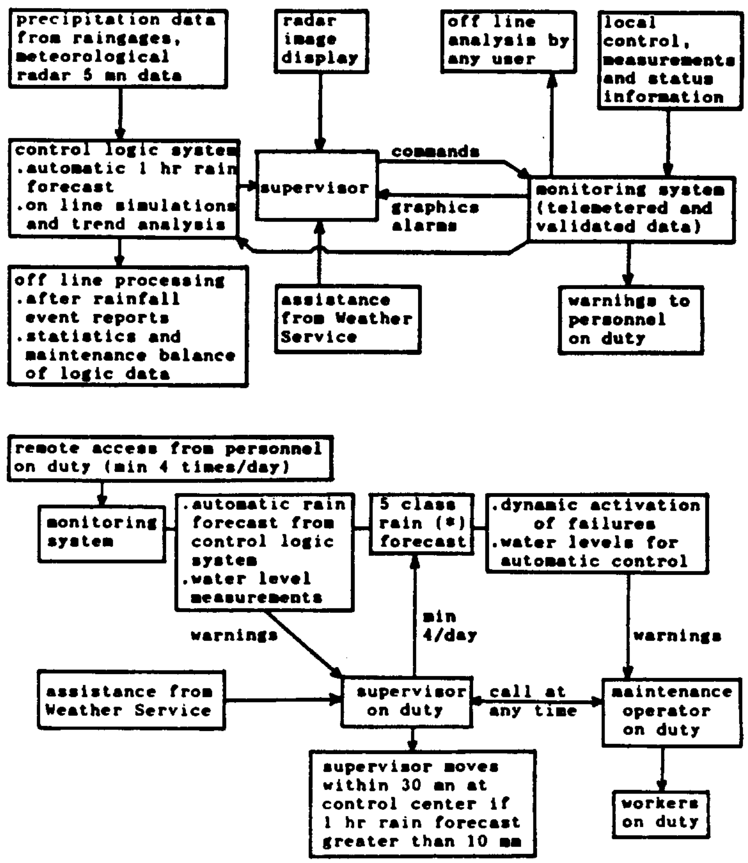

* 5 class rain forecasts: dry weather, low rain, moderate rain, heavy rain, convective instability

Source: Seine Saint-Denis County

Figure 5. Presentation of a Large-Scale Control Center Configuration Including On-Duty Operation

and memory handling may arise with all designed functions running, when adding specific new functions or updating hardware configuration.

Control logic systems for reduction of floods and combined sewer overflows

Generally, combined sewer overflows (CSO) start occurring from moderate rainfall events, while floods are less frequent. For CSO, some knowledge can be collected from rules, based on experience with manual operation, that have been used for years, together with some practical reasoning, but almost no previous validated experience or updated knowledge is available for urban flood control.

On line simulations bring a more comprehensive understanding if an adequate graphical evaluation is carried out with validated measurements and observations. Off-line simulations can help by creating some rough comparison of flow patterns for a first trend analysis by the operator.

Figure 6 shows graphical outputs of on-line simulation modelling at a detention basin, for a 2-year return period precipitation with a short duration but high intensity at the beginning. The precipitation amount within 1 hour varied from 25 mm at the detention basin down to 18 mm in the upper parts of the catchment, and maximum intensity was 100 mm/hr within a 5 minute interval and 60 mm/hr within a 15-minute interval.

Around 30.000 m^3 were stored at the detention basin, which regulated a constant 8 m^3/sec outflow, since the operator decided to apply a local strategy. Underestimation of simulated inflows and water levels at the detention basin comes from a greater contribution of pervious areas than estimated by the model. Such on line outputs were considered useful for a trend analysis by the operator.

The optimization technique is derived from dynamic programming, with a coordination procedure to reduce the dimensions of the problem to be solved, and is combined with simplified simulation models. It is actually used for regulation at 3 detention basins in the Paris area, and it is viewed as a deviation capability from local control strategies through an adaptive during-event analysis, including possible decisions at each 30-minute interval. It is sensitive to sewer configuration disturbances.

A heuristics approach, namely expert systems, looks promising where a relevant accumulated knowledge is available, and where RTC is viewed as an extension and

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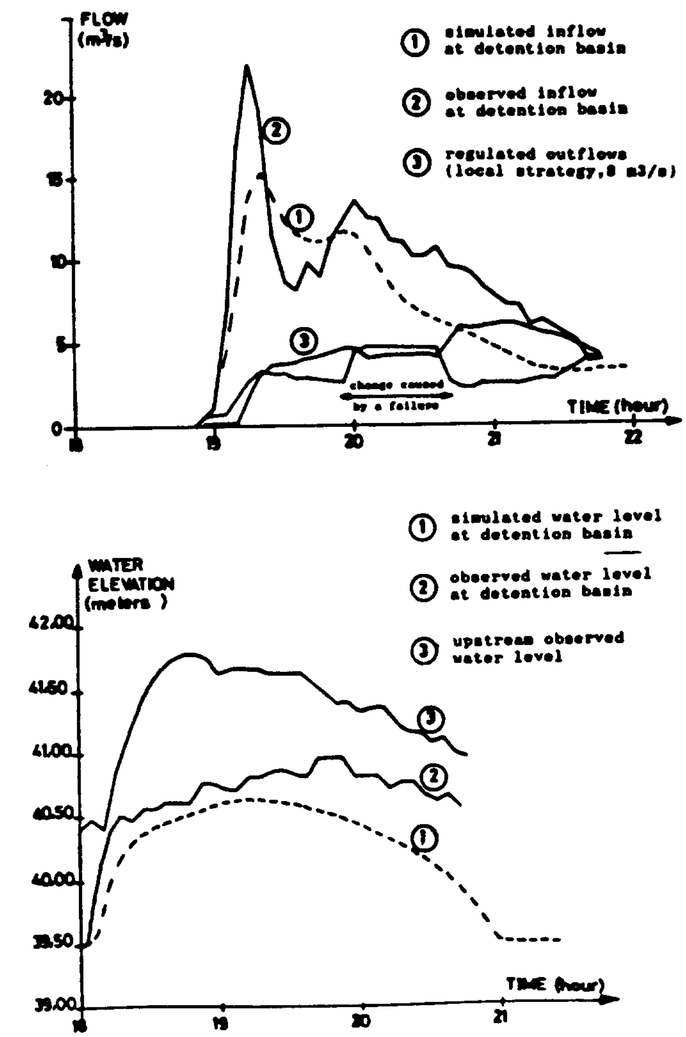

Source: Seine Saint-Denis County

Figure 6. Outputs from On-Line Simulation Modeling for a Storm in the Paris Area, August 7, 1989.

smooth adjustment of existing practices. Some progress is expected from learning procedures. No large scale heuristics approach has reached the stage of routine operation, but implementation is planned for supervision functions at cities like Bremen and Marseille.

Human validation at a control center is considered a necessary condition for RTC sewer operation, probably because a human operator shows a higher ability to identify uncertainty and to solve unexpected situations, if he is duly assisted with visualizing and modelling tools. One of the main limitations for flood control is that an operator alone does not feel able to produce complex decisions within a short interval of time, let us say one hour, for a few critical situations per year. The operator prefers not to change from local control, unless someone else agrees he should do it. Any rainfall anticipation will result in a great benefit for an operator, and a poor forecast is better than no forecast at all. Therefore exercising supervision for any significant precipitation (let us say 10 mm), evaluation after each damaging precipitation, even though there was no impact, and extending presence at the control center for extreme events, seems the proper way to encourage an operator to use aided decision tools.

One main conclusion is that operational implementation of any control logic system is costly and time consuming. However, when used on line with a true precipitation it provides some prospective view of what might occur, and it becomes a learning process for any further validation when used off-line.

4. EVALUATION OF OPERATION PERFORMANCE

4.1 Operational constraints

Maintenance of local control facilities faces strong environmental constraints, such as floating debris, corrosive and humid atmosphere, underground access below streets, failures caused by random urban rehabilitation works, traffic jams during rainy conditions, etc. For large scale RTC systems, it is necessary to make some balance of what can be really achieved at each site from a maintenance perspective and to set up priorities for corrective actions. That might lead to such measures as modifying a local control design, making spares more easily available, delaying or simplifying temporarily a control scheme, or modifying the personnel allocations. The tendency is to implement simplified testing procedures on portable devices, then to remove failing components and replace them by similar or equivalent spares.

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The feasibility of RTC alternatives depends also on the ability to solve human constraints:

(a) Sewer workers generally have a lot of experience but a low level of technical qualification. The questions are: what quality of maintenance should be achieved? What is the acceptable annual cost for maintenance? How far should existing personnel still be involved within a RTC system?

(b) Substitution procedures (personnel on duty) should be considered, particularly at night or during week ends. In this regard, procedures to identify failures and to take corrective actions should be documented and included in training programs to be effective

(c) RTC alternatives introduce a new approach: anticipation, risk evaluation, and on-event coordination. Uneven responses to these changes may arise, if technological improvements are not shared by most of the personnel

One major problem of RTC sewer operation is performance evaluation, beyond any statistical or economical analysis. RTC operation teams would like to easily learn from historical significant events, and improve a reproductive intuitive reasoning for any future event. That seems feasible for trend analysis, but no clear answer exists to assess correctly new on-line control decisions from post-event evaluation.

4.2 An overview of the French experience in RTC control

At the present time, 7 urban districts are operating large scale RTC systems, and some other cities, mainly over 100.000 inhabitants, are extending local monitoring systems or making initial steps for implementing integrated RTC systems.

Main applications deal with pumping stations, stormwater detention basins and combined sewer overflows. Operating RTC systems make an extensive use of radar imagery, or expect to use it, for preliminary anticipation of rainfall.

Let us review the 7 above-mentioned systems and briefly evaluate each specific approach to RTC operation:

Regional Paris area system

The main purpose is to supervise water level measurements, and corresponding calculated flows, along regional trunk sewers that bring wastewater flows to Acheres treatment plant (25 m^3/s capacity), northwest of Paris, and to some extent improve its operation through a flow propagation analysis of very distant inflows from combined sewers. This system has been implemented since last year. First observations of temperature data allow some inference on variations of dry weather flows caused by precipitation.

Hauts de Seine county

This is one of the first implemented systems. It collects a large number of water level and velocity measurements, and a complete validation package has been associated with the centralized collection of data. A detailed and exhaustive industrial experiment has been carried out on regulation techniques for automatic sharp-crested weirs, and on-site application is now starting to control combined sewer overflows from an interceptor located along the Seine river as well as intrusion of river high flows during the winter season. Set point levels are freely selected by experienced workers from their accumulated knowledge, and off-line simulations provide a relevant understanding of the main interceptor.

Val de Marne county

Efforts have been first concentrated on supervision of a great number of pumping stations, particularly to protect sewers from intrusion of high flows of the Marne river during winter, installation of raingages and water level sensors, and use of radar imagery for assistance to sewer personnel. More recently, a supervision project of gates has been started, in connection with operation of new trunk sewers to Valenton treatment plant, south of Paris. A main short term supervisory objective will be adequate compliance with mean and peak flow amounts and quality standards required at the treatment plant, that will probably lead to some control at inlets from combined sewers.

Seine Saint-Denis county

The RTC system was implemented to improve flood control, but included capabilities for quality objectives and remote supervision. Much effort was first concentrated on dynamic control at detention basins. The use of meteorological radar for rainfall prediction has been very much integrated within the sewer organization. It provides support for coordination of daily sewer activities and preliminary warning of personnel on duty. This RTC system has reached a large scale operation, that includes increasing supervision and updated maintenance techniques.

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Bordeaux district

The RTC approach is oriented to solving flood control problems using detention basins, and to managing tidal effects, along with a very enforced limitation of runoff inflows from new urbanized areas. A full investigation and experiment on flow regulation at detention basins has been conducted, to set up a standard local control loop, that provides the highest admissible outflows, depending on precipitation measurements and intermediate inflows. The use of meteorological radar is very integrated within routine operation. A new configuration of RTC is being installed, with more emphasis on supervision functions and integrated flexible hardware subsystems.

Nancy district

Nancy district suffers from flash floods coming down from steep catchments to a flat urbanized area. The control center is shared with supervision of the drinking water supply. Main efforts have been oriented to setting up and operating laboratory and portable tools for checking performance of sensors, mainly raingages and water level sensors. Nancy district has accumulated experience in operating underground detention basins for flood control, with sludge deposit cleaning, under urban constraints.

City of Marseille

This is the most recent RTC system being implemented. The main problems are downtown flooding, as well as combined sewer overflows along the Mediterranean coast with higher environmental impacts on the main beach of the city. From the beginning, there was a strong willingness to enlarge supervision functions, and to enforce acceptance of the system by all personnel whose work was related with sewers. A clear choice was made to implement a broad expert system approach. It looks promising but no operation evaluation is available at this time.

5. CONCLUSIONS

Operating RTC alternatives need a progressive adaptation from a usual hydrological and technological approach to a dynamic organization of supervision, depending on expected meteorological situations and external disturbances from the sewer configuration.

Coordination constraints, derived from combination of sewer inspections with potential automatic activation of gates, require consistent efforts to supervise actual state of the

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controlled sewers at any time and provide meteorological assistance through anticipation of rainfall events.

The first goal of operating RTC is to gain the acceptance of sewer personnel and to provide easy communication and coordination with the control center. That may lead to the continuation of manual operation in sites where decisions are properly made based on intuitive experience.

Because available time for decisions is short during rainfall events, dynamic control is still progressing slowly, and the actual trend is to rely as much as possible on intelligent local controls, to take a minimum of relevant more than accurate decisions, and to be consistent from one situation to the next. It is not clear that a larger amount of more accurate telemetered data will produce the most reliable on line RTC decisions. Probably validated knowledge and cumulative experience, complemented by on-line simulations and a heuristics approach, along with a limited set of telemetered data, may respond as well as on-line supervision and decision process from an operator.

Finally, human validation at a control center is widely recognized as a necessary condition to identify uncertainty and to solve unexpected decisions in sewer control, and all efforts should be oriented to take care of the operator, otherwise the problem will move from combined sewer overflows to random date overflows.

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REAL TIME CONTROL OF COMBINED SEWERS: A U.S. VIEW

by Christopher G. Chantrill, M. ASCE[1]

Introduction

After completion of some demonstration projects in the early 1970s, combined sewer overflow (CSO) control, and consequently the development of its supporting technology, has lagged. This has been due to the regulatory emphasis on control of industrial and municipal sanitary wastewater. But now a switch in regulatory priorities has put surface water management on the national agenda. Workable practical ideas are needed as the U.S. works to solve its surface water problems on a tight regulatory timetable. Fortunately, a number of researchers and practitioners have made useful contributions to CSO control technology in the lean years. The work of Dr. Cello Vitasovic of the Municipality of Metropolitan Seattle, and Dr. Wolfgang Schilling of the Swiss Federal Institute for Water Resources and Pollution Control are notable.

Another trend affecting the planning and design of CSO control systems is the movement to enterprise wide networking, the linking of all computer based activities in an organization into a single communications network. Control systems used to operate as an island of automation at most utilities; it was not practical to build links with other activities. Today's trends require that utilities plan to integrate their computer systems together to share data and operating results.

Real Time CSO Control

"Real time control of combined sewer systems" is a rather general term that could apply to any control initiative that applies to a combined sewer system. It refers here to a comprehensive system, including central

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refers here to a comprehensive system, including central computers, communications, and local controllers, for city-wide control and coordination of storage facilities in a combined sewer collection system. The purpose of such a system is to control storage facilities and flow control devices in a combined sewer system to reduce overflows of combined sewage. Particularly interesting is the problem of coordination of storage at different sites in a sewer collection system to optimize use of storage on a system-wide basis.

The Driving Force -- Regulation

At the dawn of the Environmental Age -- way back in 1969 -- CSO abatement was part of a whole range of pollution control policy initiatives begun by the federal Environmental Protection Agency. But the mechanism for regulation of wastewater discharges, a permit system called the National Pollutant Discharge Elimination System (NPDES), emphasized the reduction of "point source" industrial and municipal treatment plant discharges. Federal funding of municipal pollution control projects concentrated on sanitary treatment plant expansion and construction.

Many municipal agencies who had begun developing plans for CSO abatement in the 1970s found that federal funding would not be available, and that their energies would be totally involved in meeting the tough federal standards for treatment plant effluent.

Substantial completion of the control of sanitary treatment plant effluents have freed up political energies to attack the problems of surface water runoff. The NPDES permit system has been overhauled to include regulation of stormwater discharges. Cities will need to be in compliance with the new standards by the mid 1990s. For CSOs, the standards will require no more than one overflow event per year.

In this accelerated environment, cities need to exploit all resources to achieve the desired surface water standards. Required is a coordinated approach that makes maximum use of existing resources, builds cost effective new surface water control facilities, and coordinates the whole into an effective, optimized operation. Computer based data acquisition and control strategies can help to make this work, minimizing the need for "concrete and steel" and helping coordinate the surface water management system of a city.

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A Brief History of Real Time CSO Control

Real time control of combined sewer systems has seen only limited application in the United States. A number of demonstration projects developed in the 1960s did not translate into a national program of combined sewer overflow control. The reason is not difficult to discover. Policymakers determined that the nation should concentrate on wastewater treatment as a first priority to achieve the national goals of fishable, swimmable rivers and lakes. And many older industrial cities had combined sewer systems that were severely distressed under dry weather conditions. Rectification of these deficiencies were more pressing than CSO control.

At present, there is a renewed interest in control of combined sewer overflows. Improved treatment plants have been constructed, and many collection system deficiencies have been remedied, and CSOs are back on the national agenda.

Demonstration Projects

In 1967, demonstration projects were funded by the U.S. federal government to investigate available technologies for control of combined sewer overflows. Demonstration grants were awarded to sewer agencies in Cleveland, Ohio; Seattle, Washington; Minneapolis, Minnesota; and Detroit, Michigan. These cities all set out to build systems to control storage in their combined sewer systems.

The systems were fairly similar in concept. A central computer with a man-machine interface was used to collect data on levels at storage control structures in the collection system. This information was used, either by an operator or a simple strategy program, as a basis for gate raise/lower commands that were transmitted to the storage control structures. Leased telephone channels were used to transmit data between the computer and storage control structures. Most used narrow band frequency shift key (FSK) tone telemetry for transmission of data; one system (Seattle) used time division multiplexers. Some of the control devices had local controls which allowed operation of the facility in a degraded mode if the central station was not on-line. Others could only operate under direct supervision of the central station computer.

All of the cities experienced problems getting their central computers operational. Off the shelf control software was non-existent, and everyone underestimated the amount of computer power and software development effort that would be needed to achieve a workable system.

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Next Generation

Several cities began development of combined sewer overflow control projects in the mid 1970s, including, Cleveland, Ohio; Chicago, Illinois; Milwaukee, Wisconsin; Philadelphia, Pennsylvania; and St. Louis, Missouri. Most of these cities were experiencing overflows during dry weather, and required sewer modifications to reduce dry weather overflows as well as build control structures to control CSOs.

Technology to implement real time control of CSOs had developed considerably since the first generation of demonstration systems. Powerful minicomputers were available as central computers, and first generation microcomputers were available as site controllers. Advances in software had yielded good quality operator interfaces.

Current Efforts

A number of U.S. cities are pursuing CSO control projects as government policy and priorities have once more brought CSO control onto the front burner. Cities with recent or ongoing CSO control projects include Cleveland, Ohio; Detroit, Michigan; Cincinnati, Ohio; and Seattle, Washington.

Technologies available for control and coordination of CSO control are now microcomputer based. A utility has a variety of options in implementing CSO control. An important consideration is integration with an overall information systems strategy, including collection system and treatment plant data collection and control, automated maintenance, scheduling, parts inventory, planning and design, regulatory reporting, and financial reporting.

Systems Technology

The promise of computers for control of manufacturing process systems and utility systems was grasped immediately by many engineers upon the development of the first computers. It was generally expected that the enormous power of computers could be easily put to work and that the problem of centralized control would be solved in the 1960s. It did not work out that way, because in single-computer control systems, typical for the 1960s, the processing power of the central computer was often overwhelmed by the communications workload between the center and the sensors and final control elements. Cybernetic serendipity would have to wait for inexpensive controllers

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powered by computers-on-a-chip which could be placed right next to the sensors and control elements.

Centralized CSO control has had a similar experience. The initial systems designed in the 1960s used a central computer that, in wet weather, would control every control element directly. For instance, in Seattle (Leiser 1974), CSO control structures would run under local controllers in dry weather. In wet weather, the local controller would be bypassed to allow direct control by the central computer of the raise/lower control of each gate. The procedure to move a gate involved the following:

A raise or lower command was issued and transmitted to the remote station.

A scan of the remote station was conducted to determine that the command was received and the gate was moving.

A periodic scan of the remote station was conducted to determine the progress of the gate movement.

A command was issued to the remota station to stop the raise or lower operation.

This process was, of course, conducted across leased telephone channels, which are most likely to fail during periods of precipitation. Viewed from today's perspective the approach seems seriously flawed and violates generally accepted standards for maintaining high system reliability. The next generation of systems would improve in these areas.

In the mid to late 1970s, the first generation of microprocessor based controllers became available. They provided the user with the ability to program local closed loop controls, perform analog and digital data acquisition, and communicate with a central station using asynchronous data transmission. Now it became possible to isolate the direct control of final elements at the local controller, and limit control action from the central station to changes in setpoint (Buzcek and Chantrill, 1984).

Today there exists a whole market of standard control products that are integrated together (at least within each manufacturer's product line) to provide a hierarchical structure for control of CSO storage facilities on a system-wide basis. The growth of networking standards now permits effective integration of control systems into other utility functions such as design and planning. Data collected by a control system can be easily and quickly used to analyze system operation, and provide a database for planning and design of capital improvements.

Control Software Developments

Considerable progress has been made over the last 20 years in developing computer models and control strategies for flow prediction and control of combined sewer collection systems. Notable efforts are those operating in Seattle, Washington and Lima, Ohio, and the development efforts of Dr. Cello Vitasovic and Dr. Wolfgang Schilling.

Seattle Control Software

Most of the demonstration projects for CSO control built in the early 1970s provided no more than supervisory control of gates and pumps in the collection system. In Seattle, software was developed to implement a system wide control strategy which represented an initial attempt to coordinate use of in-line storage in combined sewers. This strategy resided as an applications program in the central computer that controlled the remote in-line storage facilities. The program achieved the following objectives:

It provided elevated setpoints, less conservative than the setpoints used for local control without the central computer. This provided more effective use of system conveyance capacity.

It included a simple algorithm for spreading storage use among neighboring in-line storage sites.

It established priorities between different subsystems of the collection system for access to the conveyance capacity of the system. Areas of the system that would overflow into fresh water were given priority over areas that overflowed to sea water.

Lima Control Software

The City of Lima, Ohio developed a CSO control system in the late 1970s. Control software was developed (Brueck, 1982) to provide coordinated control of in-line storage facilities in the main riverfront sewer. A major feature of the work was to combine control of in-storage with control of river gates regulating overflows to the Ottawa River.

The Vitasovic Model Based Development

The Municipality of Metropolitan Seattle (Seattle Metro) is implementing a comprehensive upgrade of the combined sewer control strategy for its West Point collec-

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tion system, involving a five point implementation plan (Vitasovic, 1988). The plan includes:

1. Development of a hydrological model of the wastewater collection system.

2. Development of a hydraulic model of the conveyance system.

3. Instrument upgrade in remote stations.

4. Data base development.

5. Control strategies design and implementation.

This strategy is part of a utility wide Metropolitan Automation and Control System (MACS) project, which specifies computer and interfacing standards for all systems involved with data collection, control and reporting of collection systems and treatment plants. The system is based on Digital Equipment Corporation's DECNET networking environment.

Seattle Metro has emphasized the building of two models to provide flow prediction capability. The first model, the Runoff/Transport model, provides estimates of inflow to the system from measured precipitation and routes the flow down to large pipes used in the second model, the Routing model. The Routing model simulates the action of the larger pipes in the collection system, including difficult situations such as steep pipes, inverted siphons, pumping stations and control gates. It is based on work by Chen (1979) and Labadie (1978, 1980).

A large data collection effort was used to develop the data base to support the models. The Runoff model was based on 400 catchment basins. Data to describe the characteristics of the basins was taken primarily from 1:2400 scale topographic maps.

In designing control strategies, Seattle Metro staff worked closely with Dr. John Labadie of Colorado State University in establishing the conceptual framework for the development and testing of control strategies, using dynamic programming and optimal control.

In operation, Seattle Metro's system will provide a 6 hour forecast of inflows into the system using the Runoff/-Transport model, predicted rainfall based on a short term rainfall forecast, and actual system flows from real time data. The Routing model processes the estimated inflows and computes a forecast of flows in the major pipes and interceptors; it simulates the action of local controllers

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at in-line storage facilities. Based on the results of the initial simulation, an optimizing algorithm is activated to compute an optimal control vector. The Routing model is executed again, using this optimal control strategy in order to test its feasibility and check it against system constraints. When a solution is obtained that is both optimal and feasible, new setpoints are computed and used for control.

The Schilling Development Framework

Dr. Wolfgang Schilling has developed an important conceptual framework (Doering, et al., 1987) for solution of the combined sewer overflow control problem. His concepts display a global understanding of control systems in general, and surface water collection systems in particular. He has emphasized the hierarchical nature of control systems and the limitations of prediction. He has reminded practitioners of CSO control that the operations of a sewer collection system is governed by multiple, conflicting objectives.

The universal way of successful control systems is to divide up control responsibilities into bite sized chunks. Local, detailed control and movement of final control elements is assigned to local controllers as close to the final control elements and sensors as possible. Coordination of a group of controllers which can easily affect each other is done by an area controller, which specializes on area control issues. Systems-wide coordination is effected by a central controller, which coordinates the action of the area controllers.

For combined sewer systems, Dr. Schilling has proposed three levels of hierarchy:

Local control, which involves closed loop control of storage control gates, pumps, etc.

Regional control, which provides coordination for local controllers (e.g. two storage ponds on the same trunk sewer).

Global control, which provides coordination of regional controllers to optimize operations system-wide.

Dr. Schilling has developed a useful simulation tool that simulates operation of combined sewer storage control devices at the city of Bremen, West Germany. The simulation uses inflow hydrographs of actual storms as its input. The simulation can either be run automatically, with control devices following preset control parameters, or manually with operator intervention. The simulation can be provided with "predicted flows" for one or several time steps into the future. Results have shown that these predicted flows can improve operating improvements, but only up to 30 minutes into the future. Flow prediction beyond 30 minutes does not seem to improve operating results.

Dr. Schilling has also stressed the importance of recognizing the multiple objectives of every wastewater collection system. Control objectives are many, and sometimes conflicting, requiring prioritization. Objectives include: providing safety for human life, protection of utility and other property, water pollution control, minimization of operation and maintenance costs.

Review of Development Efforts

The early efforts to develop automated CSO control strategies, conducted at Seattle and Lima, used fairly simple, fixed strategy methods to direct system-wide operation of combined sewer collection systems. These systems achieved substantial improvement over previous methods of control using technology available at that time and simple control algorithms.

Research by Dr. Labadie and others, and development work by Dr. Vitasovic have focussed the technology of optimization and computer based models on the problem. Research by Dr. Schilling has provided an overall analysis of the problem and the building of a conceptual framework for utility managers to use in formulating their strategic goals for overall management of a system of CSO controls.

One of the keys to effective development of real time CSO controls is to understand to what extent advanced modeling and optimization techniques can be effectively utilized. Throughout the computer age there has been an underlying assumption that, given a big enough computer and enough sensors, we can build a model to accurately predict the behavior of most natural or man-made systems. The history of econometric and weather modeling are prime examples of this attitude. Only in recent years have we, through the new theory of chaos, begun to recognize that small perturbations in any system can have enormous consequences, that the flap of a butterfly wing in South America can affect the weather in Europe (Gleick, 1988). We can never build a model, or a sensor network, that can measure such infinitesimal events.

Although the modeling of sewer systems has not commanded even a fraction of the resources that have been used in weather modeling, the same principles apply. Up to

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the present, such models have used extremely sparse rain gauge networks, and gross approximations of the surface characteristics of the urban watersheds tributary to the sewer system. Better gauging networks and more accurate description of watersheds could improve model results.

No model can predict the future. But models can provide estimates of future conditions which can be used as a guide to decision making, human or computer. The bigger the model is, and the bigger the sensor network is, the further out into the future its reliability will extend. The law of diminishing returns applies, and the managers of model builders must evaluate at each step whether an increment in model cost justifies the increased increment in predictive power.

Integration of Real Time CSO Controls and Other Information Systems

Utilities are conscious that "some day" all their control and information systems will be integrated together. CSO control systems are an integral part of this process, because they collect system operating data and often need analytical tools that are useful in utility planning and design. Some utilities are moving aggressively to develop data networks to promote the interchange and sharing of information within their organizations; others are more cautious. There are two basic strategies for utilities -- top down and bottom up. The movement is similar to the integration of systems in manufacturing industry. Some experts emphasize a top down strategy, defining overall standards and broad automation goals and building downward and outward to the factory floor with a comprehensive automation solution. General Motors and its MAP protocol suite is an example of this approach. The bottom up strategy is to automate in the work cell on the factory floor, building islands of automation which gradually grow together. "The Japanese" are reported to have selected the bottom up strategy in manufacturing.

Top Down Strategy

Some utilities are implementing CSO controls as part of utility-wide information systems strategies which integrate data collection and control functions with planning and design and maintenance functions. Seattle's Municipality of Metropolitan Seattle is one such utility. It has implemented a MACS system that integrates treatment plant control, regulatory agency reporting, collection system control including CSO control, and maintenance systems.

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Bottom Up Strategy

Other utilities are implementing CSO controls from the bottom up, without developing an overarching networking strategy. Cleveland's Northeast Ohio Regional Sewer District is such an example. The District is implementing a strategy to gradually replace its minicomputer based CSO control system with IBM PC-compatible systems, with both systems existing side by side until the eventual retirement of the minicomputer system. Meanwhile the new system will be growing towards, and gradually connecting with, other islands of automation at the District.

Conclusion

Coordinated real time control of combined sewer systems has experienced slow progress in the U.S. as priorities in pollution control have been focused elsewhere. This is changing as the U.S. turns its attention to surface water management. Meanwhile, information systems technologies, CSO control concepts, optimization techniques, computer modeling have all experienced dramatic development and refinement. As the nation is poised at the beginning of a nationwide effort to curb pollution from surface water runoff, practical concepts are available to build workable systems to control and coordinate the conveyance and storage of surface water to minimize pollution. But the systems will not operate by themselves in a corner. They will be integrated with other utility information systems to provide support for maintenance, planning and design.

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STORMWATER POLLUTION CONTROL USING SCREENING STRUCTURES

by Vladimir Krejci[1]

TRADITIONAL STORMWATER POLLUTION CONTROL

Problems of pollution of receiving waters in urban areas are extremely diverse and depend on the local circumstances. Each country, and each climatic, cultural, historic, or economic region, has its specific problems and priorities.

Switzerland does not have a long history of intensive scientific development in the area of urban hydrology, but due to its wealthy economic situation, high population density and long-lasting political stability, investment into water pollution control, by international standards, is relatively advanced.

Climatic conditions in Switzerland are characterized by a mean total rain depth of approximately 1000 mm/year which falls during approximately 1000 hrs. There is no typical rain season; on average about one rain event per week results in significant runoff. The topography of Switzerland is characterized by relatively steep areas and, therefore, relatively high flow velocities in sewers and in rivers.

In Switzerland, about 70% of the population are served by combined sewer systems. In the context of overflow structures it became obvious that pollution of receiving waters caused by combined sewage overflow (CSO) might cause a serious water pollution control problem. In order to minimize the negative impacts of CSO, several state (Canton) and federal guidelines and recommendations were introduced in the sixties and in the seventies. Generally, these guidelines determine what proportion of combined

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sewage may be directed into receiving waters without treatment, what proportion should be treated by simple treatment measures like storage and clarification tanks and what proportion of combined wastewater should be directed toward primary and secondary treatment at the wastewater treatment plant (Figure 1).

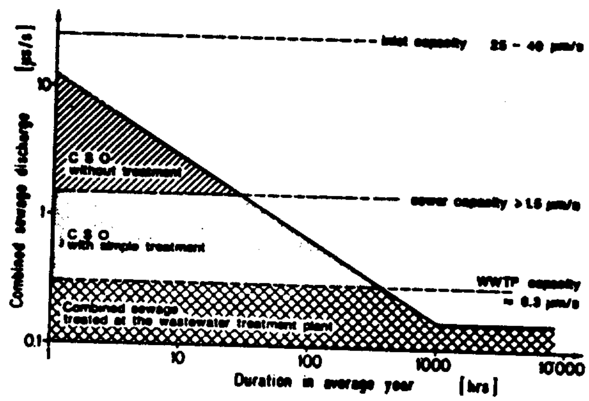

Figure 1: Principle of traditional combined sewage pollution control strategy in Switzerland: the capacity of the wastewater treatment plant (WWTP) is generally twice the maximum dry weather flow (2xDWF = 0.3 $\mu m/s$); the CSO or combined sewage discharge between 2xDWF and r_{crit} (r_{crit} = ca 1.5 - 5 $\mu m/s$) should be treated in small storage tanks ("first flush" storage) or in clarification tanks (removal of sediments and of coarse debris). The value of r_{crit} depends on simple characteristics of receiving waters, on the storage capacity in sewers and on the time of runoff concentration. The combined sewage discharge greater than r_{crit} may be directed into receiving waters without treatment.

These guidelines were based on studies which were conducted by civil engineers. Parameters considered were derived from their experiences with traditional wastewater treatment. These guidelines neither consider the dynamic and statistical nature of the rainfall-runoff phenomena, nor the ecological requirements of receiving waters. They led to countrywide uniform application of several hundreds of storage and clarification tanks with a specific volume of about 15 - 25 m³ per ha of impervious area (about 0.05 - 0.1 inch of rainfall- runoff).

EMPHASIS ON RECEIVING WATER REQUIREMENTS

Recently, the water pollution control strategies in Switzerland changed the emphasis from setting effluent standards to the definition of receiving water requirements. This approach supported a wide introduction of site-specific and problem-related water pollution control measures like advanced wastewater treatment, substitution of phosphorus in detergents, introduction of unleaded gasoline, etc.

This approach deals primarily with "general" water pollution problems; it does not touch the "special" situation like the stormwater pollution problems. However, the emphasis on problem-related measures has also led to investigation of storm water pollution problems during wet weather, investigation of efficiency of existing storage, and clarification tanks, and to introduction of some alternative control measures (e.g. the screening structures).

These investigations yielded much important information. For example, significant ecological problems related to combined sewage overflow are rarely observed during single rainfall events in Switzerland. There are nearly no observations of insufficient dissolved oxygen concentration in rivers and in creeks (due to high flow velocity). Similarly, hygienic aspecta (coliform bacteria, etc.) are not regarded as a problem. However, local aesthetic problems, caused by floating debris in combined sewage overflows led to very frequent citizen complaints. For this reason, as long as ecological problems related to combined sewage overflow cannot be identified, the water pollution control measures during wet weather conditions should be primarily viewed as a solution of local aesthetic problems.

INTRODUCTION OF CSO SCREENING

To support the problem-related CSO pollution control, different screening structures have been tested and applied as an alternative to clarification tanka or as an addition to small storage tanks ("first flush storage tanks"). It is well known that screena are effective in removing suspended and coarse material. The range in sizas varies from < 0.1 mm clear opening of microscreens to large clear

Figure 2: Debris caught by branches of a tree downstream of a CSO structure. This type of aesthetic problem frequently leads to the construction of storage/sedimentation tanks for CSO in Switzerland. These problems are not ecologically important and might be solved with installations which are totally different from those required to retain ecologically significant pollutants.

openings of bar screens. The following information deals with coarse screens and bar screens with openings between 3 and 10 mm.

With respect to screen cleaning, two different groups of screening structures have been tested and applied:

(a) Screens (sieves) and bar screens (bar racks) without cleaning during the operation

(b) Bar screens (bar racks) with cleaning during the operation.

NECESSARY EFFECT OF SCREENING

The long lasting visibility of debris in bushes and trees indicates that even if overflow volume is greatly

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reduced by storage/sedimentation tanks, visible pollution may still occur for several weeks in a year (Mutzner, 1987). Mutzner also found that there is no relationship between the amount of visible pollution and the antecedent dry weather period, the hour of day, the overflow duration, overflow volume, or the maximum discharge. The most important parameter in relation to the visible pollution from CSO is simply the overflow frequency of untreated sewage.

The design of screening structures with respect to the frequency of untreated overflow should strongly be related to the site-specific significance ("aesthetic sensibility") of observed or predicted problem. With respect to possible long lasting visibility of debris in bushes and trees, it appears necessary that the discharge of untreated (i.e. unscreened) CSO not occur more than once in 1 - 2 years.

SCREENING WITHOUT CLEANING DURING OPERATION

In 1980, the City of Bern decided to apply screening structures as an addition to a small ("first flush storage") tank. For this reason, different screens and bars racks were tested at a suitable site in the sewer system under dry weather flow conditions (Kaufmann, 1981; Meyer and Kaufmann, 1981). Based on this investigation some screening structures were built at different places in Switzerland between 1982 and 1986. They were installed either as an addition to small "first flush storage" tanks or as an alternative to the clarification tanks.

To verify the design recommendations gained from the pilot investigations mentioned above, the Swiss Federal Environmental Agency (BUWAL) began an investigation of several new screening structures in 1986. For this investigation the screening structures Elfenau (in Bern) and Sagenbach (in Hochdorf/Luzern) were chosen.

The experimental investigations were performed by the consultants Huber-Enviro-Consult AG in Belp. The BUWAL and the Swiss Federal Institute for Water Resources and Water Pollution Control in Dübendorf/Zürich (EAWAG) contributed to the planning and to the evaluation of this investigation.

During several dozen overflow events in 1986 and 1987 different operation parameters and the effects of the screening were observed (Huber Enviro Consult, 1988,). The most important questions of this investigation were:

(a) Efficiency in removing coarse substances,

(b) Frequency and volume of untreated combined sewage overflow after clogging of screen,

(c) Efficiency of cleaning equipment

The screening of CSO in Elfenau and in Hochdorf is accomplished by perforated plates with holes (slots) of 6 mm diameter. The perforated plates are set up horizontally with up-flow operation in order to enable flush cleaning from the top down after the operation (= after clogging). About 500 - 1000 l of water are needed per m^2 cleaned. The minimum distance between the flushing equipment and the screen surface is about 2 - 2.5 m (Figure 3).

Investigation of screening structure Elfenau (Bern)

The screening structure Elfenau was built as an addition to "first flush storage". Table 1 provides some technical data on the catchment area and the screening structure:

TABLE 1: Screening structure Elfenau (Bern): Size of the existing and of the planned catchment area, storage volume and screen characteristics.

Screening structure Elfenau (Bern)	Planning	Existing (1986)
Connected catchment	97 ha_{imp}	41 ha_{imp}
Volume of storage	745 m^3	745 m^3
Specific volume of storage	7.7 m^3/ha_{imp}	18 m^3/ha_{imp}
Coarse screen (perforated plates):		
Total surface (gross)	30 m^2	30 m^2
Clear surface	12 m^2	12 m^2
Specific surface (gross)	0.38 m^2/ha_{imp}	0.7 m^2/ha_{imp}
Diameter of holes	6 mm	6 mm

To verify the design criteria the investigation was performed for the design (planning) conditions. The function and the effect of this screening structure Elfenau were also investigated for two following configurations:

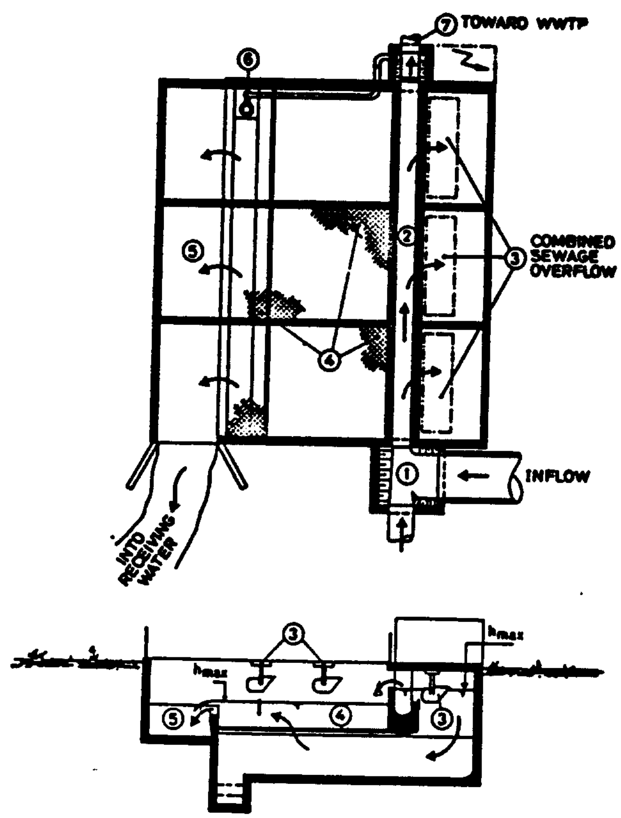

Figure 3: Screening structure Sagenbach: 1. Inflow, 2. Overflow to screening, 3. Cleaning equipment, 4. Screens, 5. Outflow, 6. Pump, 7. Discharge toward WWTP

(a) Configuration 1: Operation of screening structure as an alternative to clarification tank. The specific surface of screen was 0.38 m^2/ha_{imp}; the volume of storage in front of the screening was negligible.

(b) Configuration 2: Operation of screening structure as an addition to "first flush storage tank": The "first flush" (= 745 m^3 of CSO) was stored before starting the screening operation. The specific surface of the screening structure was the same as in Configuration 1 (0.38 m^2/ha_{imp}).

The results of these investigations show that only a small part of the overflow events were completely treated by screening:

Configuration 1:

During 21 investigated CSO events between June and August 1986, ca. 43% of CSO volume was treated by screening; however, only 4 CSO events were completely treated by screening (see also Table 2);

Configuration 2:

During 8 investigated CSO events between September and December 1986, ca 49% of the CSO volume was treated by screening; CSO events were treated completely, 5 CSO events were only partially treated (see also Table 3).

Investigation of the screening structure Sagenbach

The screening structure Sagenbach in Hochdorf was built as an alternative to a clarification (sedimentation) tank, i.e. there is no volume in the structure for the "first flush storage".

The size of the catchment area is 44 ha_{imp}. The important technical data of the screening structure are as follows:

Screening structure (perforated plate):

total surface (gross)	38.7 m^2
specific surface (gross)	0.7 m^2/ha
clear surface (net)	15.6 m^2
diameter of holes:	6 mm

TABLE 2 Efficiency of Screening Structure Elfenau (Bern), Configuration 1 (Screening as an alternative to sedimentation tank).

ELFENAU CONFIGURATION 1		Combined Sewage in m^3				CSO treated by screening until clogging of screen		
Date in 1986/87	Storm in mm	Total	Toward WWTP	CSO treated by screening	CSO un-treated	m^3/ha_{imp}	m^3/m^2 screen	% of CSO
2.June	22	13053	7546	3604	1903	87	240	65
4.June	17.5	11818	7272	4483	63	109	300	99
5.June	2.7	2566	1985	581	0	*)	*)	100
6.June	2.9	1744	1418	326	0	*)	*)	100
11.June	20.3	13573	7489	2320	3764	56	155	38
20.June	8.6	4224	2639	1343	242	32	90	85
6.July	30.5	12894	6901	2814	3179	68	187	47
18.July	9.0	5317	3542	1334	441	32	90	75
18.July	8.9	3395	2337	513	545	12	34	48
22.July	23.6	11060	6015	1955	3050	47	130	40
24.July	7.5	4315	3237	917	162	22	61	85
31.July	4.5	1407	1081	326	0	*)	*)	100
4.Aug.	6.2	4059	1313	406	2340	10	27	15
4.Aug.	15.1	7160	4504	2337	319	58	155	88
9.Aug.	2.7	1648	991	451	206	11	30	69
11.Aug.	12.7	5501	2975	1882	644	46	125	75
15.Aug.	6.2	2505	1655	850	0	*)	*)	100
18.Aug.	14.7	5531	2599	877	2055	22	58	30
23.Aug.	45.0	19748	6656	2014	11078	49	134	15
24.Aug.	14.7	6383	2950	1501	1932	36	100	42
26.Aug.	28.0	13167	5064	3583	4520	86	239	44
Total		151029	80169	34417	36443	$\bar{x}$=46	$\bar{x}$=127	$\bar{x}$=43

*) no clogging

TABLE 3 Efficiency of Screening Structure Elfenau (Bern), Configuration 2 (screening as an addition to "first flush storage").

ELFENAU CONFIGURATION 2		Combined Sewage in m^3				CSO treated by screening until clogging of screen		
Date in 1986/87	Storm in mm	Total	Toward WWTP	CSO treated by screening	CSO un-treated	m^3/ha_{imp}	m^3/m^2 screen	% of CSO
14.Sept.	9.1	3651	2811	840	0	*)	*)	100
17.Sept.	22.4	10739	8211	1188	1340	29	79	46
19.Okt.	9.4	3268	2932	336	0	*)	*)	100
20.Okt.	10.6	4752	2693	588	1471	14	39	29
23.Okt.	27.1	13208	7025	2908	3275	71	194	47
25.Okt.	15	7135	3646	1498	1981	36	100	43
23.Nov.	11.2	4052	3658	394	0	*)	*)	100
19.Dez.	16.4	9441	6419	1417	1605	35	94	47
Total		56236	37395	9169	9672	$\bar{x}$=36	$\bar{x}$=101	$\bar{x}$=49

*) no clogging

During 23 investigated CSO events between October 1986 and June 1987 more than 95% of the CSO volume was treated by screening. During 20 CSO events the combined sewage was completely treated by screening. Only during 3 events were untreated CSO's discharged into the receiving waters (Table 4).

The results of this investigation are confirmed by the observations of the screening effects in the same structure between September 1984 and October 1986. During this period 102 CSO events were observed: during 92 CSO events the combined sewage was completely treated by screening, during 10 events the combined sewage was partially discharged into the receiving water.

Discussion of the results

(a) The removal efficiency of coarse substances with the investigated screens (perforated plates with holes of 6 mm diameter) is sufficient. Until the clogging of the screen the receiving waters is well protected from aesthetic problems caused by visible coarse substances from combined sewage overflow.

(b) The effectiveness of the screening structure Elfenau for the planning conditions is not sufficient. Only 7 out of 29 CSO events were completely treated by screening during the investigated period.

(c) The effectiveness of the screening structure Sagenbach in Hochdorf with respect to frequency of completely treated CSO is significantly higher: 20 out of 23 CSO events were completely treated by screening during the investigation. The observation of overflow frequency between 1984 and 1986 confirm the results gained during the investigation period: 92 out of 102 observed CSO events were completely treated by the screening.

(d) There are some significant differences between the catchment areas Elfenau (urban residential area) and Hochdorf (village) and between the drainage systems in both areas. For this reason it is still not possible to definitely judge the value of the specific screen surface as a design parameter.

(e) The design assumptions for screens without cleaning during the operation, based on the pilot investigation in Bern, were too optimistic.

(f) The effectiveness of the cleaning equipment (flushing after the operation) is sufficient. The experience gained by the operation of the full size

TABLE 4 Efficiency of Screening Structure Sagenbach (Hochdorf).

SAGENBACH		Combined Sewage in m^3				CSO treated by screening until clogging of screen		
Date in 1986/87	Storm in mm	Total	Toward WWTP	CSO treated by screening	CSO un-treated	m^3/ha_{imp}	m^3/m^2 screen	% of CSO
19.Oct.	5.3	3300	2970	330	0	*)	*)	100
20.Oct.	11.4	5800	3760	1460	580	33	38	72
23.Oct.	22.2	?	+)	5100	0	*)	*)	100
25.Oct.	5.4	2990	2500	490	0	*)	*)	100
20.Nov	11.4	9000	8970	30	0	*)	*)	100
23.Nov.	13.7	11610	9380	2230	0	*)	*)	100
19.Dez.	14.6	18100	13700	4400	0	*)	*)	100
27.Febr.	17.2	?	+)	2450	0	*)	*)	100
28.Febr.	8.0	?	+)	110	0	*)	*)	100
4.Apr.	13.0	6710	5570	1140	0	*)	*)	100
10.Apr.	20.8	31140	24450	6690	0	*)	*)	100
20.Apr.	5.6	2860	2790	70	0	*)	*)	100
20.Apr.	4.4	2620	2270	350	0	*)	*)	100
3.Mai	12.8	?	+)	1240	0	*)	*)	100
10.Mai	11.8	?	+)	1780	830	28	33	100
5.Juni	4.0	2610	2550	60	0	*)	*)	100
7.Juni	14.0	?	+)	1180	0	*)	*)	100
13.Juni	6.7	4970	3200	1770	0	*)	*)	100
13.Juni	15.6	13220	12160	1060	120	40	46	64
15.Juni	25.2	25400	22810	2590	0	*)	*)	100
18.Juni	28.8	?	35240	+)	0	*)	*)	100
24.Juni	4.8	2910	2850	60	0	*)	*)	100
26.Juni	13.5	7290	6890	400	0	*)	*)	100
Total				> 35000	1530	Σ>34	Σ>39	Σ>95

*) no clogging +) no measurement

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structures confirmed the results of the pilot investigation.

(g) There are still some possibilities for improving the screens. For example, a means of increasing the net surface of the screens using a new shape of the perforated plate was developed recently (wave shape instead of flat plate).

(h) The conclusion of the full-scale investigation Elfenau and Sagenbach carried out by the Swiss Federal Environmental Protection Agency (BUWAL) in Bern and by the consultants Huber-Enviro Consult AG recommended the further development of screening structures, especially the possibility of cleaning during operation.

SCREENING WITH CLEANING DURING OPERATION

Starting in approximately 1982, other screening structures were developed and tested in Switzerland:

(a) "Self-cleaning" bar screen

(b) Bar screens with mechanical cleaning

The "self-cleaning" bar screen

The principle of this structure is indicated in Figure 4. The screen structure "covers" the overflow structure (weir). The thickness of the bars is 4 mm. The openings between bars are also 4 mm. Two conditions are important for a reliable self-cleaning operation:

(a) The bar screen is arranged with a slope of 17°

(b) The "self-cleaning" operates only over a relatively small range of hydraulic conditions: The ratio of the overflow discharge into receiving waters to the outflow toward the WWTP should be less than 5.

The prototype of this screen was applied at the CSO structure at the inflow of the WWTP Frenke III (Canton Basel/Landschaft). To investigate the efficiency of this structure several CSO events were observed in the summer of 1987. Unfortunately, this structure was "over-designed" and it was not possible to reach the capacity limit of the structure during the investigation. However, this investigation demonstrated that:

(a) The efficiency of the screening with respect to removal of visible coarse substances is sufficient

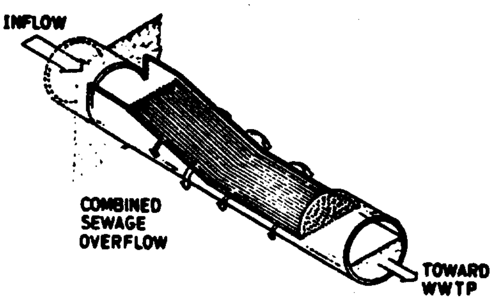


Figure 4: Principle of "self-cleaning" bar screen (Novak, 1983)

(b) The effectiveness of the structure (defined as volume of the treated combined sewage until clogging of the screen) seems to be significantly higher than the effectiveness of the screening structures Elfenau or Sagenbach.

The bar screens with mechanical cleaning

The screening principle is very similar to the "self-cleaning" bar screen mentioned above. The main difference in this screen is the intermittent or continuous mechanical cleaning. The big advantage of this screen structure is its possibility of wide application: Figures 5 - 7 show some examples of the application with respect to different CSO structures (Romag AG, 1989).

Like the "self-cleaning" bar screen, there is still not enough operational experience. However, the application of these kinds of screening structures will be financially supported by the Swiss Federal Environmental Protection Agency. A wider application may be expected in the future.

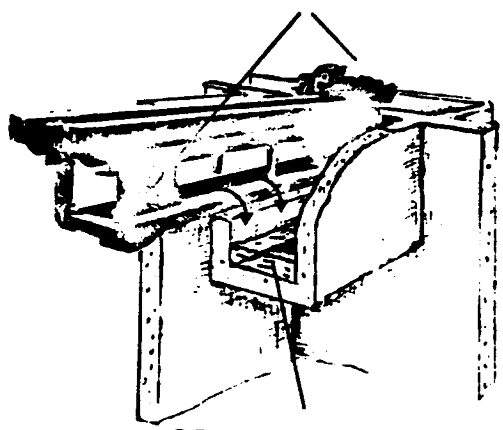
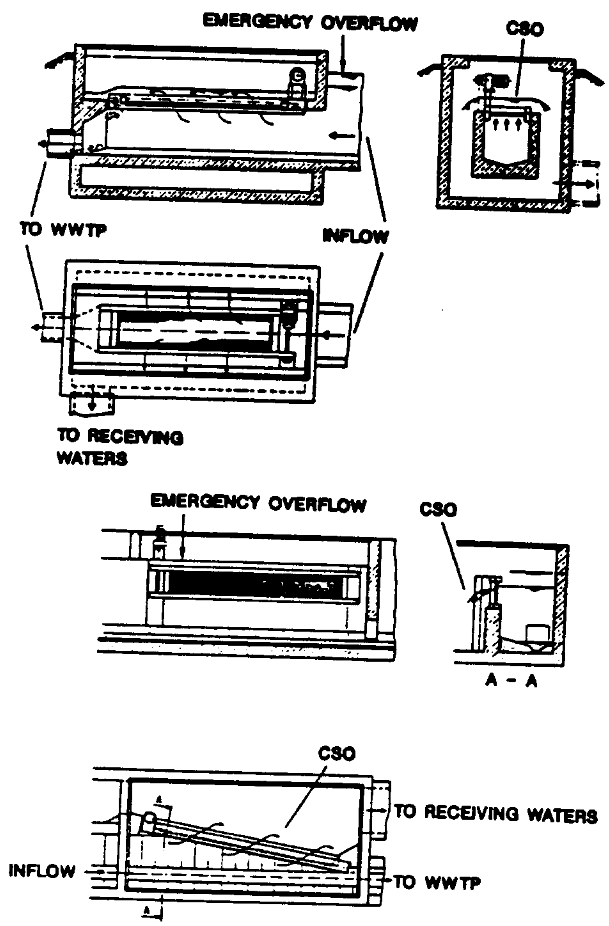


Figure 5: Principle of screening structure with mechanical cleaning (Romag AG, 1989)

CONCLUSIONS

1. The aesthetic problems caused by debris from CSO represent an important stormwater pollution problem in Switzerland. Especially because of increasing "re-naturalization" of creeks and of small rivers the aesthetic problems caused by CSO have become more and more evident.

2. The coarse screens (bar screens or perforated plates) are a specific stormwater pollution control measure. They allow abatement of local aesthetic problems caused by debris from CSO. The removal efficiency of investigated screens with clear openings between 4 and 6 mm with respect to coarse substances is sufficient.



Figures 6 and 7: Examples of screening structures with mechanical cleaning during the operation (Romag AG, 1989)

3. The most important design parameter in relation to visible pollution from CSO is the overflow frequency of untreated sewage.

4. The design of screening structures with respect to the frequency of untreated CSO should strongly be related to site specific significance of observed or predicted problems. With respect to possible long-lasting visibility of debris in bushes and trees, it appears necessary that the discharge of untreated CSO does not occur more than once in 1 - 2 years.

5. The screens without cleaning during the operation (perforated plates) are very sensitive to clogging. This problem is especially caused by the wide range in the amount and character of debris carried in the sewage. The design of this type of screening structures for untreated CSO is difficult. Therefore these structures are more or less under- or over-designed.

6. The problem of clogging during operation may be solved by screening structures with mechanical cleaning (bar screens) during the operation. Unfortunately, there is still not enough operational experience.

7. It is still not possible to definitely evaluate the success or failure of stormwater pollution control by screening. However, the progress during the last seven years, and the involvement of the wastewater professionals, allow an optimistic outlook.

ACKNOWLEDGEMENTS

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RAIN RUN-OFF FROM SEWER SYSTEMS & TREATMENT PLANTS

by Poul Harremoës[1]
Ole Bo Hansen[2]
and Christina Sund[2]

INTRODUCTION

Due to oxygen depletion in the Danish coastal waters, experienced since 1981, the Danish parliament decided in 1987 to demand nutrient removal from all treatment plants serving more than 5000 inhabitants before the end of 1992. The expansion of the treatment plants is now being designed and will soon be under construction.

Due to the increased focus on the pollution problems it can be anticipated that the protection of the local receiving waters will demand a significant increase in number and size of detention basins - at a very significant cost to the Danish society, equal to the cost of the expansion of the treatment plants. This demand in Denmark has been analysed by Harremoës (1989).

The urgent problem faced is the effect of that development on the design and operation of the treatment plants. It has come into focus that the total system, the sewer system and the treatment plant, has to be designed as an entity. From this concept is derived the potential of real time control of the total system. This paper deals with the potential of this integrated concept.

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TOTAL LOADS FROM THE TWO SYSTEMS

Engineers are always preoccupied with the technology of the systems they design: the sewer system and the treatment plant. However, the main governing factors are to be found in relation to the pollution of the receiving waters. The main features of the problem are:

- -the receiving water
- -the discharge points
- -the pollutant
- -the time scale

Today, the design of treatment plants is a highly sophisticated engineering science, and the operation calls for increasing skills. The tendency is to make more centralized treatment plants, covering large sewer catchment areas. The location is chosen at the least sensitive of the local receiving waters. However, the outlets of the separate sewer systems and the combined sewer overflows are still discharging into the local, often very sensitive, receiving waters - like small creeks.

Typical for Denmark is the interceptor carrying the daily flow to the treatment plant near the coast for discharge to the marine environment. Upstream the intermittent discharges during rain pollute the small lakes and creeks in the tributaries inland. There is a whole spectrum of combinations to this scheme. The problem is to evaluate the system as an entity.

Pollutants from a combined sewer system can be taken as an example. Figure 1 shows the effect of storage on the yearly discharge of nutrients and metal (lead) from the combined system (Spildevandskomitéen, 1986; Henze, 1987). It is an interesting fact that the nutrient load on the total system is not strongly affected by storage. The reason is that the dilution of the sewage brings the concentration in the overflow down to concentrations close to the concentrations in the effluent from the treatment plant during rain. For the total load from the system storage is not really important. However, for the local upstream small sensitive receiving water it may be very important. The total discharge of lead is very strongly affected by storage, because is it derived from the runoff and because it is effectively removed from the water in the treatment plant.

The discharge of BOD poses a very different problem. The reason is that the yearly discharge from combined sewer overflows is not the best parameter with which to evaluate the resulting pollution: oxygen depletion in the receiving water. It is the individual event that creates the problem.

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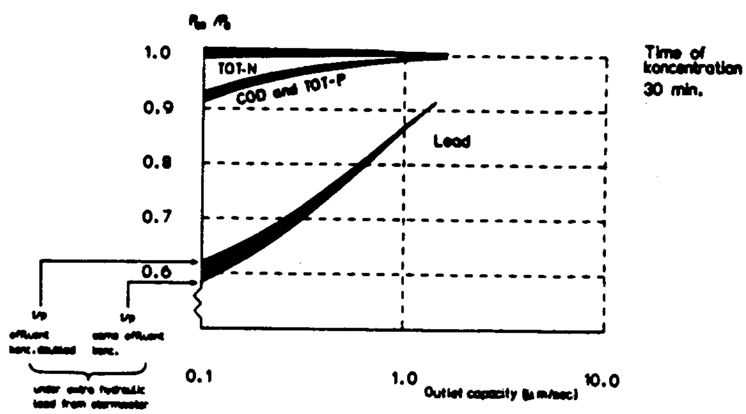

Figure 1. Discharged amounts of pollutants per year to same receiving water from treatment plant and CSO's. P_m = kg/year with storage. P_o = kg/year without storage.

Accordingly, the problem has to be evaluated on the basis of extreme statistics of the events with the highest loads on the most sensitive waters.

The solution is to set the water quality standards for each receiving body of water based on extreme statistics for pollutants with an acute effect (bacterial pollution, toxic substances and oxygen depletion) and annual load for accumulating pollutants (nutrients, metals, and persistent organics). This should be combined with standardized methods of calculating permissible loads in each receiving water involved. On this basis is derived a set of constraints on the engineering systems, which must be adhered to - by design and by operation (Harremoës, 1989; PH-Consult, 1989).

REAL TIME CONTROL OF THE SEWER SYSTEM

The hydraulic performance of many combined sewer systems is not satisfactory due to flooding and unacceptable pollution from CSO's. On the other hand most conventionally designed systems contain an unutilized potential for reducing or eliminating these problems. The means of achieving this is Real Time Control (RTC) of the runoff process in the sewer system.

Traditionally sewer systems are designed for extreme design storms that will never occur as a physical event. Therefore, the systems will never perform optimally, and during most rain storms the storage volumes of conduits and detention basins will not be utilized up to their capacity. An example of the negative consequences of this is the often reported case that CSO's are overflowing, while the storage capacity of nearby basins is not fully utilized.

The RTC system aims at maximum utilization of available storage volume and flow capacity of the system, thereby upgrading its performance to an optimal or nearly optimal stage for all rain storms that it is exposed to.

An RTC system for a sewer network consists of sensors such as water level recorders, flow meters, and rain gauges and regulators, such as sluice gates, pumps, and inflatable rubber dams, a telemetry system for data transmission, and a control unit. The control unit, which can be a computer and/or a human operator, issues its instructions to the regulators on the basis of the recorded state of the system. In case of a computer, the instructions are formulated by a control strategy. A sketch of an RTC system for sewers is shown in Figure 2.

In general the technology of RTC systems including their hardware is well known and their use widespread. What is interesting for the drainage engineer is the application of these systems to sewer networks and the development of control strategies. The strategies can be categorized into 3 types:

(a) Relatively simple rules of the "if-then-else" type based upon a recorded actual state of the system. The set-points are fixed and predetermined.

(b) Optimization using say linear programming methods in combination with current predictions based on on-line simulations.

(c) Expert systems.

The projects in Gladsaxe and Taarnby described in the following lines are based on type 1 strategies. The pre-determined set-points are optimized on the basis of off-

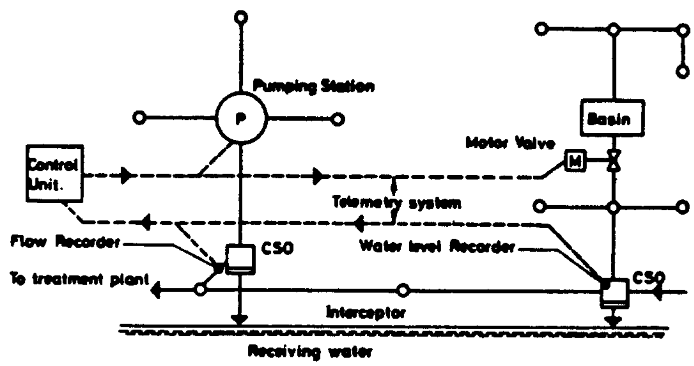

Figure 2: Fundamental sketch of RTC of the sewer system.

line simulations of the sewer runoff process using a modified version of the SAMBA model. Therefore, this model is given a brief description in the following section.

The SAMBA Model

The SAMBA model (copyright PH Consult ApS) is part of the MOUSE package (copyright MOUSE JOINT VENTURE) for analysis and design of sewer systems on personal computers (Lindberg et. al., 1986). The model was developed with the special purpose of computing pollution loads from combined sewer overflows. SAMBA computes the overflow pollution from sewer systems containing a large number of overflow structures, basins, and pumping stations on the basis of a long series (10-40 years) of historical rain data and presents the results on a statistical form.

In order to keep the computational time at an acceptable level the routing of storm water is carried out using the relatively simple time-area method, which gives a good agreement between computed and measured CSO volumes (Johansen et. al., 1984). The results consist of statistics for annual loads of say kg P/year for each overflow structure and extreme loads of say kg BOD as a result of individual rain events.

SAMBA CONTROL for modelling of RTC in the Sewer System

In connection with the Gladsaxe and Taarnby projects (see below) the SAMBA model was developed further to include simulation of various real time control measures in the sewer system. The decision variables are recorded water levels in detention basins and overflow structures and flows in selected pipes. On the basis of these variables and a control strategy, the outflows from detention basins, overflow structures, and pumping stations are regulated during each time step in the modelling. As a first step the control strategy can be built as a relatively simple hierarchy of "if-then-else" statements based upon the actual state of the system.

Petersen and Harremoës (1987) and Jensen and Jacobsen (1989) demonstrated that modelling CSO-pollution from a sewer network with RTC using the SAMBA model gives results that differ only slightly from results obtained with a full dynamic wave model. Another fundamental property of SAMBA enabling it to model RTC is that the "computational sweep" is carried out for the entire sewer network at a time each time step. It does not finalize the computation of one conduit and then go to the next one downstream, like, say, a traditional kinematic wave model. The revised version of SAMBA is called SAMBA-GLAD (SAMBA CONTROL), copyright PH Consult ApS.

The Gladsaxe Project

The municipality of Gladsaxe (population of 60.000) is a suburb in Greater Copenhagen. With Krüger as the main consultant and PH-Consult as sub-consultant, a sewerage rehabilitation master plan was prepared for a 300 ha urban catchment in Gladsaxe. The plan was completed in March 1988. Among the main planning tasks was the computation of present CSO pollution loads followed by sizing and design of future storage facilities to reduce the loads to meet the criteria decided by the county authorities. In the analysis of how the future storage capacity of the system could be increased in the most cost-effective way a solution including RTC was found to be among the most promising.

In Figure 3 is shown a sketch of the RTC system in the Gladsaxe catchment on which the SAMBA CONTROL model was applied. The system consists of 4 in-line storage basins, 3 detention basins B1-B3, 2 pumping stations P1-P2, an internal overflow structure CSO2, and an external overflow structure CSO1 discharging to the receiving water, which is a channel and a lake of high recreational value. Date from water level recorders installed in basins B1, B2, and B3, and overflows CSO1 and CSO2 are transmitted to a central control unit (PC) which, on the basis of the selected set-points in the control strategy, issues its instructions to the three motorized sluice gates (M) at the outlet of the basins and to P1 and P2.

A SAMBA CONTROL model especially tailored for this controlled system was developed, and a number of off-line simulations were carried out in order to identify the optimal combination of set-points in the strategy with the purpose of minimizing the pollution from CSO1.

SAMBA modelling of an identical system without RTC showed that a reduction of 18% of the annual CSO volume was gained through RTC. However, this percentage is on the pessimistic side, as it does not take into account that the RTC system takes advantage of the geographical variation of the precipitation - SAMBA assumes uniform distribution of the precipitation over the catchment.

The RTC system is now being implemented. Its costs amount to approximately 1.5 million US $ (including civil works) and it is expected to be in operation in January 1990. The system is equipped with a dynamic colour graphic interface installed at the Municipal Engineers Office, including an animated display of filling/emptying of basins, opening/closing of sluice gates, and start/stop of pumps together with a report generator including tables and graphics.

The Taarnby Project

Taarnby is another municipality (population of 40,000) in Greater Copenhagen. The purpose of the Taarnby project is to investigate the potential of integrated RTC of the total system of sewer network plus treatment plant, and to develop methods and software tools for the optimization of such systems. The project is financed by the Danish Environmental Protection Agency in support of the large public investments in municipal treatment plants (approx. 1.5 billion US $) and sewerage systems (approx. 1.0 billion US $) planned in Denmark for the coming 5-10 years.

The first version of the SAMBA CONTROL model was tailored for the specific catchment in Gladsaxe. If more sensors or regulators were going to be included in the modelled RTC system, or new rules introduced in the strategy, this could be done only by one of the (very few) developers of the SAMBA model. In connection with the Taarnby project, SAMBA CONTROL will be developed further to the stage of a general RTC-modelling tool for combined sewer systems. As a first

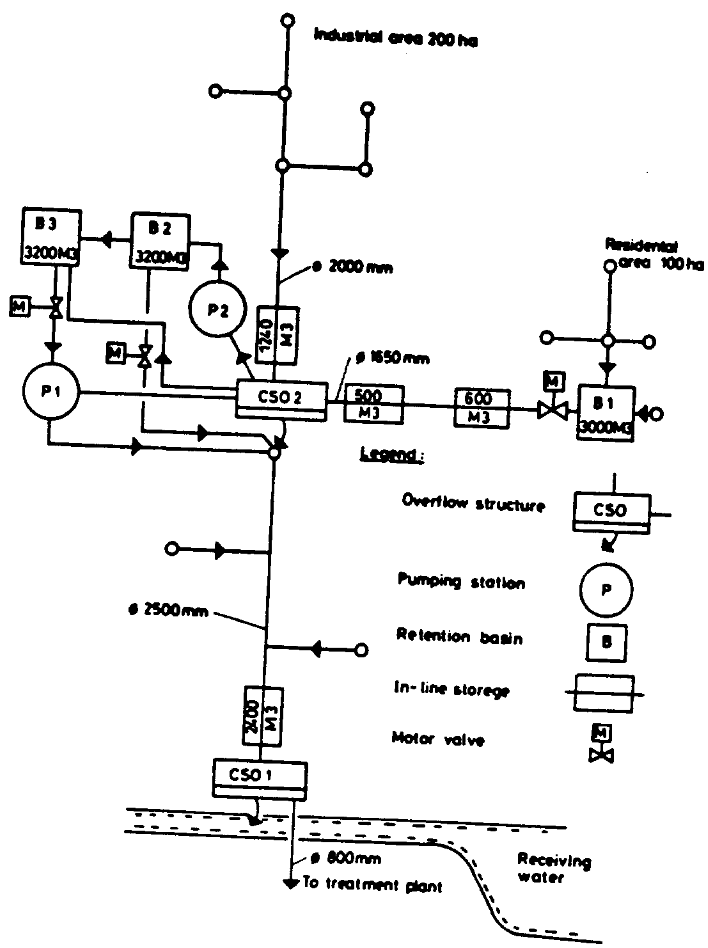

Figure 3: Sketch of sewer mains, basins, and pumping stations in the Gladsaxe catchment.

step, a module comprising an "if-then-else" strategy will be developed. Then the user himself (typically a practising drainage engineer) will be able to select positions of sensors and regulators, formulate strategies, select set-points, and carry out off-line simulations in order to optimize the RTC system. This module of SAMBA CONTROL is expected to be completed by December 1989.

The next step is planned to be off-line simulations of predictive strategies including optimization. In the longer term it is intended to develop SAMBA CONTROL to an on-line simulator in connection with optimisation of RTC based upon say linear programming.

RTC OF THE TREATMENT PLANT

Hydraulic Load on Treatment Plants due to Surface Runoff

Those units of the treatment plant that are designed on the basis of the hydraulic load are screen, grit and grease chamber, primary clarifier and secondary clarifier. The hydraulically most sensitive unit of the plant is the secondary clarifier, which is also the most expensive unit expressed in say cost per m^3 of waste water to be handled.

The solids recovery in the secondary clarifier is of the order of 99.5%. The recovery is very high taking into account that the sludge characteristics may very from time to time, as the sludge is composed of living organisms. Consequently the clarifier must be looked upon as a unit extremely susceptible to hydraulic disturbances.

Due to the functioning of the clarifier, it is theoretically divided into different zones representing different sludge concentrations: the clear water zone, the sludge settling zone, the sludge storage zone, and the sludge thickening zone.

Under normal dry weather conditions the sludge storage zone is kept empty of sludge, i.e. the transport of sludge to the bioreactor by return sludge pumping is kept at a level ensuring this.

At an increased hydraulic load, the sludge transport to the clarifier increases. Normally, the return sludge pumping is increased as well in order to raise sludge removal. However, the conditions in the clarifier become more turbulent.

When the surface overflow rate is increased, the settling time for sludge particles is reduced, and the short circuiting between tank inlet and return sludge pumping is

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consequently increased. Hence the increased hydraulic loading will result in higher concentrations of SS in the effluent and an increased sludge accumulation in the tank. The sludge storage zone will gradually be filled with sludge. Theoretically this will result in a higher degree of compression in the thickening zone increasing the dry solids concentrations. This potentially positive effect will, however, be dampened by the increased short circuiting to the return sludge outlet of the waste water flowing into the clarifier, thus reducing sludge transport.

If the sludge storage zone is big enough to handle the accumulated sludge until normal loading conditions are reestablished, the clarifier operation could in principle be guaranteed under operating conditions lying within the hydraulic design limits. However, it will probably not be possible to avoid loss of sludge from the system under extreme conditions.

Extreme conditions can, for example, be very long periods with peak hydraulic loads, periods with poor sludge settling in combination with high hydraulic loads and repeated shock hydraulic loads.

Loss of sludge in high hydraulic load situations means a rapid decrease in sludge mass in the biological system. In a low-loaded biological system, as is the case when the system is designed for nutrient removal, loss of sludge is detrimental to the function of the system. Losing sludge for, say, eight hours can result in poor plant performance, i.e. increased concentrations of dissolved compounds (BOD, COD, NH_4-N, and so on) in the effluent for more than a week, and if it happens during the cold part of the year the effect can be seen for months.

With storage basins upstream of the treatment plant the number of situations with long term hydraulic high loading will be increased.

RTC Options of the Treatment Plant

The ideal solution for combined treatment of storm water and municipal waste water is naturally to ensure that the polluted water undergoes full treatment, i.e. mechanical, chemical, and biological treatment. Putting this ideal solution into practice is a big challenge technically as well as economically, and the effort must always be put in relation to the effect.

All the units in the treatment plant have their design limitations. If these are exceeded, removal efficiency will be reduced.

In order to utilize the waste water treatment plant in the optimum way so as to gain maximum possible treatment efficiency, it is desirable to control the influent to each part of the plant. Hence it is necessary to look at the sewer system and the treatment plant as an entity and to control what can be controlled.

One of the most important things to be able to control is the flow. The primary and secondary clarifiers are the units most susceptible to variations in the hydraulic load, and they are also the units limiting the hydraulic capacity of the plants.

For example, the secondary clarifier puts a limit on the hydraulic capacity of the total biological system and hence the amount of water that can undergo biological treatment.

An optimized usage of the available hydraulic capacity can be obtained by real time control where the clarifier performance continuously controls the amount of water sent to the plant.

The sludge level in the clarifier and suspended solids in its overflow can easily be continuously measured, and as these parameters characterize the clarifier performance fairly well they can be used for control purposes.

Going into more sophisticated control strategies for plant emissions, it is also very important to take into consideration the dissolved contaminants.

The ideal situation would be to be able continuously to check waste water contamination levels in relation to plant performance, to evaluate the benefit of treatment instead of bypass in relation to total plant and sewer system pollution loads.

The impediment to reaching this level of control has partly been lack of reliable sensors and partly lack of control strategies and modelling tools.

However, with a modelling system such as the SAMBA Treatment Plant Module the first steps have been taken to quantify the benefits of an improved control, and that will naturally encourage further work in this field.

SAMBA Treatment Plant Module

As the SAMBA computations are based on a large number of rain storms representing a time span of many years, the treatment module is developed using a simplistic approach in order to avoid excessive computational time. The module concentrates on describing the effluent pollution loads under the strong variations of the hydraulic load due to rain storms. The results are annual and extreme statistics for the hydraulic load on the treatment plant and effluent pollution in wet weather as well as dry weather periods.

The input to the module describes the effluent quality of the plant during dry weather and wet weather periods together with a number of characteristic plant response times describing the reaction of the plant in connection with the increasing and decreasing hydraulic loads it is exposed to. The input parameters describing the plant are:

- C[illegible] = undisturbed dry weather effluent concentrations of BOD-, N-, P-, and SS-filtrable.
- C[illegible] = typical effluent concentrations of BOD, N-, P-, and SS-filtrable after some time with maximum hydraulic load on the plant.
- C[illegible] = typical effluent concentrations of BOD, N-, P-, and SS-filtrable during periods with sludge overflow (for overloaded plants).
- C[illegible] = undisturbed dry weather effluent concentrations of soluble BOD, N, and P.
- C[illegible] = typical concentrations of soluble BOD, N, and P during perioda with sludge overflow.
- T_1, T_2, T_3, T_4, T_5, T_6, T_7, and T_8 are plant response times. For example T_1 is the time from the beginning of the hydraulic maximum load until the typical effluent concentrations C[illegible] are reached.

The input data for the actual plant can be estimated on the basis of pollutant and discharge recordings at the outlet or simulation of a limited number of selected rain storms with a more detailed and sophisticated treatment plant model capable of simulating the processes under strongly varying hydraulic loads.

Apart from plant input data the treatment plant module also uses the resulting inflow hydrographs from the SAMBA modelling of the upstream combined sewer system as input.

See Figure 4, showing the computational procedure of SAMBA and SAMBA treatment module. In the present version of the

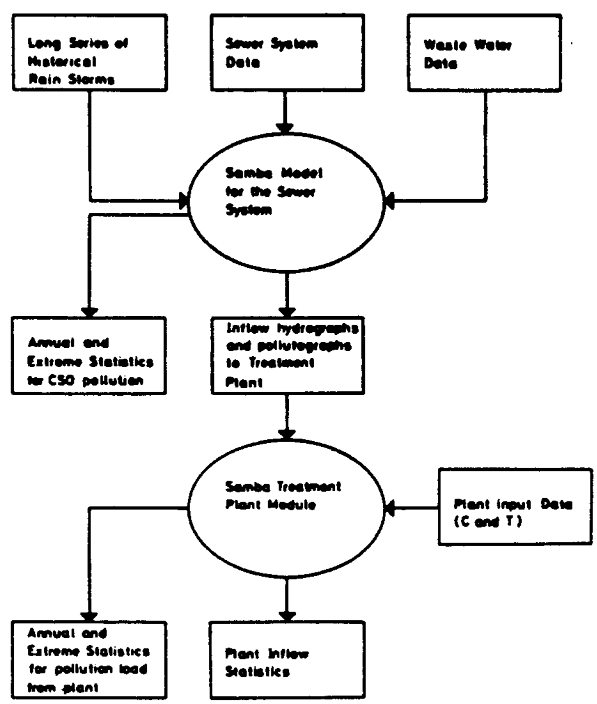

Figure 4: Overall computational procedure of the SAMBA model and its treatment plant module.

treatment module the inflow pollutographs, figuring in the flow chart, are not used in the modellings. For each inflow hydrograph to the treatment plant, corresponding to a historical rain storm, the module computes the accumulated

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amounts of BOD, N, P, and SS in the effluent on the basis of simplified relations between the specified effluent concentrations in the input data and the duration of the hydraulic maximum load.

Figure 5 illustrates how the computations are carried out.

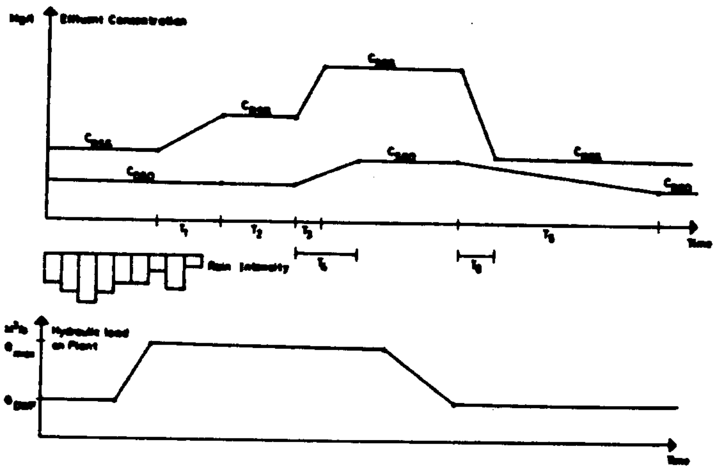

Figure 5: Effluent concentrations as a function of the hydraulic load on the treatment plant. QDWF = dry weather inflow. QMAX. = hydraulic capacity of the plant.

The concentratione for filtrable matter are climbing from the dry weather level to the C[illegible] level over a period of time of T_1. After an additional period of time of T_2 with maximum hydraulic load on the plant, sludge overflow may start to occur, and the concentrations for filtrable matter will gradually climb from the C[illegible] level to the C[illegible] level over a period of time of T_3. As a consequence of the sludge overflow, the efficiency of the plant with respect to soluble material also decreases, and the concentrations of soluble material gradually increase to the C_{max} level over the time of T_1 after the beginning of the sludge flight. After the cease of the hydraulic extra load on the plant it takes a long time, T_2, for the plant to recover with respect to the effluent quality of soluble material. This is due to the washing out of large volumes of sludge during the sludge overflow. For low-loaded activated sludge plants typical values for T_2 are 1-3 weeks.

Figure 5 is just an example of how the treatment module works. It also takes into account the special conditions that arise when the period with dry weather inflow between two consecutive storm water loads is shorter than T_2. Then the sludge volume is not regenerated up to its original magnitude, and thus it will take a longer time than T_1 in connection with the last of the two hydrographs before the sludge flight will start to occur. This facility is possible because the SAMBA model computes the historical rain storms in a chronological order and because each rainstorm is identified by its year, data, and hour. Of course the module also takes into account that the storm water inflow hydrographs can be so short that sludge overflow will not occur at all.

The module also carries out a statistical analysis of the inflow hydrographs and presents the results in a discharge--duration-frequency table. Examples of output are shown in Figures 6 and 7.

INTEGRATED REAL TIME CONTROL OF SEWER SYSTEM AND TREATMENT PLANT

The Basic Problem

The hydraulic load on a treatment plant depends upon the design of the upstream sewer system. When combined sewer overflows are reduced through larger basins and/or optimal utilization of the available volume through RTC, the storm water volumes conveyed to the treatment plant are increased. Thus solving the problems in the sewer network may create new problems with hydraulic overload on the treatment plant.

On the other hand there is an unutilized potential of integrated RTC of sewer system and treatment plant considering the system as a connected whole. For example the inflow to the treatment plant can be regulated to a low level when the sludge level in the final clarifier is monitored to be relatively high, while at the same time storage volume is available in the sewer network.

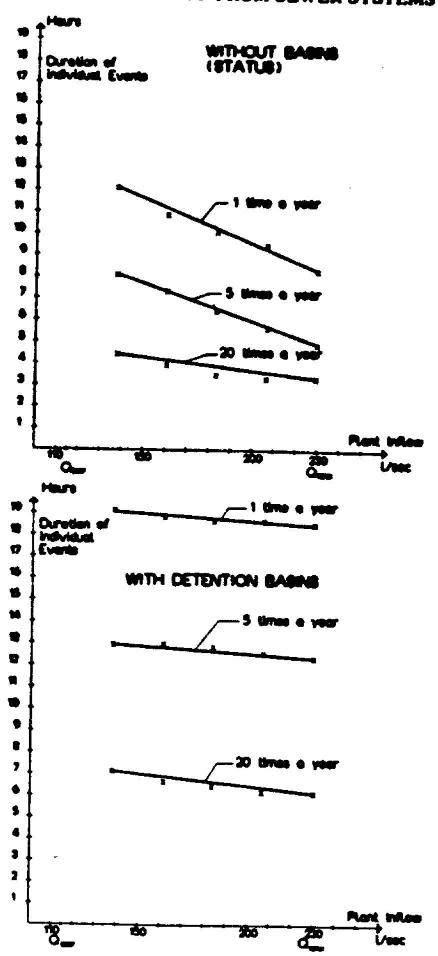

Figure 6: Extreme statistics describing inflow-duration-frequency relationship for Fakse treatment plant with and without detention basins. Example (without basins): 5 time a year an inflow event with Q ≥ 185 l/sec. over a period of time of ≥ 6.5 hours will occur. Q_{max} = plant hydraulic capacity = 230 l/sec. Q_{dw} = Average dry weather inflow = 115 l/sec.

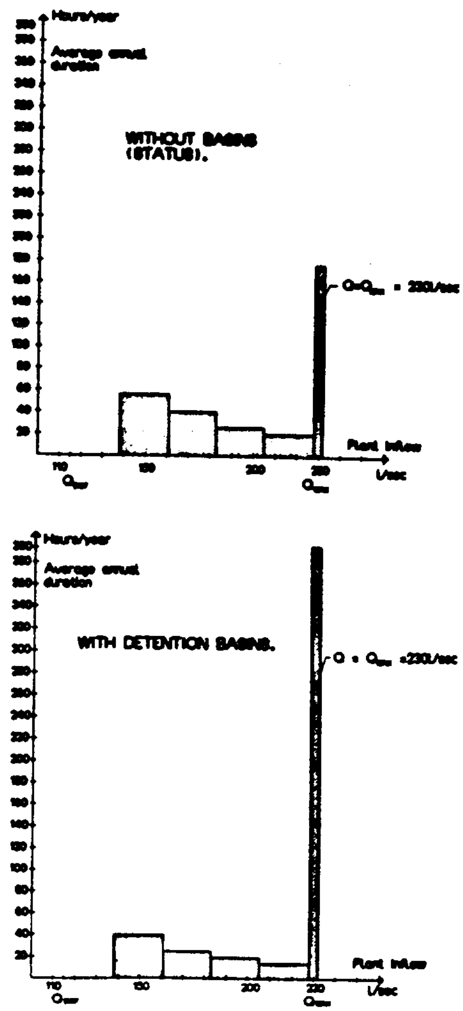

Figure 7: Annual duration of inflow to Fakse treatment plant over various intervals. Without and with basins.

In Denmark the coherence of storm water runoff and treatment plant performance constitutes a delicate problem, as many treatment plants presently are being extended to remove nutrients, while at the same time the national authorities heve not yet issued their instructions to the municipalities regarding CSO reductions. Thus the designers of the treetment plente face the problem of establishing the hydraulic design criteria for the final clarifiers on an uncertain basis.

Integrated Studies of Sewer System Treatment Plant

The SAMBA model for sewer system and treatment plant was used on the village of Fakse in Denmark. The catchment area is 114 ha, and the sewer system comprises 3 CSO's. An analysis is carried out for the existing situation without detention basins and for a planned situation with a storage capacity corresponding to 10 mm of precipitation in order to reduce CSO-pollution loads. Table 1 shows the computed total pollution loads from CSO's and treatment plant, and Figures 6 and 7 show how the computed inflow statistics are affected by the introduction of basins in the model. The modelling indicates a significant negative overall effect of the basins due to the increased hydraulic load on the plant. The strong negative effect is due to the relatively small final clarifiers on the actual plant; sludge overflow occurs frequently.

In order to minimize this uncertainty in connection with the extension of Greater Copenhagen's treatment plant of "Lynetten", a model study of the plant and its 140 km² densely populated upstream catchment will be carried out. "Lynetten" has a capacity of 2.4 mio. p.e., a dry weather hydraulic load of 3.4 m³/s and a hydraulic capacity of 11.8 m³/s. A SAMBA model covering the entire catchment will be built. The model comprises trunk lines, interceptors and approximately 500 overflow structures, detention basins and pumping stations. The treatment module will be coupled to the SAMBA network module in order to compute the inflow statistics for "Lynetten". Because of the extent of the catchment the SAMBA model will be modified to take into account the geographical variation of the precipitation by using the historical rain series from rain gauges located at 10 different positions in the catchment. The study will be carried out in 4 stages:

(a) Status modelling of present pollution loads from CSO's and hydraulic loads on treatment plant.

(b) Definition of future development scenarios corresponding to increased storage capacity (through more basins and/or RTC) in order to reduce CSO pollution. To be carried out in cooperation with the county authorities.

(c) Modelling of future CSO-pollution loads and inflow statistics to the treatment plant.

(d) Establish hydraulic design criteria for the extension of the treatment plant.

The study is scheduled to be completed by June 1990.

Table 1: Pollution loads from treatment plant and CSO's in Fakse without and with detention basins.

	Without Basins			With Basins		
	Treatment Plant	CSO's	Total	Treatment Plant	CSO's	Total
m /year	3.708.000	96.000	3.804.000	3.789.000	15.000	3.804.000
kg BOD/year	65.319	7.674	72.993	83.030	1.015	84.045
kg N/year	31.096	1.254	32.350	40.370	188	40.558
kg P/year	8.088	342	8.430	12.500	49	12.549

Integrated RTC of Sewer System and Treatment Plant

As part of the Taarnby Project the treatment plant module of the SAMBA model will be developed further to include RTC at the treatment plant, such as regulation of inflow as a function of the sludge level in the final clarifiers, regulation of recirculation from final clarifiers to aeration tanks and by-pass of the biological step of the plant.

Then this module can be coupled with SAMBA CONTROL for the sewer system to a complete model for integrated RTC of sewer system and treatment plant. The first step is to develop an integrated RTC off-line simulator using a relatively simple "in-then-else" strategy based upon the actual state of the system. The subsequent steps are planned to be off-line simulation of predictive strategies including optimization and finally development of an on-line simulator for use in the central control unit of the RTC-system.

CONCLUSIONS

With increasing demands on the treatment of sewage there will be a correspondingly increasing demand on the performance of the sewer system. It must be expected that there will be a need for investment in better sewer system performance during rain, predominantly in detention basins and better final clarifiers.

The sewer system and the treatment plant have to be designed and operated as an entity within the constraints formulated as permissible discharges. Indications are that storage in the catchment for decrease of pollution from CSO's can equalize or even increase the load from the treatment plant to the extent that the total load from the system is increased.

The increase in total load on the receiving water is the result of prolonged hydraulic loading of the final clarifiers in the treatmont plants during rain. The reason is, that the effluent quality is not only a function of the hydraulic load, but also a function of the duration of tha load. The duration is significantly increased, when more atorage is introduced to decrease the load upstream from combined sewer overflows.

There are computer programmes available with which to calculate the permissible discharges to the receiving waters, based on extreme statistics for acute pollution and annual discharges for accumulating pollutants. There are computer programmes available with which to calculate the intermittent discharges and the annual discharges from a given system, involving the totality of the system: sewer system and the treatment plant.

There is a significant potential of saving in design and of better performance by real time control of the total system. This potential is presently under intense investigation in Denmark.

It is remarkable how much can be gained with simple sets of rules, which have been chosen by trial and error through testing on the computer the performance of the system for a 40 year historical rain record. The testing of the rules involves both the extreme statistics expressed as return period (BOD and oxygen depletion) and the annual load (nutrients), to be in accordance with the constraints of the receiving waters. The next step is to incorporate operational optimization (e.g. by linear programming) and expert systems. Such projects are under development.

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STORAGE OF COMBINED SEWAGE IN A MARINE WATERBODY

by Richard Field[1],
Karl Dunkers[2], and Angelika Forndran[3]

Introduction

Pollution abatement of urban-storm-induced discharges including combined sewer overflows (CSO) is one of the major capital spending programs in the United States. The basic applied control technology is the process-combination concept of storage--treatment for the least-cost system(1,2). Instead of using conventional storage units, e.g., reinforced concrete tanks and lined earthen basins, which are relatively expensive and require a lot of urban land area, the in-receiving water flow balance method (FBM) facilities use the receiving waterbody itself for storage volume.

The FBM was conceived and developed in the latter part of the 1970's by Karl Dunkers, a Swedish research engineer(3). The FBM facilities receive and contain urban-storm-induced discharges between flexible plastic, e.g., fiberglass reinforced PVC (polyvinyl chloride) curtains suspended from floating wooden pontoons. The curtains are anchored to the receiving water bottom by concrete weights. The Flow Balance Method of storage is low cost due to its low-cost materials of construction, i.e., plastic and wood; installation time, i.e., several days to weeks; and the

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absence of land requirements. Studies show that costs could be about 5%-15% and 40%-50% of conventional concrete tank costs for freshwater and saltwater applications, respectively (without including land costs).

As indicated above, there are two basic hydraulic patterns; one is for fresh- and the other for salt-receiving waterbodies:

- In <u>freshwater applications</u>, such as those being conducted at three lake sites in Sweden, storm flow enters compartments formed by the curtains according to the plug flow principle whereby there is a vertical front or transition zone (from the receiving-water bottom to its surface) between the storm flow and the receiving waterbody. Figure 1 is an isometric rendering of an FBM facility for fresh-receiving water applications. The FBM facility acts as a storage tank and the tank bottom is the receiving-water bottom itself. The facility (or tank) is always filled up, either with polluted storm flow and/or receiving water. Under storm-flow conditions the storm flow will "push" the receiving water from one compartment to another towards the unconfined receiving water. After cessation of the storm flow or when the downstream treatment plant has available capacity, pumps start automatically and the surrounding waterbody enters the compartments and pushes the storm flow back towards the first compartment where it is pumped to the plant. Thus, the waterbody is used as a flow balance medium. The pumps stop automatically based on receiving sewer and treatment plant handling capacity and/or an override from a parameter sensor that indicates too high a receiving-water dilution.

- In <u>saltwater applications</u>, such as what is being conducted at the Fresh Creek site in New York City (Figures 2 and 3), the basic difference is that instead of storm flow traveling as a plug with a vertical front, it fills the tank from the surface and creates a horizontal layering or stratification effect (illustrated by the "boundary layer" in Figure 3). The bottom layer is the receiving-waterbody saltwater that gets displaced as storm flow enters. The displaced saltwater exits through an end-curtain bottom rectangular opening. The FBM facilities have been operating successfully for approximately ten years for control of separate stormwater entering relatively quiescent freshwater lakes in Sweden(3), and are able to take ice and wind loads without adverse impact. The objective of the project which this paper discusses is to demonstrate a facility for CSO storage in a harsh estuarine/marine site having tidal exchange, freezing, and coastal storm phenomena.

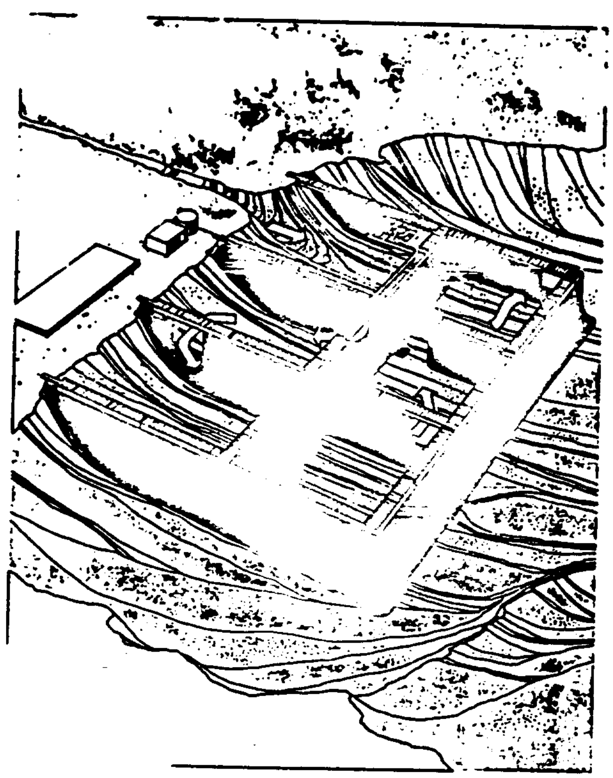

Figure 1.—Flow Balance Method (FBM) for Fresh-Receiving Water Applications; Isometric Rendering

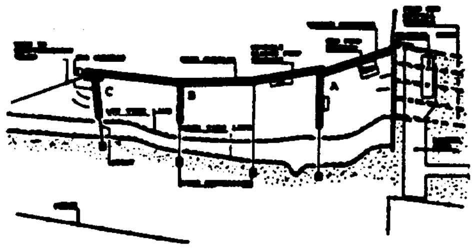

Figure 2.—FBM Facility, Salt-Receiving Water Application, Fresh Creek, City of New York; Plan View

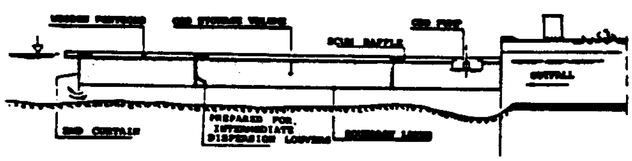

Figure 3.—FMB Facility, Salt-Receiving Water Application, Fresh Creek, City of New; Longitudinal Elevation View

The prototype demonstration facility (Figure 4; site photograph) located in Fresh Creek, a tributary of Jamaica Bay in Brooklyn, New York started operation in November 1988. The evaluation includes CSO capturing efficiency under the impediments of flow saltwater and freshwater density differences and curtain leakage; structural ability to endure the harsh coastal marine environment; and floatables and settleable solids removal effectiveness. Interim data (including that from salinity profiling) from several storm flow occurrences indicates that the saltwater-freshwater stratification phenomenon is enabling the facility to operate effectively and detailed results of the evaluation will be presented.

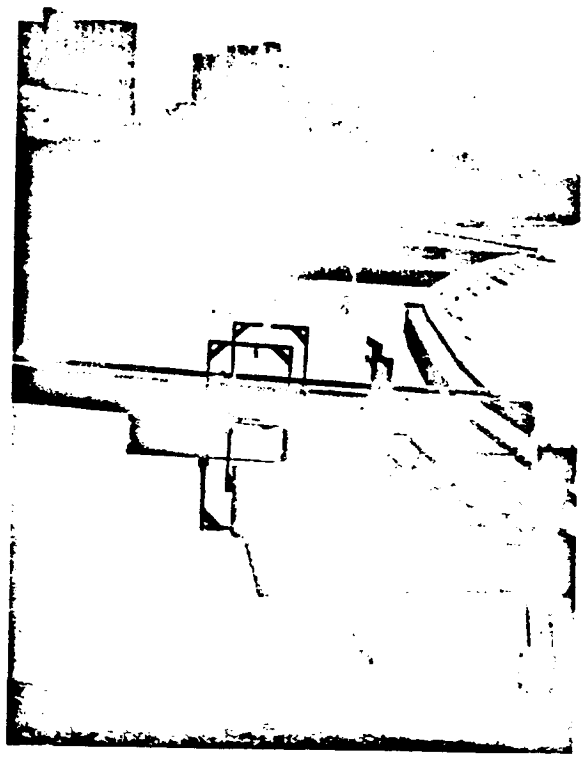

Figure 4.—FMB Facility, Fresh Creek, City of New York; Photograph from Top of Combined Sewer Outfall

Description - Fresh Creek FBM Facility

The site has a large combined sewer overflowing to the head end of the Creek which degrades water quality.

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The only mechanism for flushing this waterbody is the CSO and tidal exchange. The flow regulator located about 300 ft upstream of the outfall passes up to 51 cfs to the interceptor flowing to the sewage treatment plant located about a mile from the FBM facility. The outfall from the regulator tide gate chamber has four barrels, each 10 ft high by 15 ft wide. One of these barrels is not in use. The facility is built of pontoons and curtains which form a rectangular tank roughly parallel to the shore line. The natural Creek bottom is the tank bottom, and the natural shoreline is one of the "walls". The outer longitudinal "wall" is comprised of a solid curtain suspended from the pontoons to the Creek bottom and the end lateral pontoons suspend a curtain only partially (6 ft into the water) to permit exchange of CSO and Creek water at the Creek bottom. The intermediate lateral pontoons provide access for structural guy wires, cleanout, and water sampling. They could also be used for additional curtains suspended to the bottom with vertical louver type openings to enhance flow distribution.

Figures 2 and 3 show the plan and elevation views, respectively of the demonstration plant. Since CSO has a lower density than the Creek saltwater, it fills the tank volume starting from the top. As shown in Figure 3, stratification and a corresponding boundary layer is formed between the CSO and the saltwater. During the filling sequence, the saltwater is replaced by the CSO causing the saltwater to be discharged from the tank through the end lateral curtain opening.

When additional flow can be handled by the downstream plant and intercepting sewer, a floating pump starts to pump back the CSO to the interceptor. Creek saltwater reenters the tank through the end opening replacing the CSO in the tank and the boundary layer rises towards the surface. When the layer reaches the intake of the CSO pump, a salinity probe, indicating relatively high Creek water dilution, automatically switches the pump off. At that moment the tank is filled with saltwater again and ready to receive the next storm.

The pontoon system is supported by means of stressed wires fixed to land anchorings and a counterweight tower. The weight of the 12-in. strut pipe is balanced by an enlarged pontoon with a spherical bearing. The strut also maintains a uniform distance between the shoreline and the side or longitudinal pontoon line which is always in tension caused by the land base counterweight tower. This design maintains the

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rigidity and flexibility of the pontoon system for all design load conditions. The rigidity is required to maintain the general "tank" shape. The flexibility is required to accommodate the 7 ft tide differential as well as lateral movement during intense CSOs, wave action, and coastal storms.

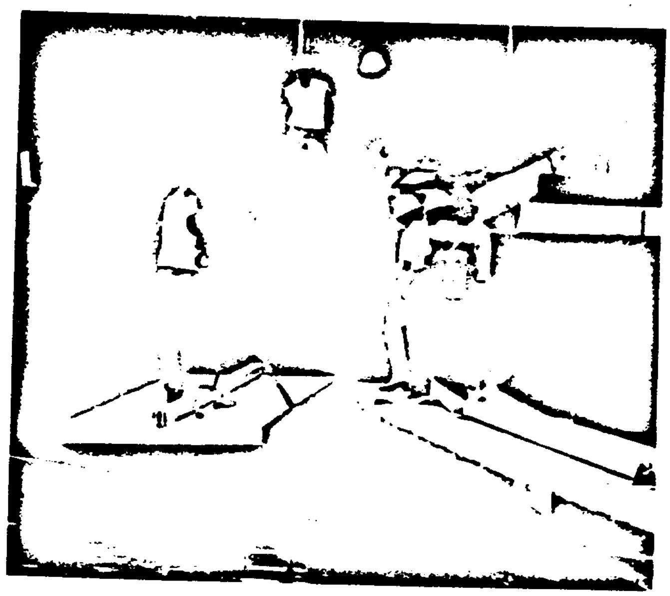

Figure 5.—FBM Facility, Fresh Creek, City of New York; Photograph during Installation

Each of the 23 pontoons (16 longitudinal and seven lateral) is about 16 ft long by 5 ft wide and can sustain 3000 lb with an 8 in. freeboard. They are made of Douglas Fir lumber on eight injection molded foam filled plastic "tubs" sealed in a polyurethane enclosure which provide buoyancy and protection against

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saltwater and its degrading pollutants. The curtain is made of a polyester textile, reinforced with polyvinyl chloride (minimum 25 mils thick). Each section of curtain is protected by a sunscreen (curtain flap) about 4 ft deep. The side curtain is anchored by concrete weights (14 lb each) 2 ft on center and has sufficient slack for the tidal range. The curtain will act like a relief valve during excessive CSO to eliminate structural tear by "ballooning" or lifting. The system permits the addition of pontoons and compartments releted to the loading capacity of the counterweight tower.

Installation

The official operational start-up date was November 21, 1988. Two months were required to build the five concrete foundations. The pontoons were delivered prefabricated to the site and were launched and coupled in one week. The curtains were installed in two days. Figure 5 depicts the pontoon launching and coupling during installation. The site work included clearing and ground leveling, laying a gravel access road, positioning the instrumentation trailer, and surrounding the area with fencing for security.

Operational and Monitoring Equipment

Figure 6 is a schematic of the monitoring and operational equipment. The monitoring equipment is used for the essential measurements of salinity, flowrate, CSO pump operation, and removal of deposited solids. The salinity measurement which controls the CSO pumpback operation is derived from a specific conductivity probe. The probe is attached to the CSO pump pontoon about 6 in. below the Creek water surface. The instrument meter with strip chart recorder is in the electronic control panel in the trailer. Pump control is based on salinity set points. Manual salinity profiles and verification checks for the salinity probe are obtained and conducted periodically.

The 400 gpm CSO pump is hung from its own pontoon and the intake is in a submerged small tank (6 ft x 4 ft x 4 ft deep). The pump is monitored by time period of operation which is logged. Pump "on/off" operation is first determined by the liquid-level sensors at the flow regulator chamber and then by the salinity reading. Operation only occurs during low salinity

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and low liquid-level readings from the regulator. Mode of operation during the evaluation includes manual start-up of the CSO pump (since the pump requires on-site checks of its condition) and automatic shutoff.

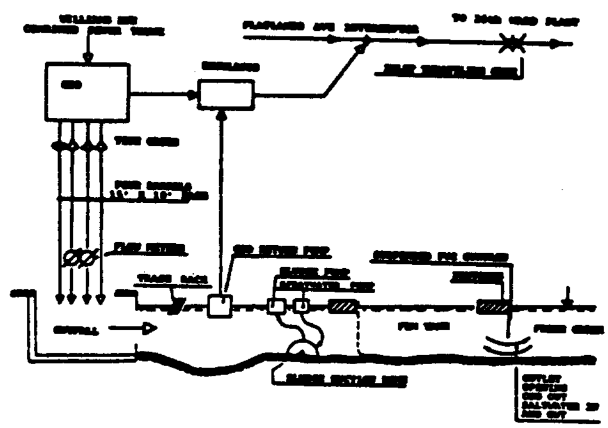

Figure 6.—FBM Facility, Fresh Creek, City of New York; Schematic Diagram of Operational and Monitoring Equipment

CSO rate is measured by two different flow instruments. Barrel No. 2 (second from the east shoreline) contains two current meters (Endeco; model 174 SSM) that pivot on a vertical shaft according to flow direction (allowing reverse [tide] flow measurement), one 6 in. from the surface, and the other 1.75 ft above the outfall invert and a pressure water level recorder (Endeco; model 1029 SSM). Barrel No. 3 contains a flowmeter measuring three cordal velocity paths based on the stream velocity attenuation of the time of sound and water level by echo sound (Accusonic; model 7410). Barrel Nos. 1, 2, and 3 could also be monitored during events by use of a portable water current meter (Marsh McBirney; model 201). (Barrel No. 4 is not in operation.)

A "sludge dome" was installed on its own pontoon for removal of deposited solids. The pontoon is equipped

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with a flexible hose and can be moved to any position in the first FBM facility compartment. The dome is raised and lowered by a ratchet lever and cable. When the dome is lowered to the desired position a small pump sprays water inside the dome mixing the sludge blanket and a large pump lifts the concentrated flow (sludge and sprayed water) to the CSO pumpback tank. The density of the bottom layer as well as the bottom profile is monitored by a portable suspended solids meter (Eur-Control; model Mex-P). Solids pumpback in the second compartment is accomplished by a portable suction pump.

A tide level gauge was marked on the outfall face with mean tide level as 0.0 (with 3 in. incremental markings up to 6 ft above and below). Additional equipment was fabricated by the operators to handle floatables which will be described later.

Evaluation

Storage Volume.—The total volume contained by the FBM facility varies with the tides. The shoreline has a significant slope into the Creek and the bottom is irregular due to the head-end scouring and subsequent settling from and of the CSO and its solids, respectively. The volumetric configuration roughly resembles a triangular prism. Figure 7 is a graphic representation of FBM facility volume to tidal stage relationship. Volumes were calculated from bathometric measurements. The facility volume at mean tide is about 410,000 gal and ranges from 160,000 to 650,000 from a mean-low to high tide.

Salinity Profiles.—Monitoring the salinity gradient from Creek surface to bottom to determine CSO and Creek water stratification is the key element of this project. The monitoring includes determining salinity profiles at seven stations along the lateral pontoons within the FBM facility and two outside the curtains both after the CSO event ends and during its pumpback.

Figures 8-10 contain profiles for CSO events during low, high, and rising tide, respectively that show the stratification which identifies the CSO volume stored within the FBM facility. The "A" pontoon stations are closest to the outfall and the "C" stations are at the facility discharge end. A pictorial presentation of the displacement of Creek water by the CSO from the surface downward is shown in Figure 11.

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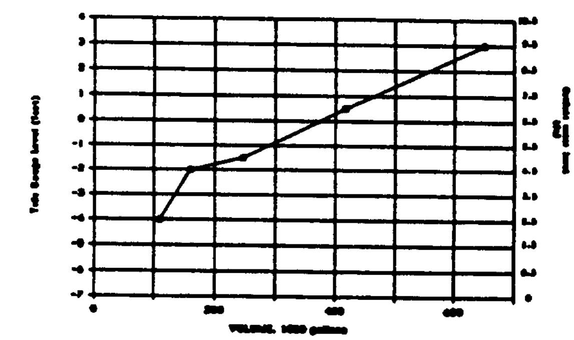

Figure 7.—FBM Facility, Fresh Creek, City of New York; Graph of Volume vs. Tide

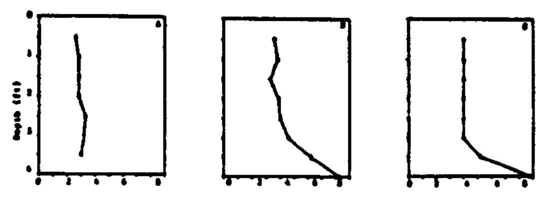

Figure 8.—FBM Facility, Fresh Creek, City of New York; Salinity Profiles, CSO Event (12/28/88), Low Tide

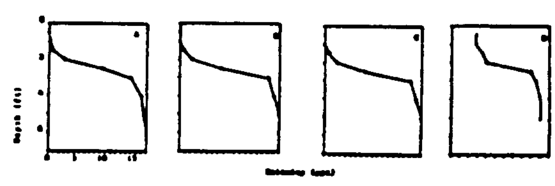

Figure 9.—FBM Facility, Fresh Creek, City of New York; Salinity Profiles, CSO Event (8/11/89), High Tide

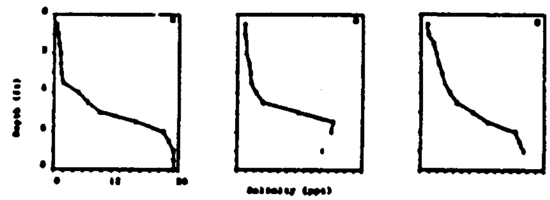

Figure 10.—FBM Facility, Fresh Creek, City of New York; Salinity Profiles, CSO Event (5/11/89), Rising Tide

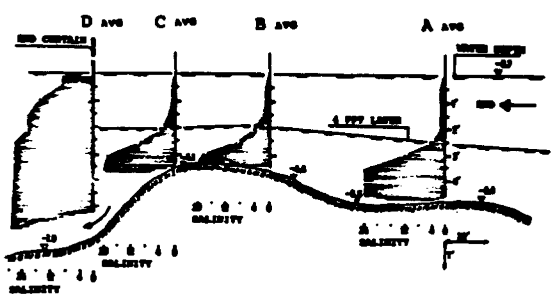

Figure 11.—FBM Facility, Fresh Creek, City of New York; Pictorial Profiles of CSO Replacing Indicated by 4 PPT Salinity Boundary, CSO Event (12/21/88)

CSO Capture Effectiveness.—Measurements for CSO rates are challenging because of tidal interchange. Having two flow measurement systems in place helps ensure availability of data when one system is down. The Fresh Creek combined sewer outfall is among the largest in the City and the volume of event overflow is disproportionately large compared to the storage volume in the facility. In other words, this is a pilot-size facility on a full main stream. The research project had limited funds and a full-size plant could not be afforded. An important reason for selecting Fresh

Creek as the demonstration site is its relative ease of access. CSO rates of over 400 cfs were recorded in barrel No. 3 with flows generally around 150 cfs. Overflow events are recorded automatically by the flowmeters but not all events have complete monitoring data because of the on-site data collection requirement and as with any demonstration plant debugging was required causing down times. Table 1 contains pumpback data for five overflow events. The most reliable data consists of manual salinity profile measurements determining actual CSO volume contained in the facility (labeled "YSI Salinity Volume"). The estimated outfall volume assumes the CSO layer extends upstream to the tide gates.

TABLE 1.—CSO Pumpback Data

Event Date	Duration of overflow, in hours: minutes	Discharge volume,* in million gallons	Tank volume during event, in million gallons		YSI Salinity volume, in million gallons	Outfall volume, in million gallons	Pump-back volume, in million gallons	Recovery, as a percentage
			maximum	minimum				
12/28/88	00:40	--	--	0.15	0.15	0.23	0.35	92
7/16-17/89	04:00	16.0	0.51	0.28	--	0.28	0.52	100
8/11/89	04:40 02:00 03:10	10.7 7.2 2.1	0.45 0.60 0.61	0.33 0.54 0.39	0.44	0.50	--	HOSE DIS-CONNECT
9/14-15/89	03:30 03:40	3.3 3.5	0.32 0.56	0.16 0.42	0.19	0.15	0.34	100
9/17/89	00:30	0.26	0.44	0.38	--	0.10	0.20	77

*Flow adjusted from Accusonics data for 3 barrels

Calculations using the pump log yielded the volume pumped back. The salinity pump control set points allowed for 20%-50% mixing at the boundary transition zone. The percent recovery is based on either the total volume discharged, if less than minimum tank volume or the minimum tank volume (conservatively assuming that high-tide storage would have escaped during low tide prior to pumpback). For all events

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which were observed, leakage or escape outside the side curtain could be seen. Minor leakage (5%-10%) is inherent with the FBM facility; however, major leakage occurred due to the relative small size of the facility. The recovery of the contained volume ranged from 77%-100% for the four storms shown.

Settled Solids Recovery.—To date, one bottom "sludge" pumpback with the dome mechanism was conducted. Positioning of the "sludge dome" pontoon was determined by scanning the bottom with the sludge blanket meter. Deposits in the second compartment were pumped out using the portable suction pump.

Floatables Recovery.—A 1 in. aperture 60° inclined manual raking screen is used for floatables removal. Any floatables which accumulate before the second and last pontoons are also removed manually. From November 1988 through June 1989 a total of 11,000 lb of trash and floatables were removed. Coarse floatables recovery (based on visual estimates) is 95%.

Floatables removal apparatus could have been better designed and automated but, as stated previously, due to funding limitations for this developmental project and the basic desire to demonstrate the FBM, low-cost equipment was used.

Costs

Total project costs are about $700,000 of which $565,000 was for equipment and construction. Capital cost estimates for full-scale facilities as a function of facility volume are shown on Figure 12 and according to a construction cost breakdown for a 10 MG facility on Figure 13. Operational costs include O&M labor, power supply, instrument supplies, and hauling fees vary widely based on geographical area, facility configuration, final design, proximity to a treatment plant, size, and performance requirements.

Permit Considerations

Waterfront activity is subject to federal and state regulations. The Fresh Creek FBM demonstration facility required a work permit from the New York City Department of Ports and Terminals, a Tidal Wetlands Permit from the New York State Department of Environmental Conservation, and an Army Corps of

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Engineers Permit. These were granted for the existing facility taking into consideration that this is a temporary demonstration plant under an EPA program. Any in-water facility would be subject to the pertinent regulatory requirements and administrative review procedures.

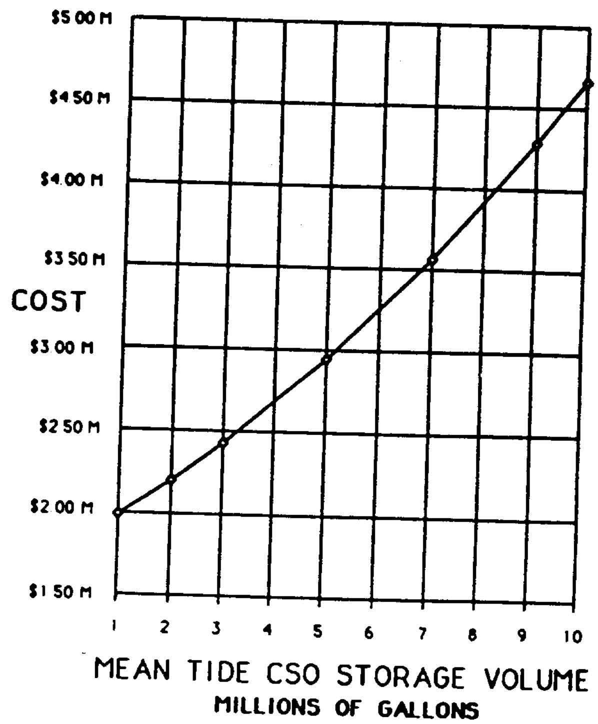

Figure 12.—CSO FBM Facilities; Graph of Capital Cost vs. Volume

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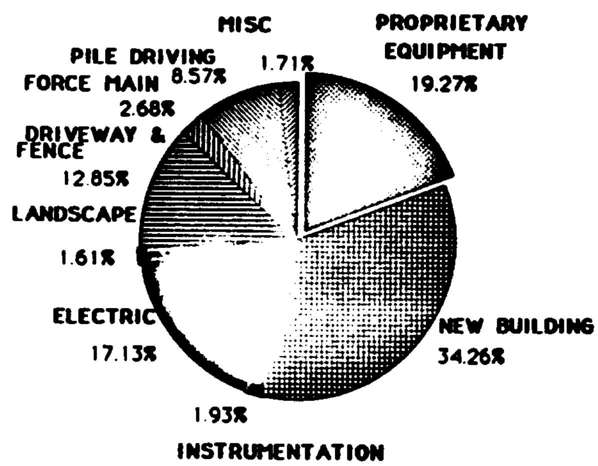

Figure 13.—10 Million Gallon CSO FBM Facility; Construction Cost Breakdown

Conclusions

- The FBM system of pontoons and curtains can be installed in estuarine waters and effectively captures CSO based on:

  (1) No structural damages or material degradation occurring after more than one year of operation. A tear in the side curtain early in the program was repaired within one day by chemical bonding of material. The system has been exposed to tidal ranges up to 7 ft and on at least two occasions to winds gusting to 40 mph. It has not yet been exposed to major ice conditions.

(2) CSO does effectively displace natural marine water inside the facility and forms an identifiable strata above it (the marine water) enabling the CSO stored to be pumped out to an existing interceptor for treatment. A transitional layer of water from 6 in. - 12 in. at the boundary interface mixes from 20%-50% of Creek water.

- Other than the dynamic volumes and rates of CSO inflow, the factors which influence the amount of effective storage volume are: tidal phase at time of CSO event and pumping, time period of storage until start of return pumping, return pump capacity, and downstream interceptor and treatment plant capacity.
- The existing demonstration plant is significantly small compared to the CSO entering. The intense CSO from the barrels caused "blowout" to occur, i.e., release of CSO under the side curtain. This condition is further aggravated by the present configuration which has the side curtain crossing the flow plume line from the outfall; however, the plant is sufficient to address its demonstration objectives which are (a) structural durability and (b) CSO storage effectiveness.
- The FBM facility is very effective in trapping coarse floatables. Based on visual estimation, 95% retrieval can be accomplished.
- Settled bottom solids and sludge can be pumped back by various means.
- The relatively low cost and ease of facility installation enables a less intensive urban hydrologic design procedure since the facility can either be made larger from start or facility compartments may be added after trial operation.

Recommendations

- The physical configuration of an FBM is critical to its performance with these recommendations being important: (a) the discharge end orifice cross-sectional area should be equal to or larger than that of the outfall so as not to cause a hydraulic constriction, enhancing CSO leakage under the curtains and (b) there should be free

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discharge from the outfall with the curtain "wall" parallel to and beyond the flow plume line but definitely not crossing it (flow plume line) until energy dissipation has occurred.

- The storage volume should be optimized using the natural existing waterbody boundaries minimizing the need for dredging.
- To optimize pollutant capture, CSO pump rates should be relatively high and deposited solids pumpback should be done as soon as practicable and its removal apparatus should be flexible and allow for easy movement around the entire facility.
- The floatables removal system should be improved and/or automated at Fresh Creek and elsewhere to reduce the labor required. The method for capturing floatables should also be flexible and allow for collection throughout the facility plan area.
- Further information on the addition of pontoons and curtains should be developed for Fresh Creek. The capability of adding or removing storage compartments at relatively low cost and time requirements means that this facility can accommodate less detailed hydraulic design volume considerations than fixed tanks, and containment volume should also be made larger to make up for leakage under the curtains.

Appendix I.—References

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Equipment and Instrumentation for CSO Control

Hansjoerg Brombach*

Abstract

In West Germany there are about 9,000 storm overflow tanks in operation. This paper focuses on equipment and instrumentation installed at these tanks.

Storm overflow tanks are classified into different basic design types. The relative numbers of in-line/off-line and first-flush/clarifier type tanks in Germany will be shown. Storage capacity can be provided by rectangular, tube-type or circular tanks.

A common problem with all tanks is outflow control. Outflow during storms is restricted to less than twice the dry weather flow. This requirement places great demands on system hydraulics and reliability. Examples of successful controllers will be shown.

Air regulated siphons and helical bends "Filippi" are devices used for level control. Low pressure check valves and anti-return flaps are used to handle back-pressure problems.

In recent years a new problem has arisen - automatic cleaning of the large number of decentralized storm tanks. Tipping flushers and motor stirrers are widely used.

The German WPCF recommends monitoring of all new and important Combined Sewer Overflows (CSOs). A battery powered "Sewer Spy" which is controlled by a microcomputer takes water stage readings every minute. The data collected is recorded in the form of stage frequency and stage duration tables. A data example will be given.

In future remote surveillance and real time control of storm tanks will be installed. Practical aspects are discussed.

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1. Storm Water Treatment In West Germany

Combined sewerage are the major type of sewerage system in this country with regard to the number of residents connected, accounting for 71.2%. Since about 1972 there has been a commitment to systematic upgrade the combined sewerage systems. The construction of de-centralized reservoirs (so-called storm overflow tanks) within the sewer network is intended to drastically reduce the frequency and quantity of sewage discharged into receiving waters during rain storms. By the end of 1989, about 9,000 storm overflow tanks with a collective capacity of 5 million m³ will be in operation. However, only 25% of the total number of combined sewerage systems have yet to be upgraded to the latest technical level. The cost of these storm overflow tanks has probably reached around DM 7.5 billion (4 billion US $). In other words DM 170 per consumer (90 US $). Further information on present stormwater treatment practices in West Germany can be found in /1,2/.

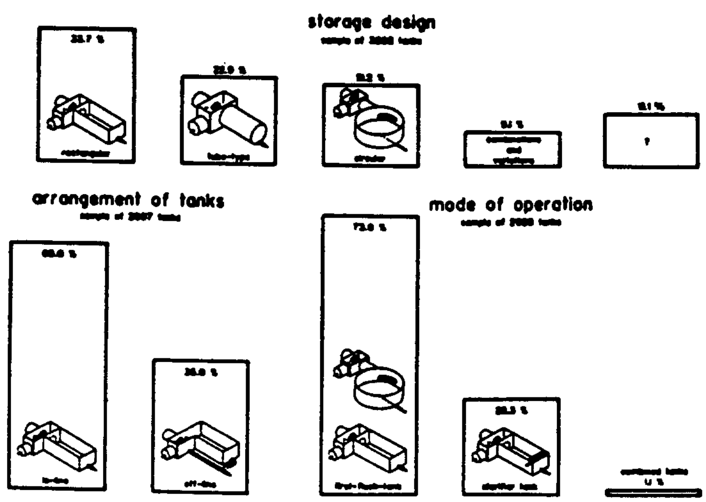

Fig 1: Distribution of storm-overflow-tanks in West Germany

2. Types and Distribution of Storm Overflow Tanks

The "A128" guidelines /3/ which are applicable in West Germany allow a great deal of latitude in the design of storm overflow tanks. This flexibility led initially to a broad spectrum of tank types and methods of operation. Today, on the basis of fifteen years of experience, it is possible to identify several basic designs which have proved worthwhile.

Statistical information has been collected on around half of the 9,000 storm overflow tanks. Investigation of the different designs of storage tanks provided the estimates shown in the top line of Figure 1. A third of all tanks are concret cuboid reservoirs which are rectangular in plan view. Around a quarter achieve their storage capacity simply by having an oversized interceptor. The advantage of this scheme is that no additional space is required, and the storage capacity is underground. The disadvantage is the difficulty of access for maintenance personel. The third arrangement which is common in South Germany uses a circular overflow tank with tangential feed. Although this design is reminiscent of the swirl concentrator familiar in the USA, its background is different. It is not intended to separate solids (this also explains why the overflow is upstream the reservoir). Instead the vortex flow is designed to keep the floor of the tank as free as possible of sediment. 21.2% of all storm overflow tanks use this design. Around 10% have special shapes which were the result of lack of space, or are combinations of the three basic designs described above.

The available drop often determines whether storage is arranged in-line or off-line with the interceptor. Off-line reservoirs can be partially or completely emptied after the rainstorm, using pumps, and require little elevator drop. At present the in-line reservoirs are most frequently used, accounting for 65 % of the total (see Figure 1, bottom row, left). However, the more awkward renovations that are encountered, the more frequent the off-line model will become.

Two methods of operation are distinguished for storm overflow tanks - the first flush tank and the clarifier-type tank. The first flush tank has no clarifier overflow, and merely collects the flush water by means of its storage capacity. Clarifier tanks are intended to keep contaminants from the receiving water by means of sedimentation in a similar way to the primary clarifier in the Waste Water Treatment Plant (WWTP). Almost 74 % of all storm overflow tanks in Germany are of the first flush type (see Figure 1, bottom right). This too will alter in the future, when a move towards a combination of the two types occurs (at present to be found in only 1% of cases).

3. A Modern Storm Water Overflow Tank

The combination-type tank, which as yet is not widely used but which will be of significance in the future, provides an example of optimum use of technical equipment. Figure 2 shows one of the latest types of

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1 interceptor
2 backwater prevention with air-regulated siphons
3 diversion chamber with three overflows
4 electrically operated knife-valve
5 flume, parabola shaped orifice plate
1,6 tube-type in-line storage
7 off-line first flush tank
8 off-line clarifier tank
9 clarifier overflow with scum board
10 clarifier overflow control
11 soft rubber check flap
12 backflow prevention from high receiving water levels
13 electronic control
14 remote control from WWTP
15 "Sewer Spy"
16 receiving waters
17 storm outlet

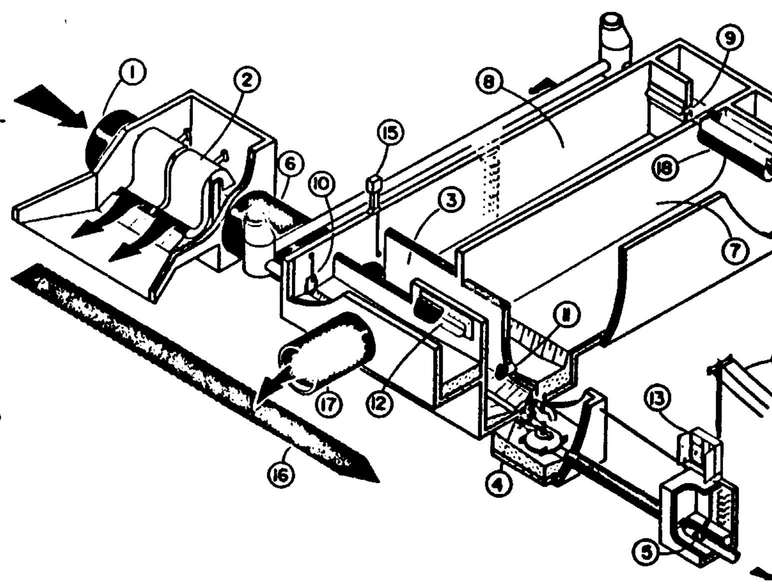

Fig. 2: Design of an advanced CSO-Control-Station

medium-sized storm overflow tanks with a storage capacity of approx. 500 m³. This corresponds to the average volume of storm overflow tanks in Germany.

The large diameter interceptor can be seen on the left and feeds a diversion chamber with three overflow weirs of varying heights. At the end of this diversion chamber is an outflow controller which normally limits the outflow to twice the dry weather flow. During dry weather, sewage flows unhindered through the system and all tanks are empty. At the start of a rainstorm, the outflow controller at first allows the level in the interceptor to rise to the height of the weir in front of the right hand storage chamber. This storage facility collects storm water from frequent short duration rainfalls. The flooded sewer acts like the tube-type storage facility.

During heavier rainstorms, the right hand storage chamber is flooded first because it has the lowest overflow weir. It is fitted with a check flap so that the chamber can empty by gravity after a rainstorm. The right hand chamber is equivalent to an off-line first flush tank.

If the rainfall continues, the left hand chamber is filled next. If this chamber is filled, then the clarifier overflow at the far end of the chamber comes into operation. To prevent the clarifier overflow from being hydraulically overloaded, the return flow line has a control orifice, see item 10, which is set to prevent re-suspension of settled solids.

If the water level increases even further, the storm overflow comes into operation. Overflow water then flows untreated into the receiving water.

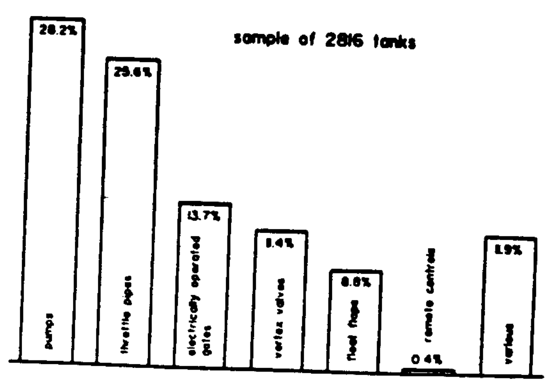

Fig. 3: Distribution of flow controllers in storm tanks

In the event of extreme flow levels, the limited length of the storm overflow weir might lead to undesirable back pressure in the sewer network. In such cases, the emergency outlet situated upstream of the tank has two air-regulated siphons to provide relief.

This combination design providing multiple functions ensures that the tube-type sewer storage tank is frequent used, the rectangular first flush tank less frequently, and the clarifier tank only rarely. This concept reduces sedimentation within the tanks. Maintenance is minimized, which means that most importantly, efficiency is increased.

We will now examine each of the technical devices and their functions.

4. Outflow Controllers

In dry weather the unhindered flow of sewage through the storm overflow tank is represented by

$$Q_{dwf} = Q_s + Q_f$$

where Q_s is the domestic sewage and Q_f is infiltration. As a rule, the outflow from storm overflow tanks should not be more than

$$Q_{out} = 2*Q_s + Q_f$$

during a rainfall event. Because Q_f is never zero in practice the outflow when the storm overflow tank is full is less than twice the dry weather flow. The difference between dry weather outflow and full load outflow is thus very small. This requirement is intended to protect WWTP's from being overloaded during periods of rainfall.

At the same time, there is a strict requirement that storm overflow tanks are to be built decentrally, close to the point of origin of contamination. This requirement leads to exceptionally small outflow rates. For this reason the outflow Q_{out} from over half of all tanks is less than 38 l/s. Therefore the most important element of the storm overflow tank is the "eye of the needle" - the outflow controller. A great deal of care must therefore go into the selection and positioning of the outflow controller.

By inspection of Fig. 3 the distribution of outflow controllers can be seen. 28.2% of all storm water tanks are emptied by pumps. These applications are primarily with off-line storage tanks which are set low requiring pumped return to the interceptor.

Due to the danger of cloggage, throttle pipes with a diameter of less than 200 mm (8 ins.) are not allowed in Germany. Even with the most optimistic of calculations, it would hardly be possible to achieve an outflow of less than 60 l/s using a 200 mm throttle pipe. This is the reason why throttle pipes are only to be found in 25.6% of cases. The hydraulic properties and disadvantages of throttle pipes are well documented.

Pumps and throttle pipes account for approximately half of all outflow controllers. When the new guidelines were introduced in 1972 /3/, there was no technical solution for the remaining cases. Today there are around half a dozen widely used and successful outflow controllers. Of the total of 9,000 storm overflow tanks, 4,500 have modern outflow controllers. Two of the most common controllers will be examined.

1 control shaft
2 inspection entrance for tube-type tank
3 in-line storage tank
4 tank outlet
5 vortex valve
6 bypass
7 knife gate with spindle
8 open outflow gutter
9 interceptor to WWTP
10 escape ladder
11 ventilation and lighting
12 man hole

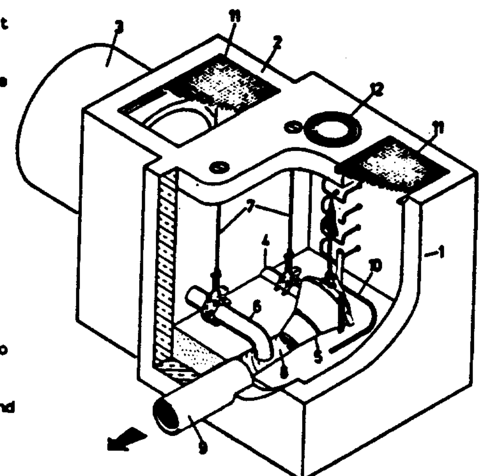

Fig. 4: Typical control shaft at storm overflow tank with vortex valve

4.1 Electronic Gate Valves

The use of electricity as an auxiliary power source has not been popular in sewerage system technology. Today it is better accepted, albeit due to force of circumstance. An example of this type of electronic outflow controller can be seen in Figure 2, bottom right. Outflow from the storm overflow tank is continually measured in a supplementary shaft, see item 5 in Fig. 2. In the example, the flow meter is an interchangeable stainless steel parabolic orifice plate with an air bubbler for measuring the water level. The measuring signal is sent to an electrical control system, which converts it into an outflow rate and compares it with the specified value. If the outflow is too great, the gate valve at the tank outlet is closed by a specific amount by means of an electric motor, or pneumatic or hydraulic cylinders, and vice versa. The controlling gate valve is often a stainless steel knife-type gate.

This system therefore represents a genuine closed loop control system, which has the familiar advantage that the system is self regulating and can be remotely controlled. If the gate valve becomes clogged up, the outflow drops below the required level and the regulator opens the gate until the blockage is removed. Disadvantages of such a system are dependance on electrical supply, the necessity for the construction of an additional measuring station and the tendency of the control loop towards instability. If the regulating parameters are not properly set, the gate will be continually opening and closing. Problems which arose when the system was in its infancy have now been overcome and are the province of speciality firms.

4.2 Vortex Valves

Vortex valves require no power supply and have no moving parts. This unique feature brought a wide application in sewer flow control. Figure 4 shows a throttle shaft with a vortex valve immediately after a sewer storage tank.

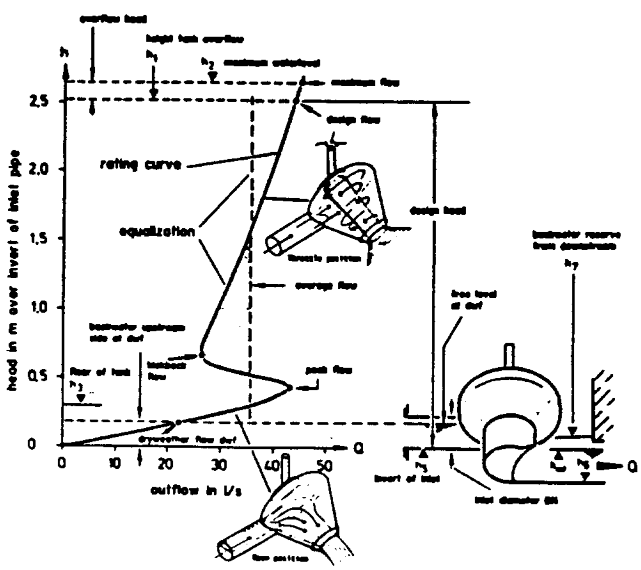

Fig. 5: Typical rating curve of a vortex valve

There are so many operational advantages to the dry location in a separate shaft that this has become virtually the technical standard for all outflow controllers. The controller is fully accessible at all times, even when the storm overflow tank is full. The floor of the shaft should under normal circumstances not flood even under full load conditions. This area remains safe to walk on and all components remain clean. The sewage outflow to the interceptor can be inspected via the open outflow gutter. If necessary the outflow pipeline can be examined and cleaned using a high-pressure water jet. All components in the shaft are normally constructed of stainless steel or plastic. The planned service life of the plant is in excess of twenty years.

The vortex valve works purely on the basis of the flow effects created in the sewage stream. Under low pressure conditions the water flows virtually unhindered round the corner. As pressure increases, a vortex is created which develops exceptionally high flow resistance. Figure 5 shows a typical rating curve for a vortex valve. The curve is S-shaped. The lower section of the curve represents the low flow resistance range. The steeper section corresponds to range where the vortex comes into operation. The hydraulic characteristics of vortex valves are described in detail in /4/. Since flow characteristics do not deteriorate with age or use, the rating curve is reproducible.

A vortex valve with a 200 mm inlet can reduce outflow to 25 - 30 l/s with tank depths of between 2 and 3 m. This makes the vortex valve twice as efficient as the throttle pipe, as well as having a far more favourable rating curve. More than 2000 vortex valves in Europe and America bear witness to the exceptional reliability of this type of controller.

5. Overflow Structures

Figure 2 shows three overflow structures of differing heights in the diversion chamber. At the end of the clarifier tank there is a fourth overflow for the clarified water. These overflow structures normally take the form of fixed weirs. The advantage of all fixed weirs is their high operational reliability. Even a weir which has been made much too short is capable of correcting the engineer's error by an increase in through-flow equal to the overflow height to the power of 2.5. There are, however, cases where more sophisticated technology is called for.

5.1 Air-regulated Siphons

If sufficient suction head is is available (see Figure 2, far left), siphons can be extremely effective water level limiters. However, traditional siphons with their undesired hysteretic characteristics can not be used in sewers. Once a siphon has started to draw off the excess combined sewage, it would continue to do so until the siphon reached its natural cut-off level. Too much sewage would be discharged into the receiving water.

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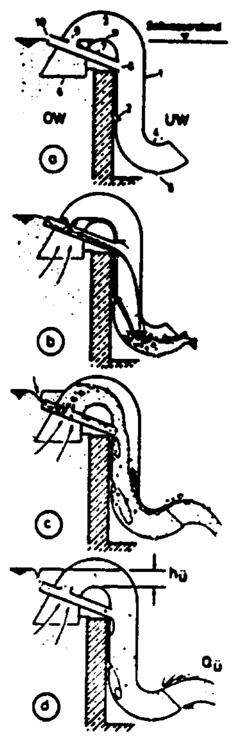
The air-regulated siphon does not have this disadvantage. An air suction pipe which extends into the upper water level ensures that the siphon has a non-hysteretic rating curve. Various operational conditions are illustrated in Figure 6. Figure 7 clearly illustrates the performance capability of this type of siphon. In order to achieve equal outflow rate at the same overflow height, a simple weir would have to be between 8.2 and 11.3 times the length of a single siphon. Further details of this special siphon can be obtained from /5/.



1 vertical suction leg of siphon
2 deflector nappe
3 siphon hood
4 exit bend
5 drain
6 bellmouth shaped inlet
7 air suction pipe
8 bottom ventilation
9 hood ventilation
10 suction nose
11 overflow crest of siphon

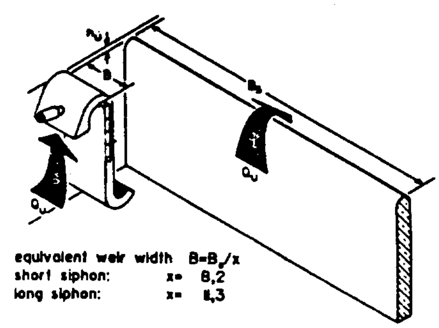


Fig. 6:
Operation of an air-regulated siphon at various heads

Fig. 7:
Comparison of weir length and siphon width for the same overflow rate

5.2 Helical Bend "Filippi"

This exotic sounding and sleekly shaped spillway (see Figure 8) is normally installed in combined sewer storm overflows in the form of a prefabricated plastic section. It was developed in Lausanne /6/.

At the inlet into the overflow chamber there is an asymmetrical venturi-type restriction which accelerates the water flow and deflects it to the left towards a gently curved side wall with an overhanging tongue. During dry weather conditions the sewage flows unhindered underneath the tongue and follows the slight left hand sweep to the outlet to the WWTP. As the quantity and therefore also the rate of water flow increases during a rainstorm, the stream is pushed up the left side wall due to the asymmetrical deflection and is directed by the tongue to the right through a finned overflow outlet to the receiving water or an overflow tank. The outflow to the sewage plant should remain virtually constant.

Insufficient data is available regarding the hydraulic characteristics and separation capability of this installation. However, it is clear that the operational range (determined by the necessity for pre-restriction of flow) is limited in comparison with a conventional overflow weir. Under conditions of even greater flow, a second, higher overflow is flooded.

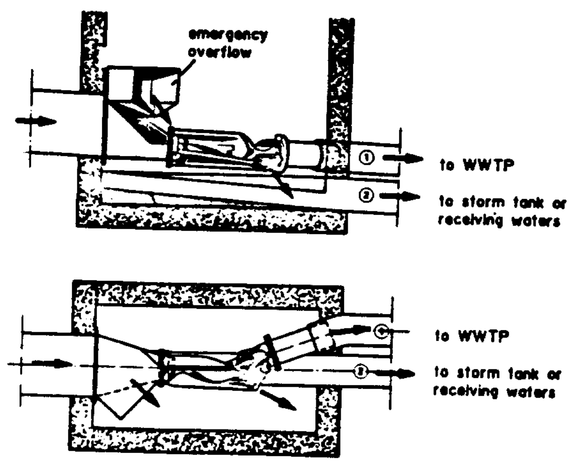


Fig. 8: Helical bend "Filippi"

6. Bar Screens and Scum Boards

As well as the smaller sewage particles, large quantities of floatables can often escape at storm overflows. These leave obvious traces along the course of streams and rivers. Even if the water quality is not impaired as a result of this residue, it is nevertheless distasteful to the public.

It has only been in recent times that attempts have been made to at least prevent the larger floating and suspended solids from escaping. Occasionally scum boards are used and even more rarely, bar screens. Figure 9 shows a combination of scum board and bar screens.

The scum board made from stainless steel sheeting has an angled lower edge to improve flow characteristics and a row of bar screens fixed to the back. The bar screens are suspended freely from loops and will lift open under positive pressure if they are clogged up. If the bar separation should turn out to be unsuitable in practice, different spacers can be used with the existing bars to build screens with alternative bar spacings.

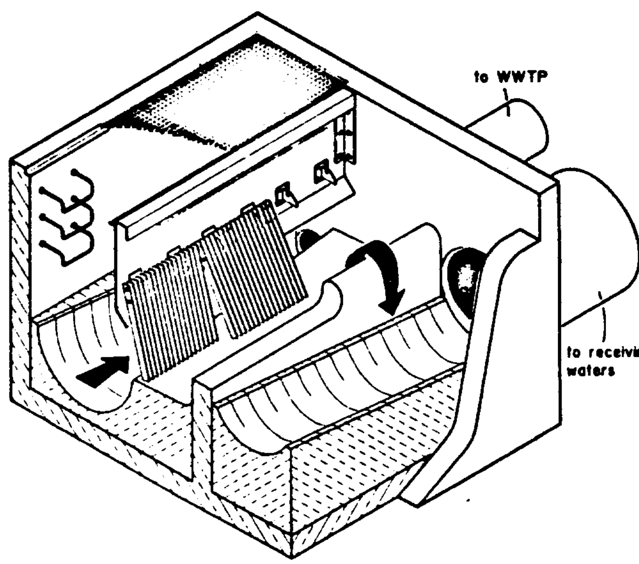


Fig. 9: Scum board with hinged moveable bar screen

7. Backflow Prevention

Off-line storage tanks often have a backflow problem with unnecessarly filling, and the tank has to empty itself. Both chambers in Figure 2 suffer from this problem.

Since pressure is generally only 1 to 3 m, low pressure valves with rubber flaps have proved to be extremely useful (see Figure 10). The flexible and elastic rubber flap seats perfectly against the oval opening even at the lowest back pressure levels. The thin wall of the oblique-cut nozzle provides high contact pressure and a good seal, even with heavily soiled sewage. Technical details can be found in /7/.

The same principle applies to overflows exposed to flood danger, see Figure 11. The soft rubber flap is lifted almost without resistance by outflowing water.

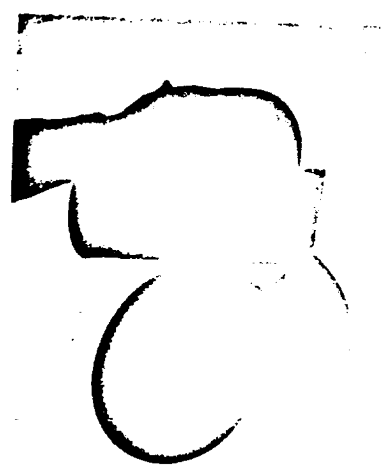


Fig. 10: Low pressure soft rubber check flap

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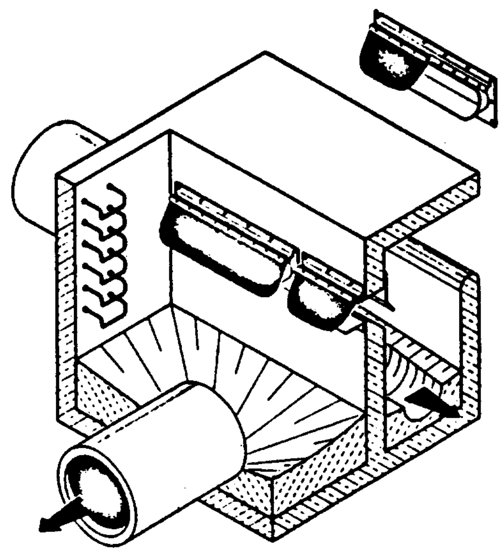

Fig. 11: Backflow prevention using soft rubber flaps

8. Tank Cleaning

During rainstorms the tank's outflow controller reduces flow rates such that a large proportion of the settleable matter is deposited as sediment. In-line storage tanks will be largely cleaned later by scouring action from dry weather flow. In off-line tanks the contaminants remain. Up to now the method of removal has been by hand using fire hoses. But since this procedure is very labor intensive, automatic cleansing systems are beginning to gain favor.

After initial failures using fixed sprayers which were not powerful enough to clean tanks of the size involved, stirrers or tipping flushers are now most commonly used. The stirrers are pumps fixed on the tank floor with exposed blades, thus keeping the solids in motion so that there is little if any sedimentation. Stirrers of this type can only be used when the tank is at least partially full. They are unsuitable for clarifier tanks since the clarification would be destroyed.

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Fig. 12: Tipping flusher in action

Tipping flushers have proved to be particularly effective for subsequent cleansing of empty tanks. An example of a tipping flusher can be seen on the back wall of the right hand chamber in Figure 2. This is a suspended cylindrical stainless steel container, capable of rotating around its own axis, and with an overflow lip facing towards the end wall of the chamber. When the tank has emptied after a period of rainfall, groundwater or river water is pumped at low rates into the tipping flusher. Shortly before the container is completely full, it suddenly tips over and empties its contents into the tank. The curved base of the tank end wall directs the flush across the floor of the tank. The flushing force depends on the height of the drop and the volume of water. Flushways up to 50 m in length can be swept clean (see Figure 12). The gradient of the flushed area need only be between 1 and 5%. Details of the method of calculation of the required volume for tipping flushers is given in /8/.

In order to prevent rebounding of the cleansing flush from the far end of the tank, a run-off sump is required. Here the heavily contaminated flush water collects and is gradually fed back into the interceptor.

9. Tank Monitoring

On average the tanks are more or less full between 30 and 50 times a year. They remain filled for around 1000 h per year. The tanks overflow for only a fraction of this time. In contrast to WWTPs, storm overflow tanks are not permanently staffed. At most they are visited and inspected once a week. It is therefore only on rare occasions that the inspection staff will encounter an overflowing tank. Often this gives the impression that the tanks are inefficient.

In order to ascertain how often, how long and what overflow actually occurred, newer storm overflow tanks are often fitted with automatic measuring systems. Figure 2 shows an example of such a "Sewer Spy" in the diversion chamber.

This is a microprocessor contained in a gas-tight metering box with a piezo-resistant pressure recorder connected to a static diving bell. The device is capable of measuring the water level every minute for a year powered by the built-in batteries. The frequency and duration of 256 water level stages are internally calculated and recorded on a removable memory card. This card can be read by a micro computer (see Figure 13). Duration occurrence can be read off and noted by hand at the tank from a display.

Figure 14 shows a print-out of the water level duration curve of an in-line first-flush tank. Over a monitoring period of 10 months, the tank was flooded for 5,900 minutes. As the tank water level increases, the length of time that a given level is exceeded continually decreases. The storm-overflow came into operation for a total of 450 minutes. The highest water level exceeded for one minute was 295 cm above the lower edge of the diving bell. From the overflow height and overflow duration it is possible to calculate the amount of water which has been discharged into the receiving water. Computer analysis of the recorded data is offered as a service /9/.

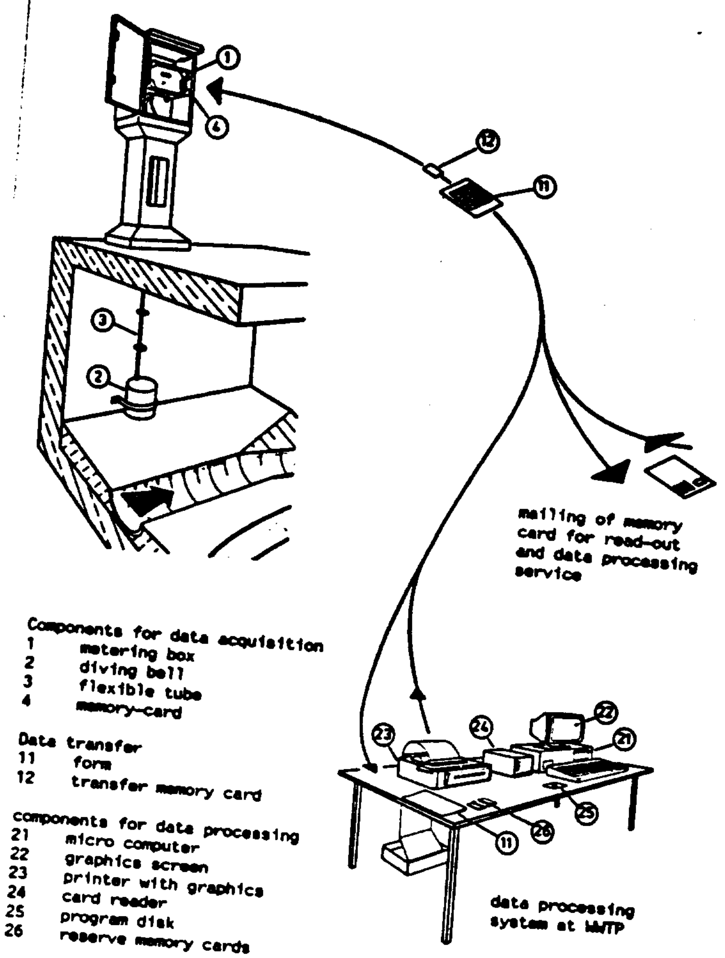
10. Remote Surveillance and Real Time Control

Storm overflow tanks are critical elements of any sewer network. If, for example, the outflow-controller for a tank becomes blocked, the dry weather flow will fill the tank within a few hours, and then overflow. Local river water will be unnecessarily contaminated. After a long period during which this problem was ignored by local authorities, there is now a growing realization that storm overflow tanks need to be regularly maintained.

It is not difficult to understand that inspection is time consuming. Suspect tanks have to be checked probably once a week. In addition to checking all tanks after every rainstorm, manhole covers have to be opened, the tank entered. Because of the safety regulations this requires an inspection team of at least three men.

If the costs incurred for often wasted trips are calculated, it soon becomes clear that remote surveillance is worth the investment. From the WWTP the status on the current outflow or water level can be automatically querried via a telephone line every hour, or on demand if a fault is suspected.

The next step would be to install automatic monitoring systems into the storm overflow tanks which would continually check and record all important conditions, memorize measured values and once a day, say at midnight, send the most important data to the WWTP. In the case of



Components for data acquisition
1 metering box
2 diving bell
3 flexible tube
4 memory-card

Data transfer
11 form
12 transfer memory card

components for data processing
21 micro computer
22 graphics screen
23 printer with graphics
24 card reader
25 program disk
26 reserve memory cards

Fig. 13: "Sewer Spy" total system

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faults which the system is not capable of rectifying itself, an alarm at the sewage plant would be activated.

From here it is only a small step to real time remote control of the storm overflow tanks. A computer at the WWTP could send optimized control commands to the storm overflow tanks based on data received from the various monitoring points, perhaps with the additional aid of current rainfall from radar weather reports.

This last scenario is as yet a utopian vision - and may always remain so. But remote surveillance is a realistic possibility today. Figure 15 shows the inside of a control cabinet at a storm overflow tank. The heart of the system is a memory operation control (MOC) system which communicates with all peripherals via a data bus in a 250 Hz cycle. The MOC program is permanently held in the non-erasable EPROM. The program includes various sub-programs for the analysis and self-rectification of faults.

The electronics are assembled in industrial standard modular fashion in 19'' racks. The system is hierarchically structured, has an interface with the remote control installation and is already capable of meeting the requirements of real time remote control.

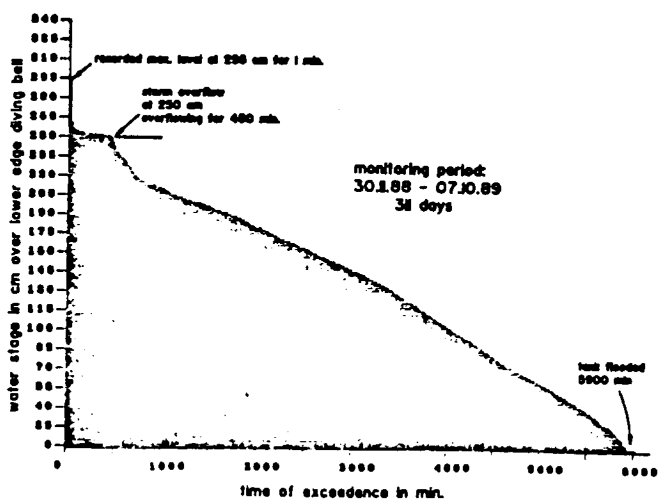

Fig. 14: Metered stage duration curve from storm overflow tank

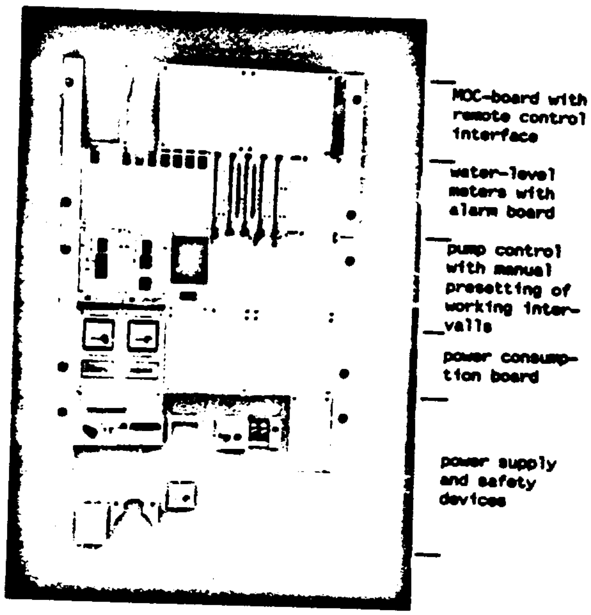

Fig. 15: Electronic control panel with data transfer to WWTP

11. Acknowledgements

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NON-STRUCTURAL MEASURES TO MINIMISE CSO EFFECTS

by Frank Sperling[1]

Introduction

For the past 20 years much effort has been expended to improve continuous river quality by construction and operation of biological sewage treatment plants. In the catchment area of the 2 water associations Emschergenossenschaft and Lippeverband, 98% of the population is presently connected by (mainly combined) sewerage systems to biological treatment plants. Thus the amount of runoff has been raised proportionally. Combined sewage overflows cause, in varying frequency and at varying river stretches, acute damage to river quality. Removal of these remaining acute disturbances are the focus of increasing attempts to tighten requirements for effluent quality and the frequency and volume of overflows.

Requirements

Laws, Taxes, Standards and GART

In order to understand the pressure towards increased technical efforts concerning treatment of combined sewage flow in the Federal Republic of Germany (FRG) it is necessary to understand the system of laws and regulations. Figure 1 shows the system which has been in place in the FRG since 1976.

The federal Water Act [1] demands the application of the so called "generally applied present rule of the technique" (GART) as a "Minimum Requirement" for a

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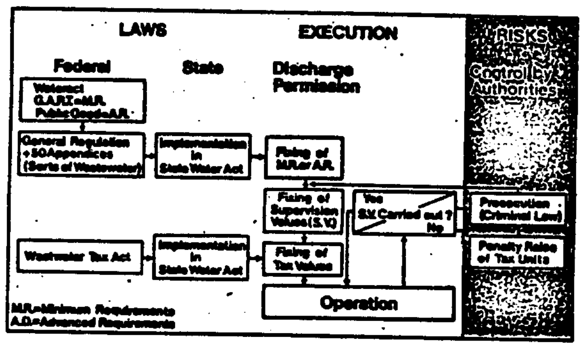

Figure 1 - SYSTEM OF REQUIREMENTS TO WASTE WATER DISCHARGES

discharge permit. "Advanced Requirements" may also be imposed if necessary for the "public good."

The GART for waste water discharges are defined [2] by workgroups of the federal government, whereas the GART for the combined sewage overflows are defined by the states or the recommendations [3] of a workgroup of the German Waste Water Association (ATV).

In a discharge permit the supervision or control value (pollutant concentration) is specified. This value is the basis for determining the wastewater discharge tax, as specified in the waste water tax law [4]. In addition, the supervision value is monitored by an authority sampling program. The results of this program show whether or not the supervision value has been exceeded.

In the individual discharge permit, the supervision value for COD, Ammonia, Phosporus and other parameters are fixed. A supervision value is held if it is not exceeded more than once in five samples within 3 years. Any exceedance must be smaller than 200% of the supervision value. If, as a result of the sampling program of the authority, the control value is not held, the owner of the discharge permit probably will undergo preliminary proceedings ("not allowed discharge," Section 324, Criminal Law).

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Pollutant discharges must be maintained at or below the GART in order to get the lowest tax rate. Otherwise the tax rate rises considerably as a kind of penalty as shown in Figure 2.

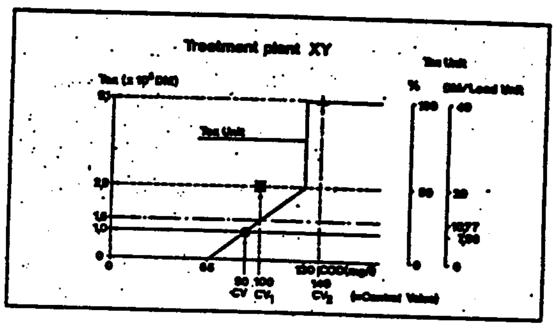

Figure 2 - PENALTY (TAX) WHEN MINIMUM REQUIREMENT IS EXCEEDED

For an existing plant one can see that the tax is raised by 190% if the supervision value is ever exceeded, but remains under the GART, which corresponda to 130 mg/l COD. If the GART are exceeded the tax is raised by 710 %.

So since 1976 there has been a close link between operational effluent results and the amount of tax. Frequent tightening of the Minimum Requirements ensured a permanent driving force requiring improved treatment plant operation. Most recently the federal government stated a 10-goals program for reducing the load in the North Sea dramatically by 1995. As a consequence the GART were tightened again. As Figure 3 shows (for the parameter COD only), the financial risk as well as the risk of prosecution has severely increased. This can happen in spite of considerable investments to obtain improved plant operation.

For the time being, the system for combined sewage overflows is not aa stringent. The GART are determined by the states. Based on the recommendations given by the ATV they require design and construction of stormwater retention tanks according to the rules of [3]. These

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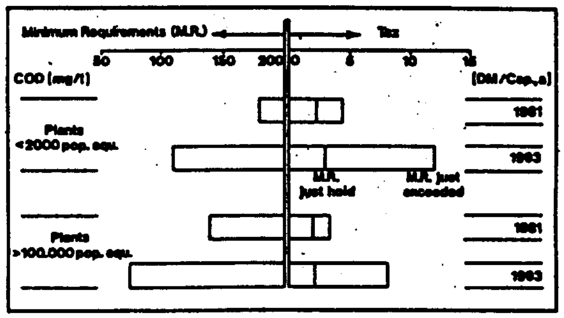

Figure 3 - TAX AND MINIMUM REQUIREMENTS FOR W.W.- EFFLUENTS

technical rules are at present being amended [5]. The new rule aims indirectly to reduce the COD load discharged by overflow weirs (e.g. 350 [kg/a, ha impervious area]) by means of stormwater retention tanks. The effectiveness of this proposal cannot be evaluated by direct measurement. One state plans to introduce the new GART by demanding the biological treatment of at least 65% of the runoff. In that case supervision will be possible. All the amendments of the GART are Minimum Requirements and are not based on river quality requirements.

The increasing difference between the quality of biologically treated waste water (e.g. 75 mg/l COD) and overflowing combined sewage (e.g. 120 mg/l COD) made the authorities demand advanced measures for minimisation of the CSO effects in an increasing number of river stretches.

As a result, the proposed amended ATV rule defines itself as a Minimum Requirement and suggests that Advanced Requirements be fixed. As various states have already developed fairly concrete ideas for the Advanced Requirements, the ATV has started to work on that subject.

A first result is a protocol of a joint meeting of engineers and limnologists regarding CSO effects on river quality [6]. There it was stated that the chronic macropollution has considerably decreased and in general no longer dominates river quality. The quality and the hydraulic effects of the CSO's, however, have come to the fore. Figure 4 of [7] shows annual saprobia-indices of one sampling point on the river Lippe plotted against the quality of rainfall for the 4 months preceding the biological survey.

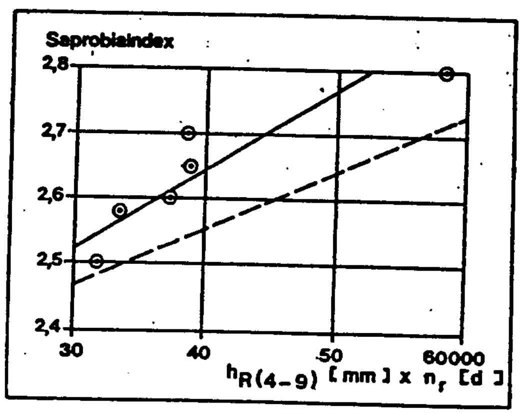

Figure 4 - SAPROBIAINDEX VS. RAINFALL-CHARACTERISTICS

The rainfall characteristics are the amount of rain and the number of days with rainfall. This relationship is very well suited for judging the significance of the CSO for a given river stretch.

An important result of the hearing was the negative significance of an unfavourable river bed morphology on the organisms indicative of river quality, and therefore the saprobia index. Higher velocities in rivers caused by CSO's change the habitats of the invertebrates and fish, or produce immediate hydraulic stress on the organisms. Consequently the organisms die or drift away, so that they cannot contribute to the self-purification of a given river stretch. The critical shear stress and the extent of the porosity (interstitial) of the river bed are of considerable influence on the drift rate of organisms. If the interstitial porosity is sufficient, the organisms can retire there while the CSO-caused flood passes. When the dry weather flow resumes, organisms will find their typical environment.

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The critical shear stress is also dependent on both the type of the organisms and the quality of the river bed. As an example, invertebrates in summer cold mountain rivers do not survive a continuous shear stress of 1000 to 3000 $dyne/cm^2$. The biological-effecting flow velocity, which organisms may not withstand longer than seconds to minutes, is said to be, depending on the organism, 0.3 to 2.4 m/s. Longer exposure time (hours) may cause damage at considerably lower velocities. Only when there remains sufficient interstitial porosity the critical shear stress for organisms is identical to the critical shear stress for the river bed structure (interstitial). In addition to the hydraulical effects, there are numerous synergisms which have not yet been proven. Suspended solids in a CSO-caused flood act like "sandblasting." When there are additional pollutants (e.g. NH_4) the interstitial pores may be vacated by the organisms, and therefore may become ineffective. Higher concentrations of suspended solids may fill the interstitial pores with the same effect.

Two or more floods per year with the effect of shifting the habitat and drift of the organisms can cause considerable long-term loss in invertebrates. The damage to fish can still be shown after 10 years where no artificial restocking has taken place.

The result of a mathematical model (Figure 5 of [8]) shows how great the influence of river bed particle size and the Froude number on the Saprobiaindex may be.

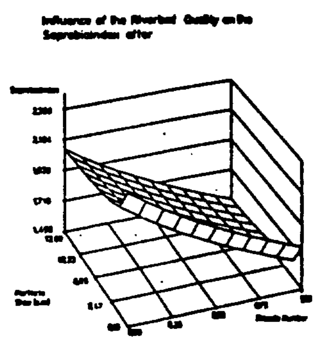

Figure 5 - SAPROBIA INDEX VS. RIVER BED POROSITY AND FROUD-NUMBER

In the FRG these relationships have been underestimated or mostly not even taken into consideration.

The influences described above are are now being examined by a number of researchers. The first results are promising, and are likely to be incorporated into the amended standards.

An indercisciplinary workgroup of the ATV and the German Society for Limnology (DGL) is now examining precisely the effects of CSO on river quality. This group have suggested criteria for when to apply Advanced Measures based on river quality requirements.

Stormwater retention tanks diminish the number of overflows and the maximum discharge. Their efficiency in improving river quality is very low. The settling rate varies between 5 and 15%. There are many cases where this minimum measure is sufficient to prevent essential damage to rivers. Advanced measures, however, seem to be advisable, if:

(a) special quality of the river water is demanded

(b) dry weather flow is comparatively low

(c) CSO-caused flood peaks are considerably higher than the "river-bed forming" flood

(d) insufficient river morphology is present

(e) weirs or other structures hinder repopulation of organisms

(f) oxygenation rates are comparatively low

The first approach to meet advanced requirements is to design larger stormwater retention basins. This would further reduce the number of overflows and the peak of discharges, but not prevent them. Because of the stochastic character of the rainfall the remaining number of overflows and amount of peak discharges would yield, for many rivers, an efficiency which is too low with respect to the above mentioned requirements. Logically consistent advanced measures therefore should strive to:

(a) diminish the amount and dynamics of untreated CSO

(b) diminish the polluting strength of the CSO

(c) diminish remaining effects.

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Methods exist to mitigate these effects, and others are being developed. They are described in the following section.

Measures

1. Diminishing of the Amount and Dynamics of CSO

Diminishing untreated storm runoff

Rainfall causes a flow of about 5000 m^3/ha,a in the combined system. The imperviousness of areas in the cities and communities has constantly increased with increases in industrial development. It is caused by:

(a) traffic area needs

(b) utilisable area needs around houses

(c) infrastructure measures

(d) increasing number of single-family dwellings

(e) conversion of grassland to impervious areas

As a consequence, especially in rural districts, the runoff from roofs and yards should be infiltrated, wherever there is no objection. More than 25% of the runoff in rural areas could be prevented from entering the sewers. Those regions often have rivers with low dry weather flow. It should be mentioned that building materials are increasingly being contaminated by additives, and weathering of these materials will increase pollution loads and therefore be counterproductive. A workgroup of the ATV is addressing this subject.

Increasing combined sewage flow to biological treatment

According to the GART, the hydraulic capacity of a waste water treatment plant should be 2 X DWF. To achieve a reduction in CSO it is proposed to double the plant capacity. The emptying time of stormwater retention basins often exceeds 10 hours, and they are, in some cases, fully loaded during half the year. As a result, larger and more frequent fluctuations and changes in (hydraulic) load, temperature, and concentration will occur.

The tightening of effluent requirements for COD and, even more importantly, for nitrogen, require more (and more sophisticated) unit operations, which probably will be more sensitive to such changes and fluctuations. We are not yet sure how to cope with these counterproductive developments.

From the river quality point of view an increase in treatment plant effluent caused by higher hydraulic capacity seems to be more acceptable than the overflow of raw sewage.

2. Diminishing pollution concentrations of CSO

Measures in the catchment area

Hydraulically disadvantageous sewer profiles cause sedimentation of biodegradable matter (Figure 6) in sewers during dry weather flow. Circular profiles in low slope sewers, especiallly, tend to sedimentation during low flow.

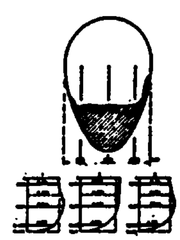

Figure 6 - SEDIMENT PROFILE IN A COMBINED SEWER

We are aware of the problems of the first flush, which is caused by resuspension of the sediment in sewers, causing problems in river quality after CSO. Figure 7 shows an oxygen depletion curve in the river Lippe, which used to happen at least once a year.

The problem of the first flush - which may happen in almost any sewer system - can be diminished or avoided by choosing sewers with a dry weather channel where the sewage transport during DWF is complete.

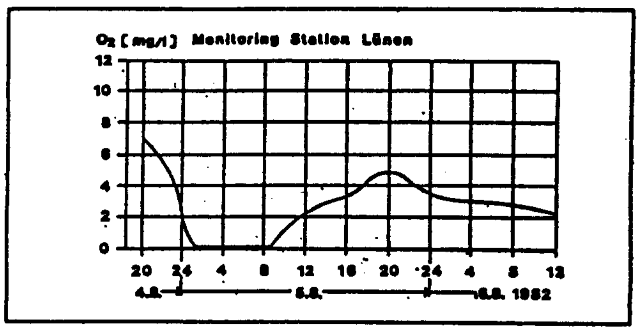

Figure 7 - OXYGEN CONTENT IN THE LIPPE AFTER HEAVY RAINFALL

Occasionally industrial dischargers contribute highly concentrated effluents. To prevent those concentrations from influencing the CSO concentrations special measures must be taken. According to GART additional volume for stormwater retention tanks must be provided. A more efficient solution is pretreatment.

Measures between the sewer network and the river

Oxygen depletion by highly concentrated CSO is still being observed. Occasionally the extent is obove any acceptable level (Figure 7). Dosing with hydrogen peroxide (H_2O_2) is a suitable method for diminishing the oxygen demand by controlled chemical oxidation. This happens by nascent oxygen (a byproduct of the decay of H_2O_2) when it meets suspended solids. H_2O_2 is easily added using controllable pumps. There are no residual reaction products in the river. If dosing is done correctly, there is no harm to fauna and flora [9]. At low CSO pollution levels the decay takes place at a proportionally slow reaction time. This can be regarded as an advantageous time-release effect.

Along the river Lippe, three dosing stations are operating succesfully. The city of Bremen intends to design such a station as a standby as well. Figure 8 shows a typical station.

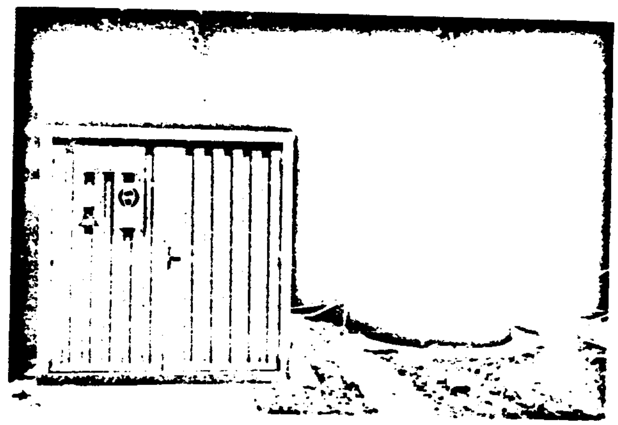

Figure 8 - HYDROGEN PEROXIDE DOSING STATION

The operating experience has been satisfactory. The oxygen demand of every CSO, no matter how highly concentrated it is, can be satified. A dosage-pump is operated and controlled by the flow. A signal indicates to the plant operator when dosing takes place. The turbidity can also be used as a control signal. Finally, for security purposes, the oxygen-content of the receiving river reach is automatically monitored for necessary adjustments.

The dosing of H_2O_2 started in 1983. At that time we registered 20 days during summer time when the oxygen concentration below the CSO was less than 2 mg/l. The lowest daily minimum concentrations were 0 mg/l. In 1986, the first full year of operation, only 2 days were registered with less than 2 mg/l at the same place. The lowest daily minimum concentration was 0.6 mg/l. Figure 9 shows the sum frequency for the 2 year period. Short-term river quality collapses did not occur after 1983.
The investment costs for such an installation (pump, pipes, measurement, data transfer, tank, fundament) is DM 22,000. Maintenance costs can almost be neglected. About 3 manhours per case of dosage is spent as a safety measure. Annual operational costs, consisting mainly of those for the H_2O_2, amount to 19.50 DM/ha impervious area.

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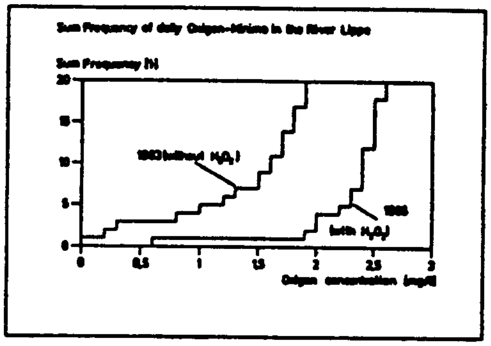

Figure 9 - SUM FREQUENCY OF DAILY OXYGEN MINIMA

3. Diminishing of Remaining Effects

Oxygenation of Rivers

Occasionally the oxygenation of rivers is applied [9] (Figure 10). This measure seldom is suitable for satisfying the peak oxygen demands of, say, 0.5 mg/l,h, which may be caused by CSO. Physical oxygenation measures of that kind achieve oxygen input up to the saturation value (7 - 10 mg/l), which may not be sufficient in a number of cases. In addition, this measure demands high investment, and the efficiency is highly dependent on location. The optimum position may shift from case to case which lowers the overall efficiency. Oxygenation of rivers therefore is a good means if oxygen is needed on a continuous basis.

Retention of Organisms

In addition to all of the techniques mentioned above, measures to retain organisms in a river stretch seem to be of vital importance. They should be directed at those organisms which are representative of natural river quality. Most of the recommended measures have not yet been sufficiently quantified.

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Figure 10 - OXYGENATION OF A RIVER

The recommended measures include:

(a) removal or diminishing the effects of river structures like weirs which prevent repopopulation after erosion

(b) raising of the porosity of the river bed, and if pores tend to be silted up, fitting in of stones or lumps of rock

(c) diversification of habitats according to species of organisms typical of the natural quality (dead tree-trunks, overhanging willow trees, fixed to prevent erosion during floods)

(d) specific bed-forming measures like slope changes to provide flat, level zones and still-water zones

(e) shadowing the riverbed, planting special trees with rich root structure reaching below water level

(f) installation of side watercourses, in between overflows and rivers, for specific sedimentation and further hydraulic retention

(g) design of flood profiles in rivers above specific dry-weather flow profiles to minimise hydraulic stress effects.

It can be assumed that the intensive application of any such measure which is suitable for a river stretch will reduce CSO effects about as effectively as biological waste water treatment, with respect to the long term river quality in general.

Conclusions

Long-term river quality has improved to a high level, and as a result acute damages caused by CSO have become more evident. Abatement measures must be enforced.

As a Minimum Requirement, the installation of storm water retention tanks is sufficient in many cases. For many river stretches this will not be sufficient to cope with the quality deterioration.

Non-structural measures seem to be most effective when Advanced Requirements must be applied. They mainly aim to stabilise the natural self-purification potential. These non structural measures should prevent clean runoff or high concentrated indirect discharges from entering the sewer net. Hydraulic and peak load qualities of overflows should be reduced. Finally, significant improvement is to be expected by using measures to help organisms not to be destroyed or drifted by CSO-caused flood and concentration waves in rivers, which can not be prevented completely.

Appendix I.- References

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COST AND BENEFIT OF CSO TREATMENT

by Rolf Pecher[1]

1. INTRODUCTION

Over the last years the building of storage tanks for the treatment of combined sewage overflow (CSO) in municipal sewage networks in the Federal Republic of Germany has increased. According to the latest assessments, over 8,000 stormwater overflow tanks have, up until now, been built. The additional requirement for stormwater overflow tanks in the Federal Republic can be estimated roughly from the number of inhabitants and from the extent of the combined sewage system. Some 73% or ca. 40 million inhabitants are connected to the combined sewage system. If one assumes that, for some 1,500 inhabitants, there is on average one stormwater tank, then, in future an additional ca. 20,000 stormwater tanks will still be necessary.

Below, using generalised estimates, the CSO treatment and the effect on the protection of lakes and rivers will be presented, employing 5 pollutant parameters. Thus a rough estimation of the effectiveness of CSO is possible; however, in individual cases, the respective principles and objectives can appear differently.

For simplification, in the calculations carried out, only the costs of stormwater overflow tanks are applied. With the choice of sewer storage capacity or with the usable sewer volume of the sewer systems the cost curves could, in any case, change. As CSO's are always to be combined with sufficiently large stormwater storage tanks the following considerations apply also for municipal drainage networks with a large number of different CSO installations. Up until now the effects of CSO on rivers and lakes cannot be described adequately. However, it is

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uncontested that, through the CSO treatment in stormwater storage tanks and subsequent purification of the stored combined sewage in biological sewage treatment plants, the protection of rivers and lakes can be improved considerably. The effects on the protection of these receiving waters, however, depend on the rate of load, the conduction of the water and the flow rate of the receiving waters. It is therefore, for instance, not immaterial whether one discharges into still or flowing waters or what quality level for the lakes and rivers is to be met.

Still to be clarified is the question whether the sporadic and more seldom discharge of the heavily polluted combined sewage is more damaging with rainfall events than the permanent runoff of contaminated water from biological sewage treatment plants. Here it should, in addition, be considered, that, with extremely heavy rainfall, despite large stormwater overflow tanks, a certainly large total quantity of combined sewer discharge is deposited, at short notice, in the lakes and rivers.

Also the type of introduced pollutant from stormwater overflow installations and from biological sewage treatment plants is to be assessed differently. Whilst mainly biologically easily degradable oxygen-consuming substances are introduced from stormwater overflow installations, from sewage treatment plants these are biologically difficult to degrade.

Despite all these imponderables, an attempt is made in the following to show in example form the costs and the pollutant load reduction through CSO treatment for 5 pollutant parameters (BOD_5, COD, suspended solids, total nitrogen, total phosphorus). Only in this way is it possible to assess the importance of CSO treatment and to draw conclusions for a precise and effective protection of lakes and rivers. With all considerations it is, however, assumed that the biological sewage treatment plants produce a good purification performance even with storm weather.

2. Assumptions for Calculations

2.1 Daily Amount of Domestic Sewage per Inhabitant and Its Pollution

The mean annual water consumption of the households in the Federal Republic in 1978 was 146 l/(I.d). Despite much discussion on usage limitations in recent years it is expected that in the year 2000 there will be a household water consumption of 219 l/(I.d); in 2010 some 245 l/(I.d).

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The daily amount of sewage per inhabitant is, already today including smaller non-water intensive commercial operations, on average 196 l/(I.d) per year. For this reason an average daily amount of domestic sewage of 200 l/(I.d) or 73 $m^3/(I.a)$ is assumed for the following considerations.

In addition, for the later comparison with the stormwater runoff, a mean population density of some 70 I/ha is used which, from experience, represents good municipal drainage areas.

The mean pollution and the annual pollutant load of the crude sewage can be estimated in accordance with Table 1.

Table 1. Pollutant Concentrations and Annual Pollutant Loads in Crude Household Sewage

Pollutant Parameter		Pollution of Crude Sewage	
		Concentration [mg/l]	Annual Load [kg/(I.a)]
Biochem. Oxygen Demand	BOD_5	300	21.90
Chemical Oxygen Demand	COD	600	43.80
Suspended Solids SS		325	23.72
Total Nitrogen N_{tot}		64	4.67
Total Phosphorus P_{tot}		20	1.46

The annual pollutant load, given in the last column, is to be understood as input load to a biological sewage treatment plant without a stormwater section. To this input load there is, in combined sewage drainage areas, additionally the load from stormwater runoff.

2.2 Purification Effect of Modern Sewage Treatment Plants

The German Association for Water Pollution Control (ATV) has published a performance table on several procedures for extensive sewage purification in accordance with biological treatment. There the concentrations of sewage treatment plant effluent to be expected are listed which are to be achieved with normal sewage ratios. For the following investigations 4 sewage treatment plant expansion stages (KW1 to KW4) with average sewage treatment plant discharges were taken into account (Table 2).

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Table 2. Investigated Expansion Stages for Biological Sewage Treatment Plants and Applied Pollutant Concentrations in Sewage Treatment Plant Effluent

Expansion Stage	Purification Process	Pollutant Concentration in the Sewage Treatment Plant Effluent (mg/l)				
		BOD_5	COD	SS	N_{tot}	P_{tot}
KW1	Biological basic purification	20	90	20	35	10
KW2	Biological basic purification with nitrification	15	80	20	30	10
KW3	Biological basic purification with nitrification, polishing tank or micro-sieving and/or rapid sand filtration	10	70	10	27	9
KW4	Aeration plant with Nitrification, Simultaneous Precipitation and Sludge Blanket Filtration	5	40	5	25	0.2

The discharge values given in Table 2 are to be understood as mean annual values. With modern sewage treatment plants with correspondingly designed secondary sedimentation and increased sludge return flow it can, in addition, be expected that, with storm weather, the pollution concentrations in the sewage treatment plant effluent will not essentially be altered if only, at a maximum, double the dry weather inflow is introduced into the biological stage.

The reduction in the pollutant load contained in the household crude sewage due to the sewage purification process is presented in Figures 1 to 5 for the 4 different expansion stages. From this it is clear that the effect of the sewage purification procedures for the individual

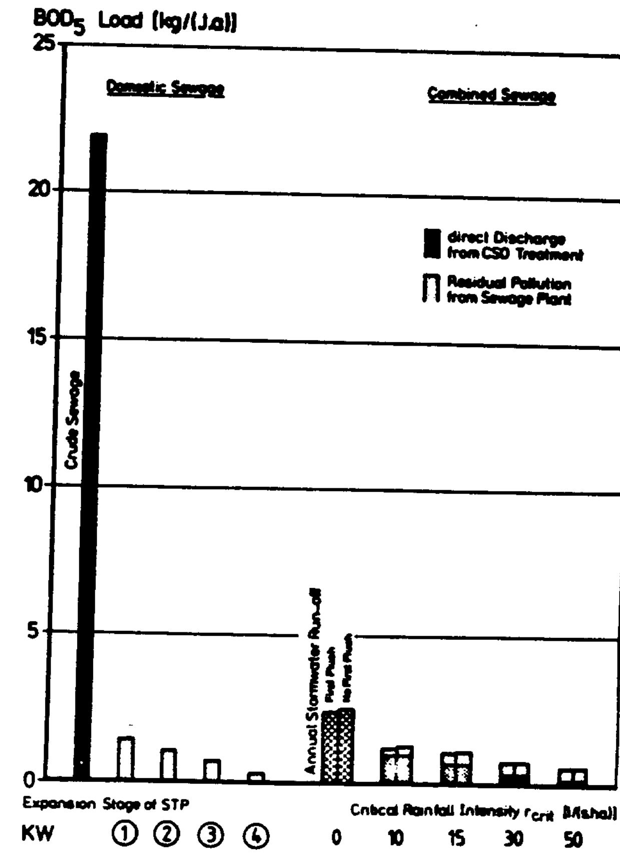

Figure 1: Reduction of Annual BOD, Load Through Biological Purification and CSO Treatment

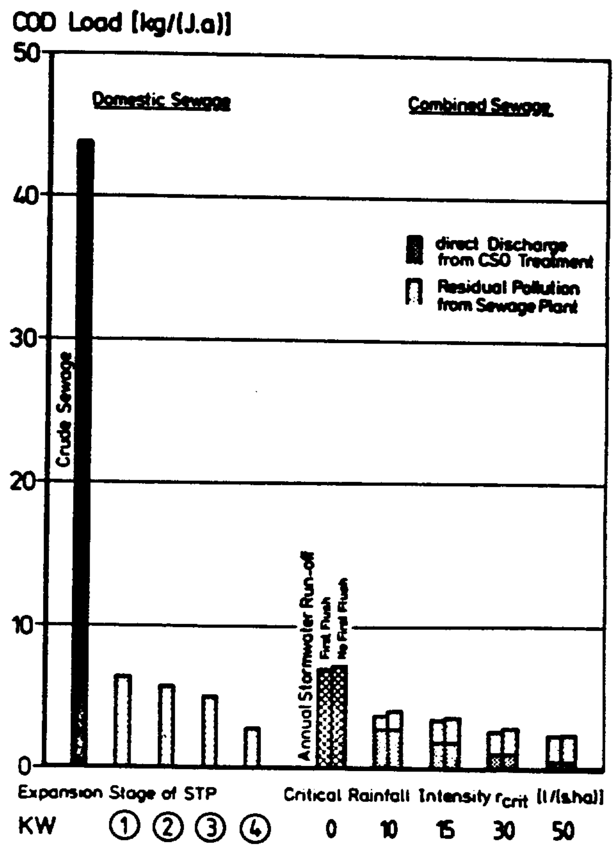

Figure 2: Reduction of Annual COD Load Through Biological Purification and CSO Treatment

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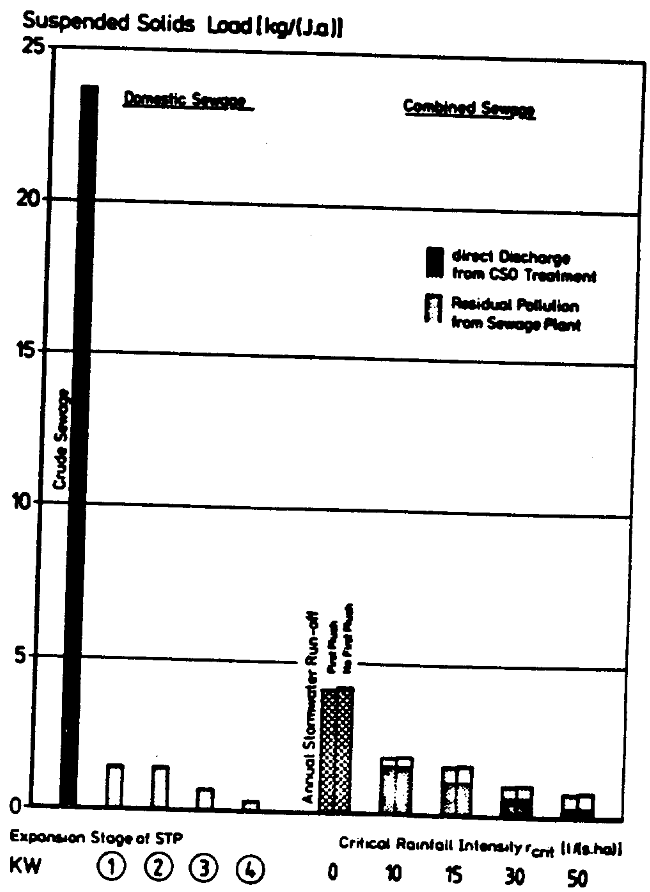

Figure 3: Reduction of Annual Load of Suspended Solids Through Biological Purification and CSO Treatment

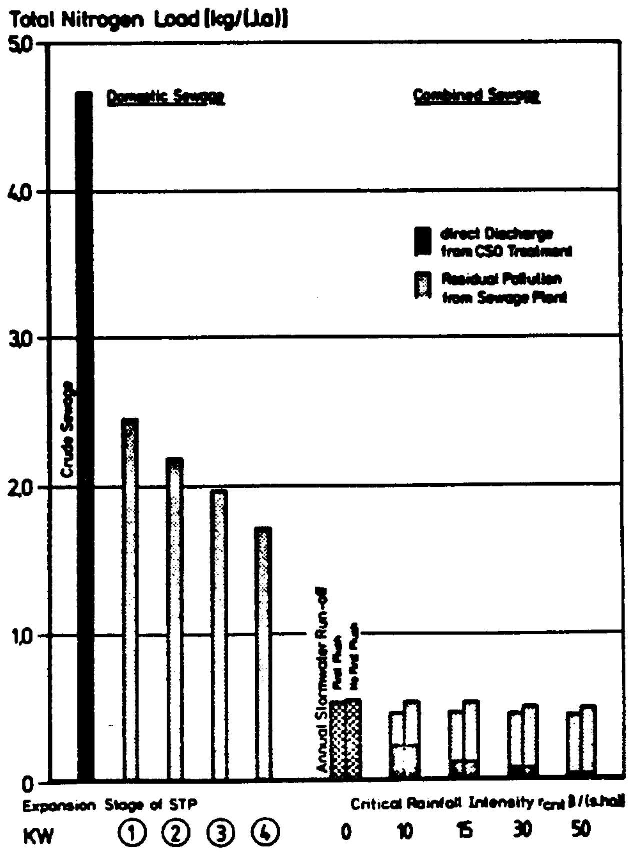

Figure 4: Reduction of Annual Nitrogen Load Through Biological purification and CSO Treatment

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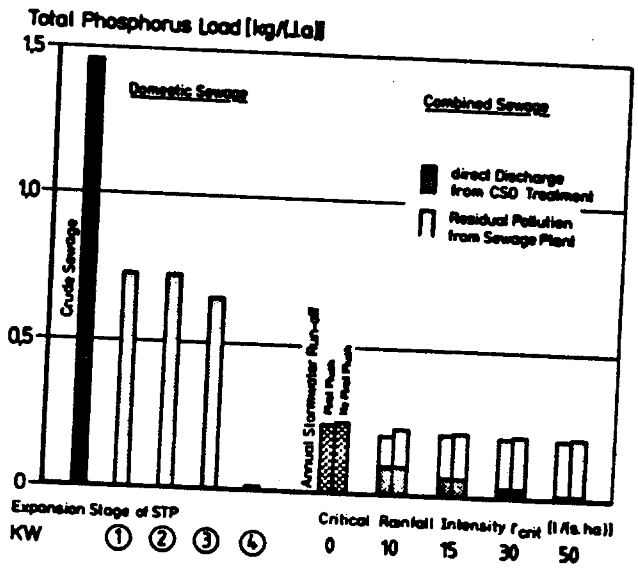

Figure 5: Reduction of Annual Phosphorus Load Through Biological Purification and CSO Treatment

pollutant parameters is very different. Whilst the Figures biological basic purification (KW1) for the pollutant parameters BOD_5, COD and SS have a higher purification effect (Figures 1 to 3) the nutrients are only inadequately reduced (Figures 4 and 5).

2.3 Annual Stormwater Runoff and Its Pollution

2.3.1 Annual Precipitation Levels

The mean annual precipitation level in the Federal Republic is 837 mm/a. It varies between 2500 mm/a at the edges of the Alps and 500 mm/a in the northern part of the Rhine valley. If one ignores the precipitation levels which cover only a relatively small area then the variation range of

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the precipitation level lies mainly between some 600 mm/a and 1200 mm/a.

2.3.2 Mean Proportion of Impervious Area of Municipal Drainage Zones

The proportion of impervious area of municipal drainage zones gives the percentage share of impervious drainage areas of the total catchment region. It varies in municipal catchment areas, to a large degree, according to the type and structure of the building development. In many cases the share of the impervious areas is between 35 % and 55 % of the total area. For further investigations a mean impervious area of 0.40 was employed for the selected mean population density of 70 I/ha.

2.3.3 Annual Stormwater Runoff

From more recent measurements and investigations the annual stormwater runoff from impervious drainage areas of municipal populated zones can be relatively well estimated. Objective stormwater evaluations with simulation of the associated discharges using runoff models (long-term simulation) allow well determined computation of the annual runoff, taking into account the loss of rain on the surface which occurs (moistening and gully losses, evaporation).

The following principles are to be laid down:

- the annual stormwater runoff depends on local precipitation occurrence. The number and distribution of heavy rain events exercise a large influence on the annual stormwater runoff and on the annual overflow data of CSO.
- with equal distribution of heavy and slight rainfall, localities with a higher precipitation also show a higher stormwater runoff.
- the annual stormwater runoff is greater the more the drainage area is inclined.

The annual stormwater runoff can, for different annual levels of precipitation and degrees of inclination of drainage area, be estimated as follows as a percentage share of the annual level of precipitation (Table 3):

For this it is assumed that the annual stormwater runoff occurs only from the impervious areas Ared. In fact, with acute inclinations of the drainage area, stormwater flows off even from permeable areas, which however is taken into

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Table 3. Percentage Rate of Annual Stormwater Runoff Related to the Annual Precipitation Level

Slope Group	Average Ground Slope [%]	Annual Precipitation Large	Small
1	Smaller than 1	50%	35%
2	1 to 4	57.5%	42.5%
3	4 to 10	62.5%	50%
4	Greater than 10	70%	60%

account by the higher runoff rate. The following calculationa were carried out according to own experiences with an annual runoff of 400 mm/a or 4,000 m³/(ha.a) referred to the impervioua areaa. With a mean annual precipitation lavel in the Federal Republic of 837 mm/a, the annual runoff rate is 47.8 %. Following the carrying out of precipitation measurement, medium to heavily inclined drainage regions were dealt with using this runoff rata. If one converts, using the mean impervious area rate of 0.40 and the applied population density of 70 I/ha, the annual stormwater runoff to the number of connected inhabitants, this gives a value of 22.9 m³/(I.a). The annual stormwater runoff therefore is, on average, 31.4 % of the household sewage which occurs (73 m³/(I.a)).

2.3.4 Stormwater Pollution

For the pollution of the stormwater runoff the following pollution can, in accordance with Table 4, on average be applied for the stormwater runoff of the combined sewage system (without wastewater component). The annual load, referred to inhabitants, given in the last column was estimated from the mean values for the population density and the level of impervious area.

2.4 Annual Total Amount of Discharged Combined Sewage from Stormwater Tanks

For the CSO treatment in a combined sewage system region, stormwater overflow tanks and storage sewers are to be emplaced for the storage of combined sewage which flows off in storm weather. The connected sewage treatment plants are, apart from a few exceptions, not in a position to process biologically the large critical stormwater runoff from stormwater overflows in the sewer network. For this

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Table 4. Mean Pollution of Stormwater of a Combined Sewage System Without Dry Weather Flow

Pollutant Parameter	Pollution of Combined Sewage (Storm water component only)	
	Concentration [mg/l]	Annual Load [kg/(I.a)]
Biochem. Oxygen Demand BOD_5	88	2.01
Chemical Oxygen Demand COD	270	6.18
Suspended Solids SS	160	3.66
Total Nitrogen N_{tot}	20	0.46
Total Phosphorus P_{tot}	9.2	0.21

reason, a stormwater overflow installation or another combined sewage storage tank must be placed, at the latest, just upstream of the sewage treatment plant in order to limit the manageable inflow into the biological stage to the level of the double dry weather inflow. If one converts this storm weather inflow to the impervious areas Ared in the populated zone, then one obtains a theoretical runoff discharge rate rab of between 0.5 l/(s.ha) and 1.5 l/(s.ha).In tne majority of cases a runoff discharge rate of 0.75 l/(s.ha) should be capable of being processed in a biological sewage treatment plant without additional storage.

In Figure 6 below one can see the annual combined sewage total overflows dependent on the specific storage volume of the CSO treatment installation. The curves were obtained from numerous runoff measurements and theoretical runoff determinations from a long representative series of precipitation. In this figure the effect of a CSO treatment in accordance with the ATV Worksheet A 128 [8] is included for comparison.

From Figure 6 it can be seen that with a 90 % pollutant load retention according to A 128, some 31 % to 36 % of the annual stormwater runoff (without wastewater component) is

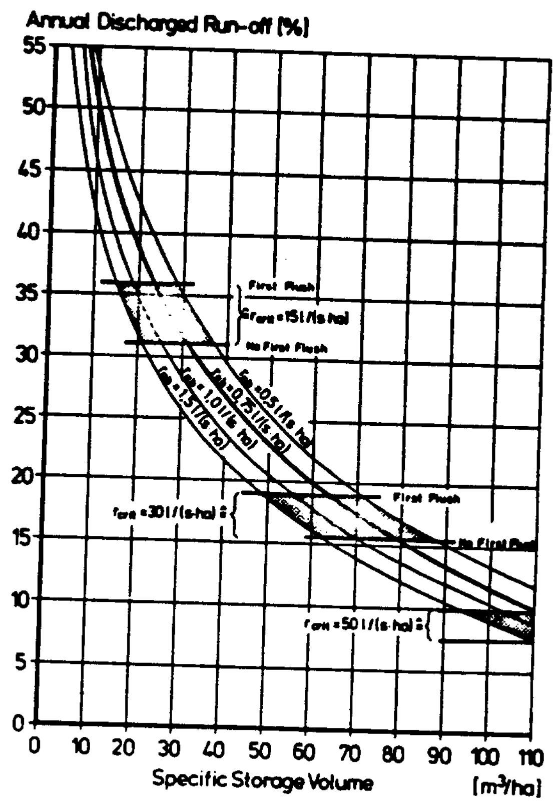

Figure 6: Annual Discharges Stormwater Runoff as a Function of Specific Storage Tank Volume

discharged into lakes and rivers. The upper limit of 36 % then applies when a marked first flush appears in the storm weather runoff (small populated area). In large populated areas (from ca. 100 ha. populated area upwards) practically no more first flush takes place, so that, in order to maintain the objective of 90 %, some 31 % of the annual stormwater runoff is discharged in the lakes and rivers, while 69 % is to be treated in the biological section of a sewage treatment plant. For this, stormwater storage tanks of between 23 and 32 m³/ha are required.

If the objective according to the ATV Worksheet A 128 is raised to 95 % (corresponding more or less to a critical rainfall of 30 l/(s.ha), some 19 % (first flush) in small populated areas, some 16 % in large populated areas, of the annual stormwater runoff is discharged in the receiving waters. However, for this, specific storage space of some 63 to 79 m³/ha, referred to the impervious area, is already necessary.

For the frequently occurring runoff from stormwater storage tanks (rab = 0.75 l/(s.ha)) the following discharged combined sewage totals (stormwater component only) are, in the long-term mean, to be expected with the above assumptions (Table 5):

Table 5. Annual Mean Total Discharged Combined Sewage Overflow Quantity from Stormwater Overflow Installations for Different Requirements on the CSO Treatment.

Objective of the CSO Treatment in Accordance with A128	Total discharged Annual Combined Sewage Quantity			
	With first flush		Without first flush	
	[%]	[m³/ha]	[%]	[m³/ha]
90% (r_{crit} ≈ 15l/(s.ha))	36.0	1,440	31.0	1,240
95% (r_{crit} ≈ 30l/(s.ha))	19.0	760	15.5	620
97% (r_{crit} ≈ 50l/(s.ha))	10.0	400	7.5	300

2.5 Loading on Lakes and Rivers Due to Sewage Treatment Plant Effluent

The purification effect of biological sewage treatment plants has already been displayed graphically in Figures 1 to 5. For the individual expansion stages the following residual pollutants can be expected from sewage treatment plant effluent with dry weather for the 5 pollutant parameters as given in Table 6:

Table 6. Mean Annual Pollutant Load from Household Sewage Carried into Lakes and Rivers from Sewage Treatment Plant Effluent (for Different Sewage Treatment Plant Expansion Stages)

Expansion Stage of the Sewage Treatment Plant	Residual Pollution in the Sewage Treatment Plant Effluent [kg/(I.a)]				
	BOD_5	COD	SS	N_{tot}	P_{tot}
KW1	1.46	6.57	1.46	2.55	0.73
KW2	1.10	5.84	1.46	2.19	0.73
KW3	0.73	5.11	0.73	1.97	0.66
KW4	0.36	2.92	0.36	1.82	0.02

From this it is clear that, above all, the nutrients such as total phosphorus and total nitrogen are only inadequately degraded. The residual load on lakes and rivers due to the stormwater runoff from the sewage treatment plant effluent with storm weather (storm water component only, without mixture with the waste water) is also graphically presented in Figures 1 to 5 for the different requirements on the discharge installations in the sewer network. Under the assumption that modern biological sewage treatment plants show no higher pollution concentrations in the sewage treatment plant effluent than with dry weather the following loadings on the receiving waters can be projected from the sewage treatment plant effluent for stormwater runoff as given in Table 7.

From this a not insignificant residual pollution of lakes and rivers due to the sewage treatment plant effluent during storm weather can be seen. This residual pollution also results in that, despite the higher requirements on the discharge installations in the sewer system, although the direct loading on the lakes and rivers decreases more markedly, the total loading however does not reduce to the same extent. Solely at the individual inlet points can the

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Table 7. Mean Annual Residual Pollutant Load from Stormwater Runoff Carried into Lakes and Rivers from Sewage Treatment Plant Effluent

Objective of the CSO Treatment in Accordance with A128	Residual Pollution in the Sewage Treatment Plant Effluent [kg/(I.a)]				
	BOD_5	COD	SS	N_{tot}	P_{tot}
90% ($r_{crit} \approx 15 l/(s.ha)$)	0.49	1.76	0.50	0.39	0.16
95% ($r_{crit} \approx 30 l/(s.ha)$)	0.48	1.94	0.49	0.45	0.19
97% ($r_{crit} \approx 50 l/(s.ha)$)	0.47	2.00	0.48	0.48	0.19

direct loading be significantly lowered by larger storage volumes.

2.6 Total Loading on Lakes and Rivers through CSO

With the directly discharged annual combined sewage total quantity, determined in Section 2.4, together with the residual loading from the sewage treatment plant effluent, results the total loading on lakes and rivers with storm weather. If one takes into account the stormwater runoff only (without mixture with the dry weather flow) then these loadings can also be seen in Figures 1 to 5. As within a larger sewer network practically no first flushes occur, the mean annual total pollution of lakes and rivers from CSO treatment can be estimated as follows as given in Table 8.

From the comparison of Tables 4 and 8 it is clear that, due to the unsatisfactory sewage treatment plant effluent to all intents and purposes the nutrients in particular cannot be kept out of lakes and rivers. However, in Tables 7 and 8, it is assumed that in the sewage treatment plant only a biological basic treatment (expansion stage KW1) takes place.

3. Annual Costs of Sewage Treatment Plants and Stormwater Tanks

3.1 Sewage Treatment Plants

The construction and operating costs of modern sewage treatment plants with biological basic purification (1st

Table 8. Annual Mean Total Pollutant Load Carried into Lakes and Rivers from CSO Treatment Plants (Only Stormwater Component without Mixture with Dry Weather Flow)

Objective of the CSO Treatment in Accordance with A128	Annual Total Pollution of Lakes and Rivers [kg/(I.a)]				
	BOD_5	COD	SS	N_{tot}	P_{tot}
90% (r_{crit} ≈ 15l/(s.ha))	1.11	3.68	1.64	0.53	0.22
95% (r_{crit} ≈ 30l/(s.ha))	0.80	2.90	1.06	0.52	0.22
97% (r_{crit} ≈ 50l/(s.ha))	0.62	2.46	0.75	0.51	0.21

expansion stage KW1), based on personal experiences, are listed in Table 9.

Table 9. Specific Building, Operating and Annual Costs of Biological Sewage Treatment Plants with Basic Purification

Connection Value [I]	Building Costs [DM/I]	Annual Costs [DM/I.a)] Operating Costs	Service of Capital	Total Costs
1,000	900.-	45.0	72.0	117.0
5,000	560.-	24.7	44.8	69.5
10,000	450.-	21.0	36.0	57.0
25,000	325.-	17.0	26.0	43.0
50,000	270.-	14.4	21.6	36.0
100,000	220.-	13.4	17.6	31.0

For the determination of the service of capital it is assumed that the construction component of a sewage treatment plant is written off in 30 years and the mechanical part, on average, in 10 years. Furthermore, it is assumed that the real rate of interest is ca. 4 %. With these corditions an annual service of capital of ca. 8.0 % of the investment costs is calculated. With these assumptions the following annual costs (1st expansion stage

KW1) for the biological basic purification can be applied as given in Table 9.

For further cost considerations the annual costs for the 2nd expansion stage are assumed as being ca. 17 %, for the 3rd expansion stage ca. 40 % and the 4th expansion stage ca. 100 % higher than the annual costs of Table 9. These annual costs are presented in Figure 7.

3.2 Stormwater Tanks

The specific building costs for enclosed stormwater tanks can, in accordance with current cost levels, be estimated as follows (Table 10):

Table 10. Specific Building Costs for Enclosed Stormwater Tanks

Tank Size [m³]	Building Costs (DM/m³)
250	2,650.-
500	2,020.-
1,000	1,350.-
1,500	1,100.-
2,000	1,000.-

The operating costs of the stormwater tanks can, according to own enquiries, be set on average at DM 10,--/(m³.a). For the determination of the annual service of capital it is assumed that the stormwater tanks are written off in ca. 40 years and the real interest rate is 4 %. From this results an annual interest payment of 4.5 % of the total building costs.

With the population density, impervious area levels and stormwater tank volumes as selected in Section 2, the building and operating costs as well as the service of capital can be converted per inhabitant. The annual costs resulting from this for different water protection requirements are also entered in Figure 7. As standard of comparison for the CSO treatment here the critical rainfall intensity, r_{crit}, is selected between 10 and 50 l/(s.ha). Under this, the costs for stormwater tanks for the storage of combined sewage, which ensures a comparable CSO treatment for stormwater overflows, is understood. As biological sewage treatment plants during storm weather are not in a position to treat biologically the higher inflows

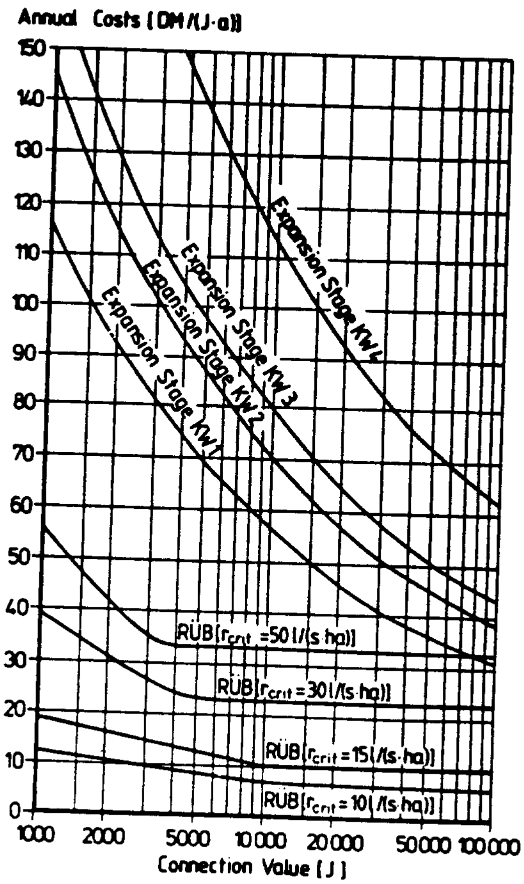

Figure 7: Annual Costs of Biological Wastewater Purification and CSO Treatment

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from stormwater overflows (critical rainfall intensity) without additional storage then in such cases sufficiently large stormwater tanks are also necessary.

From Figure 7 it is clear that the annual costs for CSO treatment, as opposed to biological sewage purification, are almost constant for larger connection values. This is due to the fact that, with higher numbers of inhabitants, more stormwater tanks must be constructed as otherwise the costs for the transport of sewage to central stormwater tanks are too large. The costs for the transport sewers are however not included. If one divides the annual costs according to Figure 7 by the annual degraded pollutant load from household sewage and from stormwater runoff there results the graphically represented specific annual costs for BOD_5, the Chemical Oxygen Demand, COD, and for the suspended solids, SS, as given in Figures 8 to 10. From this it can be deduced that, for the degrading of 1 kg pollutant load for these 3 pollutant parameters, overall biological sewage treatment plants are cheaper than the comparable CSO treatment installations. This is due to the fact that, through the biological purification:

- a considerable part of the pollutant load in the household sewage is degraded,
- the residual pollution from the sewage treatment plant effluent with storm weather is still quite large in relation to the smaller pollution concentrations of the stormwater runoff.

From Figures 8 to 10 it can be seen further that, for a connection value of more than ca. 10,000 inhabitants the specific annual costs of the CSO treatment remain almost the same. In opposition to this the specific annual costs of the biological sewage treatment plants reduce further.

However the conclusion must not be drawn from this that CSO treatment is first sensible if all sewage is treated in biological sewage treatment plants with advanced purification (e.g. 3rd expansion stage). Much more, amongst others, the question is to be answered with which type of purification (stormwater, wastewater) an optimum for the water protection with predetermined investment resources is achieved for the sewage treatment plant standard already achieved today.

4. Deductions for the Protection of Lakes and Rivers

For the assessment of a concept for the protection of lakes and rivers the costs are a suitable but not the sole standard. Upstream of a biological sewage treatment plant

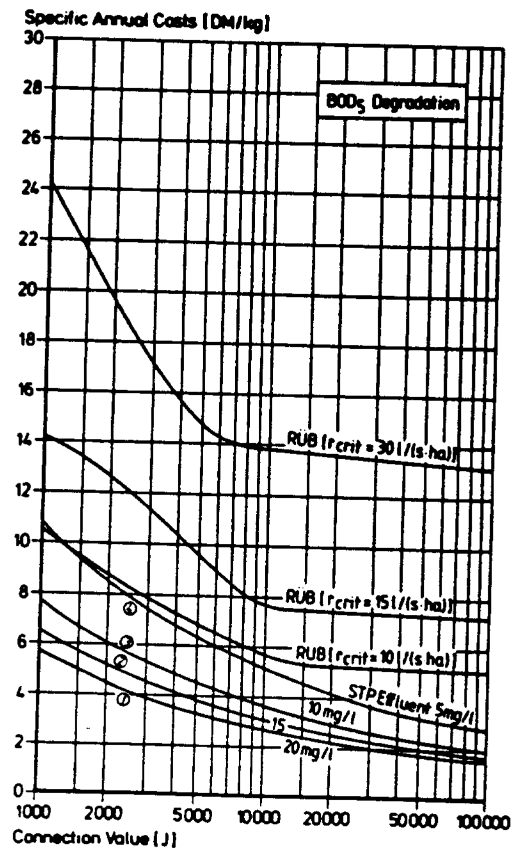

Figure 8: Specific Annual Costs for Biological Wastewater Purification and CSO Treatment for BOD, reduction

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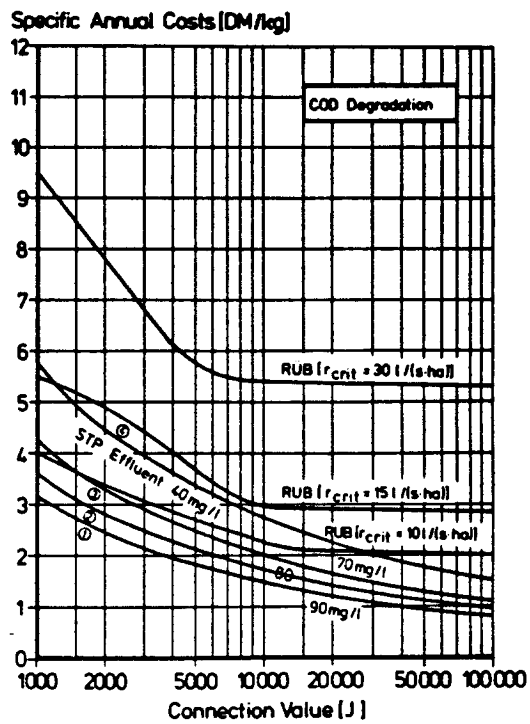

Figure 9: Specific Annual Costs for Biological Wastewater Purification and CSO Treatment for COD Reduction

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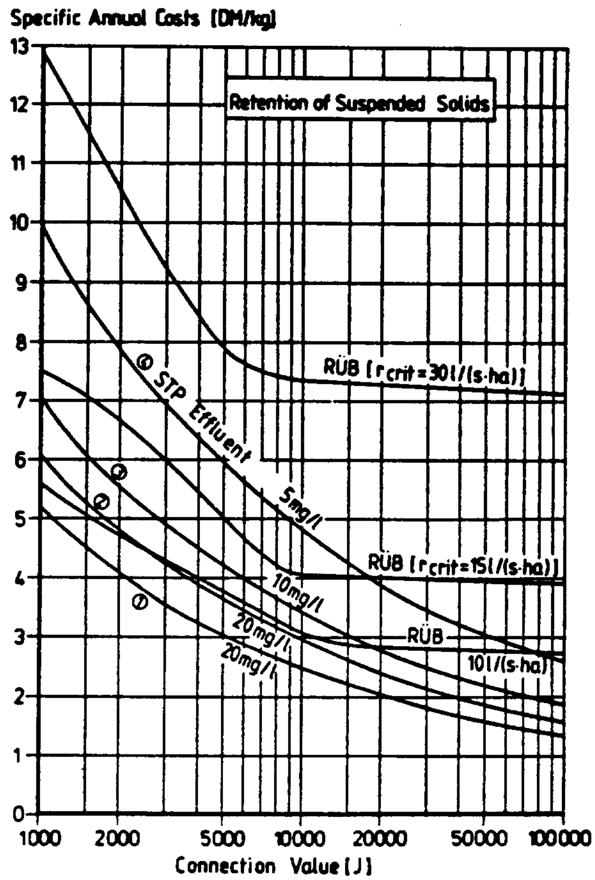

Figure 10: Specific Annual Costs for Biological Wastewater Purificaiton and CSO Treatment for Degradation of Suspended Substances

there are, as a rule, many stormwater overflow installations placed in the sewer network which, in part, can discharge into low performance receiving waters. The sewage purification plant can, on the other hand, be on a lake or river with larger flows and better water quality.

In such cases an increased CSO treatment can bring about an effective relief of weaker lakes and rivers. Furthermore the combined sewage runoff usually carry more degradable substances which can produce heavy depositing and possible silting up of lakes and rivers. The resultant costs for the removal of such effects can currently be considerable which, within the framework of the above and very generally held comparative calculations, are not taken into account.

It is to be further considered, that the discharged pollutants from stormwater overflow installations are, in the main, biologically easily degradable. In certain situations, e.g. in summer, with low water flow and small oxygen content, it can come to a critical loss of oxygen in lakes and rivers.

It is important for the further water pollution control of receiving waters that, in the Federal Republic of Germany, almost 75 % of the inhabitants are connected to biological sewage treatment plants. The alternative therefore lies in not whether a biological sewage treatment plant or CSO treatment installations should be built but in how an optimum for the protection of lakes and rivers can be achieved with the future available investment means. The scope of CSO treatment - insofar as it goes beyond the ATV Worksheet A 128 - will have to be laid down, as for the necessary wastewater purification, depending on water flow, the use and the required water quality of the lakes and rivers. If the water flow is sufficiently large and now already lies at least at Water Quality Class III, then the assessment of the most effective water pollution control cost calculations are carried out. Here, as a rule, sewage purification plants with biological basic purification are to be assumed.

As is to be seen from Figures 1 to 5, the residual loads for the pollutant parameters investigated can currently be reduced only slightly with an advanced sewage purification. With CSO treatment higher degradation effects can partially be achieved. To this and it was investigated in a further cost calculation whether it is more economic for a better water quality to expand the biological sewage treatment plants for an advanced sewage purification according to different expansion stages (KW2 to KW4) or to expand the CSO treatment for different requirements. The results of this minimum cost investigation are listed in Table 11.

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Table 11 shows for the available expansion stages of a sewage treatment plant and for the available CSO treatment (standard r_{krit}) with which connection value a sewage treatment plant, the expansion of the CSO treatment or of the sewage treatment plant is more economic. With a connection value of, for instance, 10,000 inhabitants and with an available 1st expansion stage and an available CSO treatment up to r_{krit} = 10 l/(s.ha) it is more cost effective for the pollutant parameter COD to expand the CSO treatment to a critical rainfall intensity of 20 l/(s.ha). With suspended solids it is even more economic to design the CSO treatment to a critical rainfall intensity of 30 l/(s.ha) before the next expansion stage of the sewage treatment plant (KW3) is selected. With the nutrients, on the other hand, one achieves more for the water quality, with the same costs, if the expansion of the sewage treatment plant takes place at once to the next expansion stages (KW2 to KW4). With a connection value of 100,000 inhabitants for COD the expansion of the sewage treatment plant to the second expansion atage (KW2) is more economic. With suspended solids, on the other hand, a CSO treatment with a critical rainfall intensity of 15 l/(s.ha) did more for the lakes and rivers than an expansion of the sewage treatment plant for the same cost figure.

From this comparison it is clear that, due to the already available biological sewage purification in the Federal Republic of Germany a satisfactory CSO treatment can certainly also be sensible even on cost grounds. However, how far the requirements on the CSO treatment are to be set depends on the size of the populated area (connection value of the sewage treatment plant) and on the type and quality of the lakes and rivers and thus on the pollutant parameters.

Table 11. Practical Selection of Further Sewage Treatment (CSO Treatment, Sewage Treatment Plant Expansion) with Existing Sewage Treatment Plants and CSO Treatment for Different Connection Values and Pollutant Parameters

Connection Values of the Sewage Treatment Plant (I)

Existing Sewage Treatment Plant	Existing CSO Treatment	1,000 I					5,000 I					10,000 I					50,000 I					100,000 I				
	r_{crit} (1/(s.ha))	BOD_5	COD	SS	N_{tot}	P_{tot}	BOD_5	COD	SS	N_{tot}	P_{tot}	BOD_5	COD	SS	N_{tot}	P_{tot}	BOD_5	COD	SS	N_{tot}	P_{tot}	BOD_5	COD	SS	N_{tot}	P_{tot}
1st Expansion Stage (EW1)	0	15	15	50	EW2	EW2	15	20	50	EW2 - EW4	EW2	15	20	30	EW2 - EW4	EW2	15	15	20	EW2 - EW4	EW2	10	10	15	EW2 - EW4	EW2
	10	20	15	50	EW2	EW2	15	20	50			15	20	30			15	15	20			EW2	EW2	15		
	15	20	30	50	EW2	EW2	15	20	50			EW2	20	30			EW2	EW2	20			EW2	EW2	EW3		
	30	EW2	EW2	50	EW2	EW2	EW2	EW2	50			EW2	EW2	EW3			EW2	EW2	EW3			EW2	EW2	EW3		
2nd Expansion Stage (EW2)	0	20	30	30	EW4	EW3	20	30	25	EW4	EW3	20	25	25	EW4	EW3	15	15	15	EW4	EW3	15	15	10	EW4	EW3
	10	20	30	30			20	30	25			20	25	20			15	15	15			15	15	EW3		
	15	25	30	30			20	35	30			20	25	20			EW3	EW3	EW3			EW3	EW3	EW3		
	30	EW3	50	EW3			EW3	EW3	EW3			EW3	EW3	EW3			EW3	EW3	EW3			EW3	EW3	EW3		
3rd Expansion Stage (EW3)	0	>50	30	>50	EW4	EW4	>50	30	>50	EW4	EW4	>50	25	>60	EW4	EW4	30	15	>60	EW4	EW4	25	15	>50	EW4	EW4
	10		30					30					25				30	15				25	15			
	15		30					30					25				30	EW4				30	EW4			
	30		EW4					EW4					EW4				>60	EW4				>50	EW4			

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Appendix 2: Notation

The following symbols/abbreviations are used in this paper:

Ared = impervious area
a = annum
ATV = Abwassertechnische Vereinigung
(= German Association for Water Pollution Control)
BOD_5 = Biochemical Oxygen Demand (for 5 days)
COD = Chemical Oxygen Demand
CSO = combined sewage overflow
d = day
ha = hectare
I = inhabitant
KW = sewage plant expansion stage (1, 2, etc)
l = liter
m = meter
mm = millimeter
r = rainfall intensity
rab = runoff discharge rate
r_{crit} = critical rainfall intensity
s = second

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Urban Stormwater Infrastructure: Rehabilitation Activities in the United States

J.W. Delleur[1]

INTRODUCTION

Urban drainage systems collect and convey stormwater runoff from municipalities for discharge into receiving streams or in some cases, for percolation through the ground. These systems include drainage ditches, channels, inlets, sewer intakes, collectors, detention facilities, combined sewer overflows and treatment facilities. Figure 1 shows the general configuration of urban stormwater systems after Grigg (1988). Typically, drainage or stormwater management has a flood control objective as well as a water quality objective. Whereas flood control refers to stream reaches, urban drainage and stormwater management refer to the handling of the stormwater runoff before it reaches the receiving streams. The water quality objective normally is concerned with runoff pollutant discharges, combined sewer overflows, treatment and impacts on receiving waters particularly under lowflow conditions. The recent study by the U.S. Environmental Protection Agency and the U.S. Geological Survey known as the Nationwide Urban Runoff Program (NURP) found that some contaminated stormwater discharges can contribute to water quality violations in receiving streams resulting in a need for controls. There has been a shift in public attitude about stormwater management away from the old tradition of removing all runoff from an area as quickly as possible to a concern for clean water. Despite differences in approach and concerns, the management of stormwater and of dry weather flow may use common facilities. For example in areas having combined sewer systems both stormwater and wastewater are conveyed to the same treatment facility before being discharged in the receiving streams.

INVESTMENTS AND NEEDS

The American Public Works Association Research Foundation (1966) estimated that the total capital in storm sewers was $22 billion (in 1965 dollars). Poertner (1981) estimated that as of 1978 the nationwide investment in surface drainage facilities was about $60 billion.

Information about the investment needs in urban storm drainage is incomplete. This is because the concept of need is elusive as it is based on political decision and because of the scatter of the information from local governments and agencies coupled with the lack of significant federal involvement in this category of water resources. Among the few informations available we can cite the 1983 report of the Associated General Contractors of America entitled "America's Infrastructure - A

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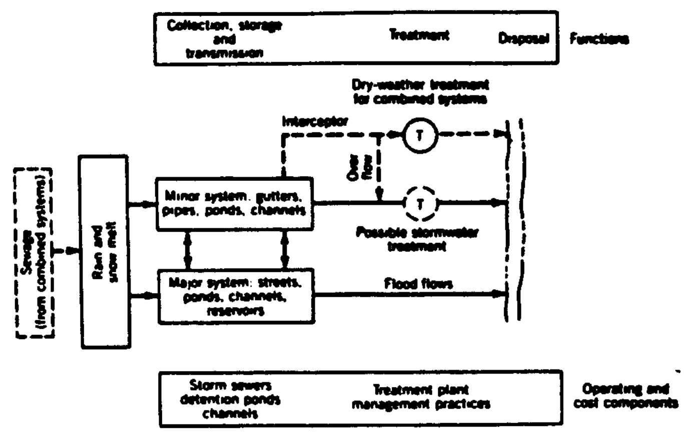

Figure 1. Configuration of Urban Stormwater Systems
(from Grigg, N.S., "Infrastructure Engineering and Management", Wiley-Interscience, John Wiley and Sons, Inc., Copyright 1988, reproduced with permission)

Plan to Rebuild" which identified a $169.4 billion need for drainage and minor flood control over a 30-year period. This is equivalent to a $5.64 billion annual expenditure. Grigg (1984) however estimated that the national need in stormwater category is of the order of $150 billion, and adding combined sewers would reach $185 billion. Grigg also cites barriers to improvement in stormwater programs which include low priority for investment, deferral of flood control, lack of technical information and general difficulties in public works management. As a result of the lack of good information, maintenance and rehabilitation are not adequate except for a few locations where management has undertaken innovative programs such as Denver, Colorado (Hunter, 1989).

STATE OF THE URBAN DRAINAGE INFRASTRUCTURE

The below ground sewers in the older cities of the northeast and midwest are often more than 100 years old and may be made of brick or even wood. As an example, the St. Louis Metropolitan Sewer District has approximately 4000 sewer cave-ins each year. Weil (1989) states that the 65 largest of these collapses since 1975 have cost over $19.5 million in emergency repair funds. However, the age and the condition of the systems throughout the nation is variable and difficult to determine. A 1983 study of the National Leagues of Cities revealed the following:

storm drainage facilities in good condition: 24%

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needing major repairs: 24%
needing major rehabilitation: 32%
need of replacement: 11%

Regarding the financial needs the study found the following:

financing from the city's own sources: 16%
financing from the city's own sources with great difficulty: 26%
needing up to one-half state or federal assistance: 19%
needing more than half from state or federal assistance: 29%
city budget does not include funds for stormwater maintenance repair or replacement: 5%

The same report indicates that in many cases, cities in all regions ranked stormwater collection second after streets and roads. Only eleven percent chose stormwater collection and drainage as a first priority. The National Council on Public Works Improvement (Giglio et al., 1988) gave a grade of "C" to wastewater on the report card on the nation's public works, whereas it gave a grade of "B-" to water resources and "B" to water supply.

The National Council on Public Works Improvement has found "convincing evidence that the quality of America's infrastructure is barely adequate to fulfill current requirements, and insufficient to meet the demands of future economic growth and development". In view of the C-grade assigned to wastewater it may be concluded that the Urban Drainage Infrastructure can be considered as performing at only passable levels.

Part of the problem is financial. As a result the Council made several recommendations in order to mobilize adequate financing to meet the current and future Public Works needs which would require participation by all levels of government. The Council also recommended sharpening the accountability for infrastructure, strengthening the systems performance and accelerating innovation.

Regarding innovation, the Council recommended an increased level of effort in research and development applied to infrastructure. It stated that in 1985 the Federal spending on infrastructure R & D was less than one-third of one percent of the total new infrastructure construction for that same year. It pointed out that in view of the large size of the infrastructure investment, small changes in the reliability or efficiency of key components can result in major savings. The National Science Foundation has reacted to the need for more intense national focus on Public Works technology. For example, it has established specialized engineering research centers at a number of universities focusing on major topics. However, to the author's knowledge, none of the centers is related to the urban water infrastructure.

The Council also recognized that in parallel with the implementation of innovative technology, adequate education and training must be provided for the people who build, manage and operate Public Works. This means an increase in enrollments in the Schools of Civil Engineering which have traditionally have been the mainstay of the Public Work profession. In their report on "Civil Engineering Needs for the 21st Century" Roesset and Yao (1988) identify maintenance, monitoring and rehabilitation as one of the problem areas of civil engineering for the 21st Century. They further state the need for research to design infrastructure that is easier to monitor and maintain and to improve methods of nondestructive testing.

The Committee on Infrastructure Innovation (1987) of the National Research Councils (NRC) categorized the promising areas for innovation in four groups: "1) improvement of existing systems through new technology or upgrading methods, 2) improved maintenance of existing systems through such techniques as performance monitoring and failure detection, 3) development of new, alternative systems and

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technologies, 4) management and policy research". As an example of the research and development that has already yielded significant advances the report lists in-place relining of water and sewer pipes.

Considerable research and development effort is already underway by the US Army Corps of Engineers, the Environmental Protection Agency, and professional organizations such as the American Public Works Association and the American Water Works Association. However the Council on Public Works improvements recommended that demonstration project follow research and development and precede wide spread application. The formal risk-sharing demonstration projects also provide for a wide exposition for new or unproven technology.

FAILURES

Failures of the Urban Drainage Infrastructure can be categorized as being structural, hydraulic or environmental in nature (Delleur, 1989). This is summarized in Table 1 along with sample methods of diagnosis and rehabilitation.

Table 1. Summary of Failure, Diagnosis and Rehabilitation of Urban Drainage Infrastructure

FAILURE	STRUCTURAL	HYDRAULIC	ENVIRONMENTAL
Type	Subsidence Total or Partial Collapse Corrosion	Flooding Surcharge Leakage Flow Instabilities Increased Roughness Water Hammer	Pollution of Receiving Waters CSO/SSO
Diagnosis	Sewer Survey Monitoring	SWMM Model Monitoring	SWMM Model Monitoring
Rehabilitation	Repair Renovation/ Renewal Lining Replacement	Maintenance Flow Attenuation/ Reduction Aeration Lining Real-Time Control Replacement	Flow Attenuation/ Reduction Real-Time Control Replacement

The structural failure is the predominant mode. Typically it starts with a minor defect such as leaking joints, corrosion, bad bedding or cracking. This initial defect can further deteriorate when water can flow into or out of the sewer or when water flows parallel to the sewer through the bedding material causing soil migration. In warmer climates the presence of hydrogen sulfide in sewage combines with condensed water at the crown of the sewer forming sulfuric acid (Kienow, 1980)

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which destroys the concrete pipe wall near the crown. Once the cavities have formed the final collapse is triggered by some other mechanism such as vibration due to a nearby excavation or an intensive storm.

The most common hydraulic failure is that of flooding either in the streets or in basements of buildings. Flooding can be caused by inadequate flow capacity or by surcharge of the sewer system which passes from free surface flow to pressure pipe flow with the hydraulic gradient reaching the top of the manholes.

Hydraulic failures are usually related to insufficient discharge capacity. This can be due to increased hydraulic roughness caused by aging of the pipe material, sediment deposition, pipe joint eccentricity, sliming, worn brick work, root penetration, infiltration, deformation or partial collapse of the sewer pipe, heavy incrustation at joints, accumulation of debris and rubble. Reduced flow capacity can also be due to inappropriate hydraulic conditions such as standing waves under part full flow condition and flow instabilities. Zech et al. (1984) found that pulsating flow due to air pocket can exist for the discharges in the range $1.90 < Q/D^{5/2} < 2.50$. For discharges greater than $Q/D^{5/2} > 2.50$ both full flow and free flow can exist depending on aeration. This flow instability can lead to changes in pressure that can cause damages either in pipes or in manholes. Water hammer is another source of failure known to have occurred in sewage force mains (James et al., 1980).

The most common environmental failure is the discharge of storm sewer overflows (SSO) and combined sewer overflows (CSO) creating water quality violations in receiving streams. The impacts of urban runoff on receiving waters have been summarized by Field and Turkeltaub (1981).

The Nationwide Urban Runoff Program (NURP) performed by the U.S. Environmental Protection Agency and the U.S. Geological Survey found that some contaminated storm discharges can contribute to water quality violations in receiving streams. As a result, there have been several attempts to regulate stormwater discharges. It has been a requirement of the Federal Clean Water Act since its creation in 1972. The 1987 Clean Water Act Amendments require States to develop a non-point source program. The EPA published on December 7, 1988 in the Federal Register the proposed regulations for the control of the point source discharge of stormwater. These regulations are an attempt to mitigate and to regulate the environmental failures of urban drainage systems by limiting the pollution loads of combined sewer overflows and of storm sewer overflows.

DIAGNOSIS

Databases and Geographical Information Systems

The development of a database management system or geographical information system is probably the top priority in most cities for the management of repair, rehabilitation and replacement of sewerage systems. Hansen (1988) indicates that the development of this database requires three basic steps. The first step is the identification of the key system attributes. This includes pipe type, length, diameter, invert elevation, design flow, measured flow, date of installation, date of the last TV inspection and so forth. This can include as many as twenty different pipe types and 350 data elements. The second step is concerned with the inclusion in the database of the overall condition of the sewerage system obtained from field inspections. This can be automated by means of lap top computers used to collect and transmit field information to the central database. The degree of detail typically differs from one city to the other. Some would identify cracks, for example, as small, medium and large while others will include their dimensions such as 0-1/2 inch in width and 0-1 foot in length as compared to 0-1 inch in width and 1-2 inches in length. Likewise the categorization of infiltration and inflow can be either light, medium or heavy for some, while in some others it is quantified as 0-1 gpm, 1-5 gpm and more than 5

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gpm. The third step is the development of a "intelligent infrastructure" database. This is essentially an expert system capable of utilizing previously collected maintenance and rehabilitation information to recommend and prioritize rehabilitation activities. The suggested rehabilitation activity is selected from a list of typical pipeline and manhole repair alternatives. A cost matrix indicating the cost of each type of repair activity is included and can be updated by the user. Added costs are also included such as removing and replacing surface covers at entry trench excavation and associated street and above ground works. The cost of different alternatives must be compared. For example the cost of numerous point repairs requiring multiple excavation and disruption of surface covers should be compared to the cost of pipeline inversion lining and conventional replacement. Similarly reduction of infiltration and inflow must be included. In summary, the development of the intelligent database requires interdisciplinary information including construction, operation and maintenance, cost accounting and engineering.

Bristol et al. (1988) describe the application of one such database management system for a comprehensive evaluation of the sanitary sewer system in Fairfax County, Virginia which includes over 2200 miles of sewer line, 56 pumping stations and 53 flow monitoring stations. The systems serve a population of approximately 670,000 in a 410 square mile area and handles an average flow of about 75 mgd. The Fairfax County project involved the inventory of the sewer system, the digitization of the entire sewer network, the creation of maps using AutoCAD, the development of sewer flow projections, and the development of a model of the existing and future sanitary sewer system. The computer system designed to accomplish this objective included five modules: the system management, the database maintenance, the workfile management, the bulk data input and reporting, and lastly the modeling and reporting module, as shown schematically in Figure 2.

The database contains four main generic files: 1) the pipe file, 2) the node file, 3) the area file and 4) the parameter file. The pipe file contains information for each link of the pipe network such as the identification number, the identification number of the area in which the pipe is located, the order number in which the pipe is to be processed, the number of the nodes upstream and downstream, the pipe diameters, the pipe shape, the pipe material, the year the pipe was installed, the upstream and downstream pipe inverts, the coordinate information for the AutoCAD link, and some user defined fields. The node files include the type (such as standard manhole, treatment plant, metering station, pumping station and so forth), the identification number, the area identification number in which the node is located, the coordinates of the node for the AutoCAD link, and so forth. The area file includes information on the spatial aspects of the network. It includes the identification number of the area and the modeling level of the area such as individual parcel subarea, sewer as a whole, treatment area as a whole. The parameter file includes information that pertains to the entire sewer network such as flow factors that are used for many area records. The modeling and reporting module contains the necessary routines to route the flow through the pipe network and produces reports summarizing the results of model runs.

Although Geographical Information Systems (GIS) are becoming the preferred method for handling diverse geographical information, such as that needed for urban drainage infrastructure, the cost to acquire and support a GIS may be excessive for several municipalities. In order to minimize the cost of development of a GIS that would allow the evaluation of the hydraulic performance of the stormwater system from within the mapping environment, Weber and Schaefer (1990) incorporated the GIS technology into the AutoCAD package. For the city of Port Angeles, Washington, they provide linkage between various low cost commercial software products and AutoCAD. Various external modules were programmed and linked to AutoCAD such as a package that performs a complete stormwater and sanitary analysis to model large networks including overflows, diversions, pump stations,

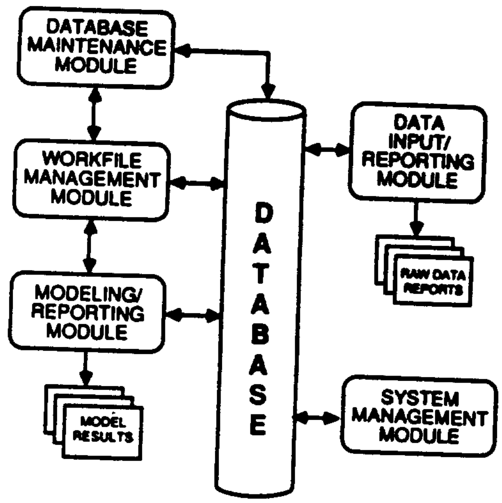

Figure 2. Fairfax County Database Management, System Schematic
(Bristol et al., copyright ASCE 1988, reproduced with permission)

detention facilities and so forth.

Structural Diagnosis

Many defects can be detected by visual inspection when walking along the sewer right-of-way or by internal inspection. Right-of-way inspection may detect items such as sunken areas over sewers, ponding water, condition at stream crossings, manhole frame and cover, condition of visible structures. Visual inspection of manholes can detect the conditions of manhole shaft, structural condition of walls, joint conditions and any leakage. Larger sewers can be inspected by walking, while smaller ones are generally inspected by closed circuit television. These observations can indicate defects such as root penetration, grease, sediment, horizontal deviations, open joints, circumferential cracks, longitudinal cracks, and missing pipe segments.

Non-Destructive Remote Sensing Diagnostic Methods

The infra-red scanner system that uses the temperature differentials surrounding a sewer void gives a picture of that void from above ground and appears to be a promising diagnostic technique of potential failures (Weil, 1983, 1989, 1990). The infra-red image can be recorded on 35mm film or in digital form. Weil (1989, 1990) has reported the successful use of this technique in St. Louis. Observations were made at noon and at midnight to maximize temperature differentials.

Another remote sensing technique that appears promising is that of penetrating radar. In this technique, short pulses of electro-magnetic energy are emitted and from the wave form of the echoes returned by the various interfaces of different materials it is possible to detect deterioration of concrete and voids. The method has been applied by Maser (1989) to assess the condition of asphalt overlayed bridge decks. It can also be potentially used to detect concrete disintegration and voids around concrete sewers. As radar has the ability to detect freeze-thaw disintegration and high moisture content and as infra-red tomography can detect delamination under dry condition, Maser (1989) suggests that the combination of radar and tomography might provide the best method of detecting deterioration conditions in asphalt overlayed bridge decks. Weil (1990), however, found that the infra-red tomography used in conjunction with digital computer analysis yields superior results and that in this case study electronic interference caused by a water line prevented a complete survey of the area of interest using ground-probing radar.

Diagnosis of Hydraulic Failures

As hydraulic failures are usually related to insufficient discharge capacity, flow monitoring programs are essential. Methods of monitoring flows within a wastewater collection system include the use of weirs, Parshall flumes, Palmer-Bowlus flumes, dye-dilution/chemical tracers, depth and pressure sensors, ultrasonic surface level detection devices. In addition, pump stations are a logical choice for monitoring wastewater flows. These different techniques are appropriately described in manuals (ASCE-WPCF, 1983).

Simulation models can be used to detect malfunction of sewerage networks. The assessment of the hydraulic performance consists of four parts: 1) the selection of an appropriate model, 2) the calibration and verification of the model, 3) the use the model to assess the hydraulic performance, and 4) the identification of the location of performance deficiencies and their causes.

The model most commonly used for this purpose in the United State is the Storm Water Management Model (SWMM) developed by Huber et al. (1984). SWMM is a comprehensive mathematical model developed for both continuous and single event simulation of the urban runoff quantity and quality in storm and combined sewer systems. All aspects of the urban hydrologic and quality cycles are simulated including surface runoff, transport through the drainage network, storage and treatment and receiving water effects. The runoff block generates surface runoff based on observed or arbitrary rainfall hyetographs, antecedent conditions, landuse, topography and so forth. The Transport and Extended Transport Blocks combine and route the inflows through the drainage system. Dry weather flow and infiltration into the sewer system can optionally be generated using the transport block. The effect of control devices on flow quality and quantity are simulated in the storage/treatment block and finally the receiving block routes the effluent hydrographs and pollutographs through the receiving waters.

Maalel and Huber (1984) have shown that the use of multiple event simulation proved to be more robust than the single event simulation and better suited for SWMM calibration and verification for continuous simulation. An expert system for the estimation and calibration of the parameters used in the quantity part of the runoff block of SWMM was developed by Baffaut and Delleur (1990). After the model has been calibrated it is essential to proceed with the verification to ensure that the model predictions are in agreement with known local performance. All available flow measurements in the network and at pumping stations should be used for this purpose. The simulation model is then ready to assess the hydraulic performance and to determine the conditions when a pipe begins to surcharge, when flooding begins at a location, when the first overflow occurs, the maximum volume of the overflow, the flow directed for treatment and storage, and so forth.

Environmental Diagnosis

The diagnosis of excessive pollutant discharge is based principally on two procedures. The first is water quality monitoring and the second one is simulation. Automatic samplers are available and they can be programmed in such a way that the

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time elapsed between consecutive samples is shorter during the rising hydrograph than the during the falling or recession part of the hydrograph. The protocols for the chemical analyses and interpretation of the data have been developed by the U.S. Environmental Protection Agency and the U.S. Geological Survey for the Nationwide Urban Runoff Program (NURP). The US EPA through its storm and Combined Sewer Pollution Control and Development Program has developed counter measures to control overflow pollution problems. The merits of source control, collection system control storage and control have been examined by Traver (1982). Runoff quality simulation can be performed by mathematical models such as SWMM cited earlier. Baffaut and Delleur (1990) developed an expert system to assist in the calibration of SWMM runoff quality. As for the modeling of the runoff quantity, it is important that the simulation model be verified before it is used to evaluate the excessive pollutant loads and the combined sewer overflow and their effect in receiving streams.

REHABILITATION

The new technological developments that have occurred in pipeline rehabilitation during the last ten years have been summarized by Schrock (1984, 1988). Schrock distinguishes external and internal rehabilitation methods. External methods include chemical and cement grouting. Internal methods include chemical grouting, cement mortar lining, placement of reinforced shotcrete or concrete, placement of fiberglass reinforced cement, cured-in-place-pipe (Insituform) pipe insertion, coatings and linings, mechanical sealing devices, spot (point) repair and replacement.

Chemical grouting is commonly used for sealing leaking joints in structurally sound sewer pipes. Chemical grouting does not improve the structural strength of the pipe. The main types of chemical grouts are: acrylamide gel, acrylate gel, urethane gel and polyurethane foam. These materials provide a good pipe joint that is water tight, flexible, durable and root resistant. Further details about their properties may be found in ASCE-WPCF, 1983. Shotcrete (Gunite) is a mixture of fine aggregate cement and water applied using air pressure. Shotcrete is denser and has higher ultimate compressive strength than cement mortar. It works well in deteriorated large sewers where workers can operate without restriction.

Extensively cracked sewer pipes especially in unstable soil conditions are conveniently repaired using the slip lining technique. This involves sliding a flexible liner of slightly smaller diameter into the existing pipe and reconnecting the service connections to the new liner.

Olson (1986) reported on the study made for the U.S. Environmental Protection Agency on four sewer rehabilitation methods: Insituform lining, test-and-seal, point repair and conventional slip lining. The Insituform lining is a relatively new technique and received more attention. In this technique a thermo-setting-polymer-soaked bag is blown into the existing sewer line, then hot water or steam is used to cure the polymer producing a rigid liner conforming to the original pipe. The liner offers structural stability and thus can be used to rehabilitate badly deteriorated sewers. The test-and-seal procedure uses chemical grout that is injected into the imperfections of the pipe. This method cannot be used in badly deteriorated pipes. In the point repair method, the deteriorated pipe is replaced by a new one and this method is used where the sewer condition is too poor to apply any of the less complete rehabilitation procedures. Conventional slip lining involves the insertion of a slightly smaller diameter pipe inside of the original one. The availability of slightly flexible pipe allows a long length of sewer to be re-lined in one operation. Field studies were performed in Hagerstown, Maryland and in LaGrange Highlands, Illinois and in thirteen other North American sites including vastly different climatic conditions such as those of Winnipeg, Canada and central Florida. It was concluded

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from the study that the Insituform procedure is an advancement in the field of sewer rehabilitation and deserves a great deal of attention.

New advancements which include techniques for reconstructing laterals from inside the pipe and reinstatement of surface laterals by means of a remote controlled robotic cutter have been described by Osborn (1990). Osborn (1990) also describes the use of polyvinyl chloride (PVC) pipe in folded configuration. The material is reheated to make it flexible at the site of installation, and it is pulled into the existing pipeline. After bringing the folded pipe to the appropriate temperature it is pressurized internally to unfold and round out to conform to the existing pipe. Osborn concludes that "the latest advances in sewer reconstruction technologies now allow total collection system renewal using only manhole access points. This includes service laterals as well as mains, collectors, interceptors and manholes."

Counter measures for mitigating hazards to buried pipelines in earthquake prone areas such as California are receiving new attention. From the experience gained in previous earthquakes, Wang (1988) concludes that the pipes failed more in weaker soil, soil liquefaction causes most damage, substantial damage occurs where ground conditions change rapidly, more failures occurred at connection between manhole and pipe, and damage continues to appear several years after the earthquake because the initiation of cracks cannot be detected immediately after the earthquake.

STRATEGIES FOR REHABILITATION

Systematic strategies for rehabilitation and maintenance of urban drainage infrastructure are needed to replace the currently often used crisis management (Weissert, 1989). Karaa (1989) proposes a five-step strategy for the rehabilitation improvement and maintenance of sewer infrastructure. The first step is an inventory of the drainage infrastructure which may be conveniently performed with the help of Geographical Information Systems. These have been discussed earlier in this report. The second step is the maintenance history and failure analysis. This is to track the deterioration and failure trends of the several components of the infrastructure system. As discussed earlier in this paper, simulation models such as SWMM can conveniently be interfaced to analyze the hydraulic and environmental performance and reliability of the drainage system. The third step is the tracking of the effectiveness of the maintenance program and its cost effectiveness. The fourth and key step is the capital improvement strategy for the scheduling of capital improvements under budget constraints. The final and fifth step is the planning and scheduling of the work load. The next paragraphs will elaborate on these last two points.

Several methods of systems analysis have been used for the scheduling of capital improvements of urban drainage facilities. Jacobs and Wright (1989) developed a strategy for the allocation of resources to infrastructure rehabilitation and repair based on the perceived reliabilities and the future deterioration expected in the rehabilitation interval. A sewer inventory and maintenance management system as described by Karaa (1989) was implemented by the Waste Water Division of the Massachusetts Water Resources Authority in 1988.

Expert systems are gradually being implemented to assist the facilities engineer at US Army installations in directing the repair and maintenance of facilities. Expert systems have been proposed to evaluate sanitary and storm sewer utilities. Such an expert system would aid in the determination of the effects of new facility construction on the existing utilities at Army installations and would assist in the determination of adjustments needed to the current system (Williams et al., 1989).

New strategies have been proposed for the abatement of pollution in receiving water bodies due to combined sewer overflows. The reactive strategy, which is the most commonly used, responds to the state of the system as the storm progresses over the catchment. Case studies in which the combined sewer overlfows are minimized by means of in-system storage have been reported by Brueck et al. (1982) and by Ward (1982). Patry and Mariño (1984) extended the strategy to include the predictive mode in which the system is operated in response to its anticipated state prior to the actual occurrence of the rainfall, and in response to both the actual and predicted states of the system once the event has started.

CONCLUSIONS

The rehabilitation of urban drainage infrastructure is an important problem in the United States. The cost of this undertaking is staggering. Failures have been identified as structural, hydraulic and environmental. New techniques of diagnosis of these failures are emerging. Databases and geographical information systems are becoming the common building blocks of strategies for diagnosis and rehabilitation. New non-destructive remote sensing diagnosis methods are appearing, infra-red tomography and ground-probing radar appear to be promising. The use of simulation models such as SWMM are facilitating the task of evaluating both hydraulic and environmental failures. New methods of repair are rapidly being developed as an alternative to the replacement of the sewerage. New methods such as the Insituform are gaining wide acceptance. Techniques of systems analysis, optimization theory and expert systems are becoming the new promising analytical tools for the development of strategies for rehabilitation of the urban drainage infrastructure while taking into account the physical and economic constraints.

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APOGEE 94 - TOWARDS AN OPERATIONAL SYSTEM

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Introduction

The APOGEE 94 program was started in 1985 by the Val de Marne County Council and is made up of many studies at varying stages of development. The main objectives of these studies are to improve sewer maintenance through the early diagnosis and treatment of structural and geotechnical anomalies. Various methods and computer based tools have been developed to help carry out the tasks involved in sewer rehabilition. These include an expert system for the structural and geotechnical diagnosis of the sewer network as well as a decision aid tool for choosing the most appropriate rehabilitation technique.

The expert system was programmed in and on top of prolog on a VAX 750 in collaboration with France's National School of Civil Engineering (Ecole Nationale des Ponts et Chaussées). The system was later ported onto tha IBM personal computer.

Several working groups have been created and charged with the investigation of specific aspects of sewer maintenance and repair. The topica looked at include the causes of structural anomalies (geotechnical, ageing, corrosion etc.), the types of rehabilitaion works possible, the different monitoring and site investigation techniques as well as the general planning and decision process.

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So as to ensure an efficient integration of the APOGEE 94 project a study was conducted with the aim of having a rational use of the information managed by the Val de Marne County Council. A specialised team of sewer workers and technicians has been trained to use different modules of the APOGEE 94 system. Work is continuing on adapting and improving the user interfaces and on extending and validating the knowledge base.

A short history of the project

The Val de Marne County first began to give thought to the process of optimizing the planning of the rehabilitation of sewer networks in the early 1980's. After investigating classical maintenance planning techniques, the idea emerged of developing an expert system approach to both the diagnosis and the rehabilitation of the sewer network. A feasability study was conducted in collaboration with France's National School of Civil Engineering (Ecole Nationale des Ponts et Chaussées).

This first knowledge system was restricted to the diagnosis of the state of repair of the network following geotechnical disorders (MacGilchrist, 1986). The expert system was programmed in and on top of Prolog on a VAX 750.

The knowledge base was provided by an internal expert of the Val de Marne County and was organised in the form of "and/or" rule trees. The expert system, which consisted of approximately fifty rules, was later tested on several hundred sewer sections in a town in the Val de Marne County. The initial results of this test run proved to be promising and it was decided to include a prototype expert system within the APOGEE 94 program.

Several French organisations became involved in the next phase of development of the expert system, these included the Val de Marne County, the Ministry of Urbanism, the Ecole Nationale des Ponts et Chaussées and various research organisations. Study groups were created and charged with the investigation of specific aspects of sewer maintenance and repair. The main objective of these study groups was to produce handbooks on specific aspects of sewer maintenance. The knowledge in these handbooks was later extracted and formalised so as to be in a usable form for the expert system. These rules are of the following form:

IF : Soil slope is greater than 5 degrees

AND Hydrological conditions favour earth slide

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THEN : Topological and hydrological conditions favour earth slides.

IF : Soil mass not protected from infiltration due to precipitation

OR Water flows around the sewer line

OR soil mass is serving as a barrier for suspended groundwater table

THEN : Hydrological conditions favour earth slide

Various organisational factors made it difficult to adopt the rapid prototyping approach to knowledge extraction. This point led to many difficulties which were only identified later during the preliminary validation of the geotechnical knowledge base (Ortolano et al. 1989).

Originally developed on a VAX 750, it was decided to port the inference motor and the necessary human interfaces onto IBM personal computers so as have the option of a decentralised architecture of the APOGEE information system.

The planned architecture of the APOGEE 94 expert system

The APOGEE program is made up of many studies at varying stages of development. When totally operational the APOGEE 94 system should include several knowledge based systems.

(a) An expert system for the diagnosis of the state of repair of different parts of the network, the probable causes of structural anomalies as well as the most likely evolutions.

(b) A decision support system for choosing appropriate manual or automated site investigation techniques, given the nature and quality of the information sought and the local constraints (i.e. size and location of structure).

(c) A decision aid system for planning the necessary rehabilitation techniques and site investigations according to the relative importance of the role of different parts of the network and the strategic objectives of the network managers.

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Dealing with risk and uncertainty

The inference motor developed for diagnosing the state of repair and the likely evolution of the different sewer network elements is capable of dealing with incomplete and uncertain information. The algebra used to propogate uncertainty is based on a form of fuzzy logic (Cohen, 1985), (MacGilchrist, 1986).

Uncertainty considerations were, however, left out of the working prototype of the structural diagnosis expert system because of the complexity of the knowledge base. The long term objective is to incorporate them into the knowledge base once the knowledge extraction procedure has stabilised. The role of uncertainty is likely to be crucial in the elaboration of relevant monitoring techniques as well as in establishing the urgency of a particular rehabilitation measure.

The validation of the geotechnical knowledge base

The first draft handbook on geotechnical issues was produced in early 1988, from which a set of rules was extracted and inserted into the expert system. It was then decided to conduct an exercise in the validation of the the knowledge base. The study had the following objectives (Ortolano at al., 1989);

(a) To evaluate the validity of the rule trees extracted from the first handbook on geotechnical risks

(b) To provide insights into the effectiveness of knowledge acquisition techniques,

(c) To yield a basis for designing the validation method for the entire knowledge base.

The results of the study highlighted the shortcomings linked to the differed validation of the knowledge base. It was decided to adopt a rapid prototyping approach to knowledge acquisition whenever possible (rapid prototyping refers to the practise of immediately testing each "package" of knowledge on real cases directly using the expert system).

The exercise revealed the difficulties linked with making two different disciplines adopt a common language, in this case soil mechanics and geology. It emphasized the need for keeping a regularly updated common dictionary of terms.

The validation study not only lead to the identification of the shortcomings of the expert system but also to a better understanding of the limitations of the existing expertise. The results of the expert system were found to differ with external experts in about 30 to 40 percent of the cases and the knowledge base was found to be lacking in a further 20 to 30 percent of the cases. However, the same level of dissension was found amongst the conclusions of the different experts. The disagreements were found to be due to the existence of information (about the case studies) known only to some of the experts concerned, as well as differences in the reasoning process.

The study group on rehabilitation works

There are usually many possible courses of action open to the decision-maker confronted by a sewer section showing signs of, or under risk of, significant structural degradation. The number of possible actions, as well as the specific constraints associated with them, was at first underestimated by the APOGEE team. An additional study group was therefore created with the following objectives:

(a) To list and describe all the main current rehabilitation techniques

(b) To list and describe all the main current monitoring techniques and methods for detailed site investigation

(c) To explain the reasons which lead to the choice of a particular action (and hence ensure the link with the study groups on structural diagnosis and the decision process)

(d) To list the possible combination of actions associated with different structural risks and states of degradation of the network

(e) To list the constraints associated with each action (geotechnical, structural, level of training etc.)

(f) To evaluate very roughly the efficiency and the duration of the effectiveness of these actions. This was done as much as possible using the vocabulary and criteria provided by the group on the decision process

(g) To give a rough estimate of the necessary investment for each action.

The main objective of the group was to bridge the communication gap between the results of the study groups on structural diagnosis and those concerned with the decision process. A great deal of attention was paid to

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the eleboration of common dictionaries of technical terms. All the terms were defined in a precise and easily transferable manner. Possible ambiguities and common differences in usage were also briefly looked at.

The work of the study group on rehabilitation actions has not yet been completed. Existing results are proving to be fairly reliable and easy to use.

The decision making process

A study group was set up to look at the decision making process of the sewer network managers. Its aim was to search for possible improvements to the existing decision making process and evaluate the opportunity of various decision aid tools.

The type of information used together with the reasoning process which led to the decision to rehabilitate a specific section of network was closely analysed. The nature of the problem was found to be complex for the following reasons:

(a) There was uncertainty in the validity of the technical diagnosis that could be made concerning the likely evolution of the structure as well as the probable causes

(b) There was no clear, commonly accepted method for evaluating the relative usefulness of one section of the network compared to another. Although the functions of the network (flood control, structural stability, water quality etc.) were well identified, there was no method for comparing or combining the different factors which contributed to the "usefulness" of a particular section of sewer

(c) The problem was clearly dynamic, as the nature (asymptotic, linear, step, sudden, gradual etc.) of the evolution of the structure had a strong influence on the types of remedial measures chosen

(d) The duration of rehabilitation works varied from a few days to several years and were therefore not always in phase with financial and administrative procedures

(e) The urgency of remedial and preventive actions varied considerably and consequently placed a great strain on the response time of the decision making procedure

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(f) The substantial administrative and technical investment needed in analysing the rehabilitation problem encouraged decisions to be based more on past actions rather than on a fresh look at the state of the problem.

The study group looked at several decision aid techniques and examined their adequacy for planning rehabilitation works, the monitoring of structures and detailed site investigations. These methods included (Bouyssou et al., 1988):

(a) Cross matrix impact analysis

(b) Multi-attribute utility theory

(c) Outranking techniques

(d) Electre methods

(e) Pertinence trees

(f) Fuzzy logic and endorsement theory

The study group recommended an approach combining pertinence trees and fuzzy logic. This approach consisted in elaborating a set of decision rules of the form:

IF : signs of degradation of the structure are MANIFEST

AND there is a HIGH risk of vertical collapse

AND the structure is CLOSE to IMPORTANT infrastructures

THEN: TEMPORARY consolidation works are URGENT.

The conclusions of these rules can be combined to create rule trees. The advantages of this approach are the following:

(a) It is possible to obtain semantic statements which combine the influence of several factors (the different structural risks, the vulnerability of the surrounding environment, the various roles of the structure in question)

(b) The method provides an efficient and concise way of dealing with uncertainty, ignorance and semantic imprecision (there is no need for the elaboration of a

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complex algebra for combining and propogating uncertainty and imprecision)

(c) The approach to the decision process is modular and hence capable of dealing with changes in the policies and the knowledge of the decision maker

(d) The system only simplifies the decision making process insofar as it provides a series of semantic statements readily accessible to the decision maker.

(e) The meaning of key words like HIGH, MANIFEST, URGENT etc., can be handled by fuzzy logic composition rules to produce meaningful statements.

The proposed decision aid method has yet to be implemented and tested on real cases. It is hoped to incorporate the findings of the study group on rehabilitation works.

Management of the information system

Following the promising results of the prototype expert system for structural diagnosis as well as the advanced state of the methodoligical studies, the study group responsible for the APOGEE 94 program began to look at the various ways in which these results could be integrated into the existing practices of the Val de Marne County Council.

Many actors of the Val de Marne County are directly or indirectly concerned by the inputs and ouputs of the APOGEE 94 system. A study was conducted with the following objectives:

(a) The identification of the types of actors involved according to the roles they played

(b) An exhaustive listing of the types of information used, their origins, the circuits they follow and their final destinations,

(c) The locations and means of storage of each type of information, average turn over period etc.

(d) The identification of the various processes through which information is either transformed or created,

(e) The identification of the interactions between the various actors and the types of information going through the system

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(f) The identification of the various sources of know-how and the means used for transfering it.

The study led to a few unsurprising findings concerning the use of information within the DSEA. A great deal of information was found to be lost at various intersections of the information system, thus leading to decisions being made based on insufficient data. There were considerable differences in the levels of expertise amongst the various departments. There was little exchange or transfer of knowledge and experience amongst the operational bodies.

Following these findings the APOGEE team made the following recommendations for ensuring the proper integration of the APOGEE studies:

(a) Whilst a centralised architecture of the information system would prove useful in the long run it was likely to be difficult to make such a system rapidly operational,

(b) Fast results could be achieved in dividing up the know-how into small packages (knowledge based tools, methodologies, decision aid tools) and distributing it directly to the actors in need of it

(c) Emphasis should be placed on small personal computer systems which encouraged local know how and added to the robustness of the general information system

(d) The transfer of information should be more closely monitored and standardised (use of common dictionary etc.) so as to avoid waste

(e) All proposed tools should be of a decision aid type so as to promote internal expertise and hence the capacity to criticize and improve upon the tools in question

(f) The use of commonly accepted methods was of key importance to ensure the quality of the decisions made.

Making the expert system operational

The geotechnical knowledge base is being run on the entire sewer network. The results are being compared to those of a group of geologists and soil mechanics experts. Large discrepancies still exist between the conclusions of the external experts and those of the expert system (as much as 50 percent of the results differ). These differences are more the consequence of errors in the way data is

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collected and transfered than in shortcomings of the knowledge base.

A specialised team of sewer workers and technicians has been trained to use different modules (data acquisition and structural diagnosis) of the APOGEE 94 system. Work is continuing on adapting the user interfaces so as to ensure better user friendliness and extending and validating the knowledge base.

Conclusions

The first validation study of the geotechnical knowledge base allowed the APOGEE team to not only identify some of the shortcomings of the expert system but also to have a better idea of the limitations of the existing expertise.

One of the most important results of the APOGEE 94 program has been to provide a tool for clearly identifying the level of usefulness of the information collected. Future work should lead to more efficient and effective monitoring techniques as well as the identification of areas where additional research is needed.

It is useful to look at the APOGEE 94 program as an attempt to improve the performance of the information system involved in the management of the sewer system. The problem is essentially one of the efficient and reliable creation, circulation and use of information amongst the various actors concerned.

The division of the APOGEE program into separate autonomous modules is necessary if some of the tools developed are to become rapidly operational.

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SEWERAGE POLLUTION CONTROL: UK RESEARCH PROGRAMME

by R W CRABTREE[1] and I T CLIFFORDE[1]

INTRODUCTION

A recent survey of perceived river quality problems and outstanding modelling needs (Crabtree, 1986) placed controlling urban runoff pollution and non-point pollution in rural areas in the UK as top priorities for the Regional Water Authorities and other responsible agencies. Examination of the changes in water quality between 1980 and 1985 (HMSO, 1986) shows two clear trends. First, the deterioration of previously good quality rural streams particularly in the west of the country and second the persistence of the "poor" and "grossly polluted" watercourses, concentrated around the older industrial conurbations particularly in Lancashire, Yorkshire and the Midlands. The aim of this paper is to discuss the significance and causes of pollution in the second of these; the urban watercourses. In particular, the rôle of urban drainage systems in contributing to river pollution is presented and collaborative research at WRc into urban river pollution control, within the River Basin Management Programme, is described. Upon completion, the products of this Programme (Clifforde et al, 1986) will enable the Water Industry to manage the quality of urban rivers and carry out pollution control measures in a more objective and cost effective manner that has been possible in the past.

BACKGROUND

In the UK the typical drainage system (Figure 1) has a core of combined sewers in the older central area with separate sewers in the suburbs. With such a drainage system, there are three possible sources of pollution.

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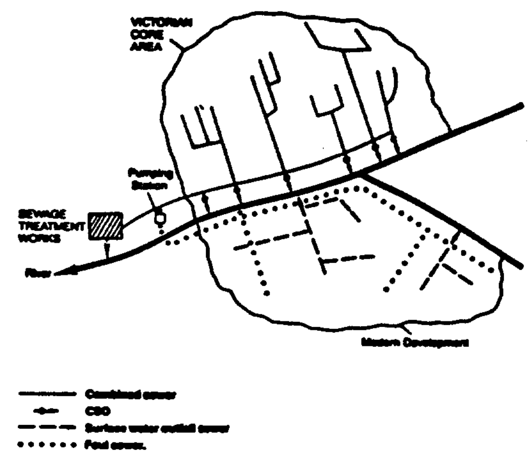

Figure 1. A typical urban drainage system in the UK.

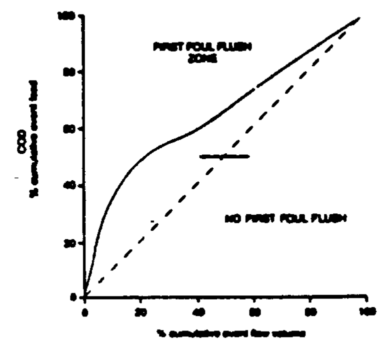

Figure 2. Characteristics of a first foul flush in a combined sewer during storm flow.

These are the discharge from the sewage treatment works itself; discharges from surface water sewers and discharges from combined sewer overflows (CSO).

Many urban rivers are polluted by the continuous discharges of effluent from sewage treatment works and industrial plant. These continuous discharges can be controlled by means of discharge consents, within the legislative framework of the Control of Pollution Act 1974 Part II (COPA II)(Matthews, 1987). Adequate methodologies exist for consent setting (permitting) for continuous discharges which use statistical techniques and deterministic steady state river models.

While a framework exists for controlling continuous discharges, there are at present no similar quantitative methods for controlling storm sewage and surface water outfall discharges.

These discharges are intermittent in nature and the transient pollution they may cause can have both short term (acute) and long term (chronic) effects on the downstream river quality. To date these discharges are consented, within the framework of COPA-II, in a qualitative sense. For example, the consent may be that the overflow or outfall should only discharge during times of rainfall.

Increased public awareness of environmental issues and the privatisation of the Water Industry have highlighted the need for more effective techniques, both for regulatory purposes and for planning and management activities. A major programme of research is under way to address this issue. The River Basin Management (RBM) Programme is funded by the Industry and central government and coordinated by WRc. The present programme is principally directed towards providing a methodology for the Industry to deal with transient river pollution caused by spillage from combined sewers via CSOs. A wider view of all sources of intermittent pollution is also being taken with an emphasis on relating the observed and modelled chemical impacts to ecological effects. This will lead to the development of standards and a classification for intermittent pollution.

While the short term objectives of the RBM Programme are aimed at alleviating river pollution problems associated with storm sewage discharges, in the longer term, the aim is to produce a methodology for integrated catchment quality planning and management. This will provide the Water Industry with a framework for controlling pollution from both continuous and intermittent, discrete and diffuse sources in rivers and coastal areas.

SEWERAGE REHABILITATION: CONCEPT AND APPROACH

The principle objectives of a sewer system are twofold. First, to carry foul sewage and surface water to a suitable point for treatment or discharge without causing flooding. Second, to safeguard natural watercourses from pollution. However, sewers can only be designed to have a finite maximum carrying capacity and therefore, in the case of combined sewers, excess flows during storms are diverted directly into rivers via overflows to avoid flooding. The provision of CSOs as safety valves on combined sewers is necessary since it is not economically viable either to transport or treat the high rates of flow associated with extreme rainfall events. Financial constraints on sewerage expenditure are such that systems of this type are likely to remain in service for the foreseeable future. Over 90% of the UK population are connected to main drainage. Most systems are essentially combined to a significant degree. Some 50% of all sewers were constructed before 1945 (Fiddes, 1986). Consequently the emphasis on capital sewerage expenditure is now directed towards the rehabilitation of these existing systems, rather than towards major new construction schemes.

It is a fundamental tenet of UK sewerage rehabilitation strategy that combined sewer systems, when effectively designed and operated, need not discharge storm sewage with such frequency or of such large volumes as to cause unacceptable pollution of the receiving water. However, the age of most UK systems; the piecemeal way in which they have been extended and the limitations of currently available investigative tools for planning, maintenance and operation, mean that excessive pollution through poorly controlled spillage of storm sewage does occur in many cases. Engineers have been handicapped in their efforts to alleviate these problems cost effectively by a considerable degree of uncertainty with regard to both the operation of these overflows and the consequences of the discharge of storm sewage to receiving streams.

At present the effects of CSOs on rivers in the UK cannot be accurately quantified, nor is it known if these effects are increasing or decreasing. However, CSOs are seen to be a major contributing factor to the unsatisfactory quality of many urban watercourses (North West Water, 1983). To a certain extent the true impact of intermittent CSO discharges on rivers may be masked by the effects of continuous discharges. In many cases, schemes aimed at improving river quality by controlling continuous discharges have not achieved their expected results. At many locations the effects of intermittent CSO discharges have been recognised as having a dominant

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controlling influence on river quality as determined by biological monitoring, which may be considered to be a time integrated assessment. Such rivers may be capable of achieving their quality objectives in terms of sampled chemical parameters and corresponding classification (NWC, 1978) but are nevertheless still unsuitable for their designated use.

Traditionally CSO setting, in the UK, has been based principally upon sewerage orientated criteria by considering the desired or practicable maximum carry on flow in the sewer. Flows in excess of this capacity have been discharged to watercourses without due consideration of the assimilative capacity or desired quality. This approach led to the establishment of fixed criteria, such as multiples of the dry weather sewer flow. For example 6X DWF has been commonly used as the desired carry on flow to treatment. This approach makes no allowance for variations in the strength of crude sewage between sites, nor the dilution ratio of the receiving watercourse. The "Formula A" approach (HMSO, 1970) is an extension of this concept which allows some subjective variation in setting depending on sewage strength.

"Formula A" is expressed as:-

required carry on flow = DWF 1350P + 2E

where

DWF = dry weather flow in sewer
P = population
E = industrial discharges

The flows are expressed in terms of litres per day.

In the UK, this is probably the most extensively used criterion for the design of recent CSOs. It would seem to be reasonable to assume that river pollution would be significantly reduced if all CSOs operated in accordance with this setting, although many "blackspots" would still exist. However, many CSOs currently operate at or near dry weather flow. In addition, "Formula A" takes no objective account of the sensitivity of the receiving water and this can lead to unsatisfactory performance, particularly where CSOs discharge to small urban streams.

The other major aspect of CSO design and operation is the incorporation of storage. Storage improves performance in two ways. First, for a given spill event, the volume of spill is reduced and second, the frequency of spill events is reduced. Storage is a relatively simple and cost effective way of reducing CSO pollution by keeping more flow within the sewer. However, the

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consequent increase in treatment costs that are likely to arise from greater flows passed to treatment must be recognised.

Monitoring of changes in the quality of sewage during storm events has indicated that there can be marked temporal variations in the strength of sewage (Thornton and Saul, 1986). Many combined sewer systems have been shown to exhibit a marked "first foul flush" of pollutants at the onset of storm flow, as illustrated by Figure 2. Obviously, the spillage of this highly concentrated sewage could be extremely damaging to the environment. Incorporating storage into CSOs can be an effective means of retaining the "first foul flush". Guidelines have been produced for the design of such storage overflows, which attempt to store the first flush and spill the subsequent, cleaner storm water (Ackers et al, 1968). However current data suggest that the "first foul flush" phenomena can be highly variable and this brings into doubt the validity of such criteria for producing satisfactory SSO performance, in terms of its effect on the receiving water.

The WRc/WAA Sewerage Rehabilitation Manual was produced in the early 1980s to address the UK Water Industry's needs in respect of maintaining and upgrading the performance of sewer systems. The first edition (WRc/WAA, 1983) was mainly concerned with the hydraulic and structural upgrading of sewerage systems. However, it recognised that pollution of receiving waters due to CSO spills was a significant problem and that in many cases past practice, such as the use of "Formula A", had provided inadequate means of ensuring the satisfactory performance of combined sewer systems. At that time it was felt that the technology then available only gave limited scope for improvements over the traditional approach.

SRM-II, the second edition of the Sewerage Rehabilitation Manual (WRc/WAA, 1986) provides an Interim Procedure for the control of pollution from CSOs, pending the development of more robust techniques by the RBM Programme. The philosophical approach behind the interim and eventual methodology is that, while existing sewers can only carry a finite maximum rate of flow, a river can only accept a certain maximum amount of storm sewage if its quality objective is to be achieved. Hence, surplus storm sewage must be stored within the sewerage system or diverted elsewhere. Associated with this concept it is argued that efficient hydraulic design of CSOs will significantly reduce the problems of aesthetic pollution caused by the spillage of large objectionable solids and their subsequent

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stranding within watercourses. There are three main recommendations for the rehabilitation of CSOs. These are (WRc/WAA, 1986):

(1) The selection of an appropriate location for relief of an overloaded sewerage system and the capacity of the receiving watercourse to accept the resulting discharge.

(2) The setting of the CSO to fully utilise downstream hydraulic capacity within the sewer and to minimise the spillage.

(3) The efficient design of each CSO to ensure effective hydraulic control and the maximum separation of gross polluting matter.

Individual CSOs should not be considered in isolation but in combination for each sewerage system. This can only be carried out by using a sophisticated hydraulic model of the sewer system, such as WASSP-SIM (NWC/DoE, 1981). Past practice to alleviate sewer flooding has resulted in large numbers of small overflows which often discharge to fairly minor watercourses. Cost effective rehabilitation may be achieved by combining groups of small CSOs into a single large modern structure.

The Interim Procedure employs approximate methods and makes general assumptions to provide a usable methodology which must be applied with a substantial degree of judgement. However, this represents a significant advance over past practice. The method permits estimates of CSO spill volume and polluting load to be established. These can then be compared to the assessment of the assimilative capacity of the receiving watercourse.

PRODUCTS OF THE WRc RIVER BASIN MANAGEMENT PROGRAMME

The initial objective of the programme is to develop rational methods for sewerage rehabilitation by permitting the effective design of CSOs and associated storage requirements to control river pollution. For scarce capital resources to be employed to the best effect, a rigorous working methodology is required which recognises both the limitations of the sewerage system and also those of the receiving water. To this end 5 major products have been identified as being necessary to allow the objective planning of discharges from both CSOs and the less polluting but still significant surface water drainage systems. These are:-

(i) appropriate rainfall inputs to simulation models;
(ii) a sewer flow quality simulation model;
(iii) a river impact model;
(iv) a river quality performance classification system which recognises the significance of intermittent pollution events;
(v) assessment of engineering designs for CSOs.

This section outlines the progress and ongoing developments in each of these five areas.

1. Rainfall Time Series for Sewer System Simulation Modelling

The objective of this work was to produce an annual series of fine resolution, historic rainfall data for use with the WASSP-SIM sewer hydraulic analysis model (NWC/DoE, 1981). The traditional approach to the use of sewer flow models has embodied the concept of design storms of standard profile and of a return period equal to the frequency with which exceedance of hydraulic capacity could be tolerated. While such design rainfalls represent extreme events they give little indication of the day to day performance of the sewerage system. To assess the performance and polluting impact of CSOs, the magnitude, frequency and duration of spills are required over a long time period, such as a typical year. This can be carried out using a flow simulation model, for example WASSP-SIM, by inputting a temporal sequence of rainfall events. Such a sequence, termed Time Series Rainfall (TSR) has been produced (Henderson, 1986). Several comparatively crude series, each representing a typical year, have been statistically synthesised for regions of the UK. These series, in effect 1 year design rainfall sequences, are considered to be acceptable tools for the investigation of CSO performance and now incorporate techniques for adapting the regional TSR to local circumstances.

2. MOSQITO - A sewer flow quality simulation model

MOSQITO is the initial version of a sewer flow quality model which is being developed by Hydraulics Research Ltd and the Water Research Centre. MOSQITO will simulate the time-varying behaviour of suspended solids, biochemical oxygen demand, chemical oxygen demand and ammoniacal nitrogen on catchment surfaces and in sewer systems. The model produces discharge pollutographs for these determinands which can be used as input to a river water quality model. A pollutograph approach has been adopted due to the sensitivity of receiving waters to short term variations in pollutant concentrations and the need to plan cost effective rehabilitation works.

MOSQITO consists of four sub-models which represent washoff from catchment surfaces, foul water inflow, pollutant behaviour in pipes and channels, and pollutant behaviour in ancillary structures within drainage systems. These sub-models are linked to the flow simulation model incorporated in the WALLRUS package This is the successor to WASSP-SIM. Calibration and verification of the model are being carried out using data from a variety of experimental catchments in the UK. These catchments have been selected to exhibit a wide range of characteristics and include separate and combined sewer systems.

The surface washoff model represents the removal of sediments and pollutants from catchment surfaces using a modified form of the model proposed by Price and Mance (1978). The effects of gully pots are not modelled explicitly but have been taken into account during calibration. Studies of sediment and pollutant behaviour in the UK suggest that the amount of material washed off catchment surfaces by rainfall is independent of the length of the antecedent dry period. MOSQITO, therefore, assumes that the amount of material available for washoff is unlimited. Pollutants are associated with sediments by the use of potency factors. There are potency factors for soluble and insoluble fractions, which are subsequently treated separately in the below-ground model. Sediments can be eroded from the catchment surface by raindrop impact, and eroded or deposited by overland flow. The relative importance of these processes has been determined by calibration. The foul flow sub-model FOUL, is a separate program based on the statistical analysis of data collected from nine catchments served by combined systems, plus additional data from sewage treatment works. Flow quantity and quality are calculated from catchment land use, population, and "connectivity" (the degree of separation in partially combined systems) using annual average values for flow and for each pollutant. The calculated flows and their quality are then adjusted using a set of time dependent factors which take account of hourly, daily and seasonal variation.

In the below-ground model, pollutants and sediments from the catchment surface are mixed with those from the foul flow and transported through the drainage system. Additional pollutants and sediments are derived from re-entrainment of sediments previously deposited in the system. The quantity of deposited sediment and its physical and chemical characteristics are defined by the user in the input data. Pollutants in the below-ground model are dissolved or attached to sediments by potency factors, as in the above-ground model. All pollutants

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are modelled as conservative because storm flows generally pass through sewer systems quickly enough for biochemical changes to be insignificant. The sediment transport rate in MOSQITO I is determined using an adaptation of the Ackers-White sediment transport model (Ackers, 1978). Sediment deposits in pipes are modelled as two types:

(a) an active layer on the pipe invert in which sediment is unconsolidated;

(b) a storage layer on the pipe invert in which sediment is consolidated and exhibits a cohesive shear strength.

Although most of the MOSQITO sub-models are physically based, there are a large number of parameters which require calibration. Other models in the Wallingford Procedure have been pre-calibrated for use in the UK, and this has been of considerable benefit to users.

3. CSO River Impact Assessment Techniques

It is envisaged that there should be a range of modelling methods to assess the effect of intermittent CSO discharges. This will enable the appropriate level of modelling effort to be applied to a particular situation. The current models are CARP and SPRAT.

Sophisticated simulation models such as MOSQITO and SPRAT are the major products of the RBM Programme. However, interim tools are required prior to their general availability. CARP (Comparative Acceptable River Pollution) was developed as such a tool. The lack of available river flow and time of travel data coupled with an absence of suitable criteria to assess CSO pollution performance have also hindered the development of the simulation models.

In areas where CSOs are known to cause the receiving watercourse to fail its quality objective, the SRM-II interim procedure is used to calculate the spill load for each overflow on an annual and event basis. The CARP procedure is used to calculate acceptable CSO spill loads to individual river reaches by comparing the pattern of load input rate per event with a reach which, whilst significantly affected, is not considered to be unacceptably polluted by CSO inputs, i.e. attains its designated quality objective despite CSO spills. The comparative statistic used is expressed in units of kg pollutant load spilled per event from all SSOs in a reach per km reach length per Ml per day base flow. The use of a comparison of input rates is only valid for

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rivers with similar characteristics. This assumes that acceptable spill loading rates implicitly include an assessment of the river's capacity for pollution assimilation and self-purification within each reach. CARP avoids the need to specify recurrence frequencies for overflows and allows greater flexibility in design and planning by looking at individual reaches to identify where available capacity may exist in a river system or where the capacity is exceeded.

To assess and verify the performance of the CARP procedure, a field study exercise is under way on the River Roch, in North West England (Figure 3). A recently completed sewerage rehabilitation scheme for the small town of Littleborough involved the closure of 8 small CSOs on the Roch and the construction of a new large overflow structure. It was anticipated that the rehabilitation scheme would result in an improvement in the quality of the Roch from Class 2 to Class 1B above the new overflow. However, it was important that the increased flows to the new overflow did not cause a deterioration in river quality downstream. Hence, a volume of storage was to be included in the new overflow structure. Following previous practice, the new overflow was originally designed with 2800m³ of storage installed as a tank located downstream of a high side weir. This volume was calculated from the method of Hedley and King (1971) based on 25% of the demi-hydrograph produced by a design storm of 90 minutes duration and with a return period of 2 years. However, application of the CARP procedure (Parkinson et al, 1989) suggested that a storage volume of only 1500m³ would enable the current downstream quality to be maintained (Figure 4). Due to the potential construction cost savings this revised design has now been constructed and the new overflow is fully operational. The performance of the overflow and river quality are being monitored for a two year appraisal period to check the performance of the CARP based design.

Continuing on from CARP, the development of the river impact model SPRAT (Spill Pollution Response Assessment Technique) has been governed by two constraints. These were that data requirements should be kept to a minimum; and all significant processes affecting river quality should be simulated. In many cases a balance has had to be struck between these two constraints. Care has been taken to ensure that the trade off between data requirements and process simulation accuracy can be adjusted in future versions of the model.

A fundamental decision in developing a model is the choice of the modelling framework. There are two

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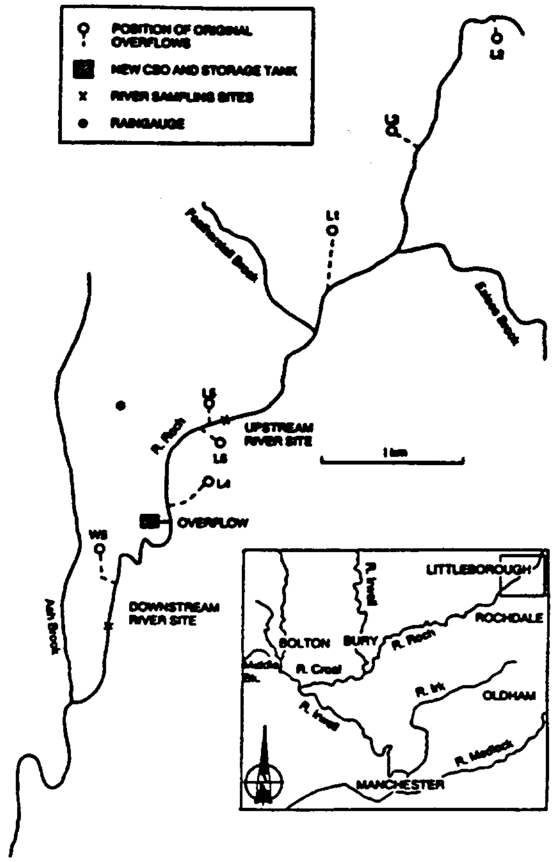

Figure 3. River Roch at Littleborough.

modelling frameworks which can be adopted, either design or forecasting. In the forecasting algorithm, the unknown values are calculated sequentially for all spatial points at a given time. With the design algorithm, the unknown values are calculated sequentially for all relevant times for a given spatial point. SPRAT has used the latter modelling framework. This enables pollutographs and hydrographs to be easily produced for the complete time range of the storm event. Consequently, the model can compare the simulated concentration/duration of a pollutant below a discharge with intermittent river quality standards as it steps along the river system. The model can therefore be used to estimate the required storage within the sewerage system to enable the designated intermittent standards to be met. The main drawback in adopting the design algorithm is that the model is not capable of predicting the backwater effects of control structures. SPRAT has four major components, flood routing, pollutant routing, sediment interactions and biochemical processes.

Two flood routing options are available in SPRAT, either fixed or variable Muskingham-Cunge (Price, 1985). Both methods adopt a fixed four point time and space Eulerian grid to solve the unknown discharge. The stability of the two methods is related to the spatial and temporal steps adopted in the model. A simple equation has been developed to predict suitable values. Headwater and contributing catchment hydrographs are calculated using the unit hydrograph method (NERC, 1985). During high flow conditions, pollution transport is dominated by advection rather than diffusion, or biochemical reactions (Bedford et al, 1983). Therefore, tha need for an accurate solution of the advection term was fundamental in the selection of a solution method for pollutant routing. Pollutant routing in SPRAT is solved using a Lagrangian reference frame. This approach tracks parcels of water as they are moved through the velocity field, defined by the Eulerian reference frame created by the flood routing solution. Dispersion is solved using a simple explicit finite difference approximation. An analysis of various numerical solution algorithms for the transport equation concluded that Lagrangian algorithms effectively eliminated both numerical dispersion and solution oscillation problems (Sobey, 1984). Fourier analysis showed that very simple Lagrangian algorithms can be very accurate, compared to the conventional but relatively complex Eulerian algorithms.

The application of an early pseudo-dynamic version illustrated the need to take into account the release of pollutants from river bed sediments during high flows.

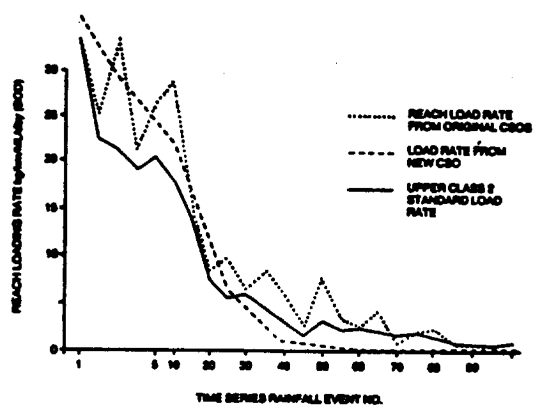

Figure 4. CARP loading rate curves for River Roch.

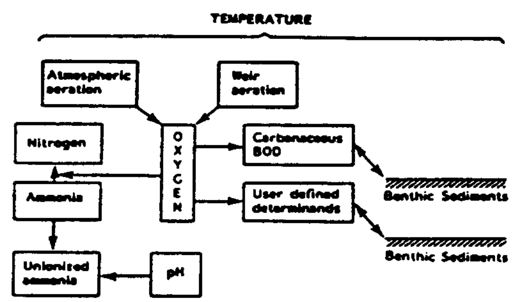

Figure 5. SPRAT deterministic processes.

The present version of SPRAT uses conventional, non-cohesive sediment transport theory (Ackers-White, 1973) to calculate the possible concentrations of sediment within the flow.

The deterministic process interactions in SPRAT are shown in Figure 5. At present, the following determinands are simulated: BOD_5, dissolved oxygen, ammonia, temperature and pH, plus the option of two further user defined determinands. The decay of BOD_5 and ammonia are represented by first-order rate decays. The concentration of these two determinands can also be influenced by the settling and resuspension of sediments. The re-aeration rate can be calculated from a selection of formulae. The influence of weirs on dissolved oxygen concentration has also been included.

To apply the model, the river system is split up into a number of reaches of similar hydraulic characteristics. A reach may contain a number of river features, such as weirs, continuous discharges and intermittent discharges. The model begins at the primary headwater. The distance to the next river feature, or the end of the reach, is split into computational steps. The length of these steps depends upon the stability of the flood and pollutant routing numerical solutions.

At the headwater, all the flows over the simulation period are calculated using the unit hydrograph approach. The downstream flow values on the fixed time Eulerian grid are calculated using a four point Muskingham-Cunge solution. The velocity at each of the grid points is obtained from a flow/velocity relationship. The pollutant parcel is then routed through the described velocity field. The associated dispersion for each determinand is then estimated using the previous, original, and subsequent upstream pollutant parcels.

A sediment load calculation is carried out for the linked upstream and downstream pollutant parcels. The difference is either entrained or deposited, with an associated loss of pollutant. The final step is to estimate the changes in determinand concentrations due to the biochemical reactions over the time period of the spatial step.

The solution steps are repeated until the whole river system has been simulated. At a confluence, upstream values can be stored while the tributary stream is simulated. A time/concentrations graph for a point in the river system can be plotted as the model simulation passes that point.

4. A River Quality Classification for Transient Pollution

In order to produce a fully objective procedure for controlling pollution from CSOs, a classification framework is required within which the transient pollution resulting from CSO discharges may be related to the designated quality objectives of the receiving water. The present river quality classification system (NWC, 1978) is based around the compliance of routine monitoring samples with probabilistic river quality performance criteria. This approach does not consider short duration pollution episodes, which may effectively limit the river biota, yet only occupy a very restricted time period. The quality objectives for receiving waters are primarily related to the uses to which those waters are to be put. Uses may range from the supply of water for a variety of purposes, through fisheries and other biological aspects to amenity considerations. The significance of transient inputs of pollution will vary for each potential use and this must be reflected in the classification system that is developed.

A programme of research has been initiated (Bowden and Solbe, 1986) to investigate the relationship between acceptable concentrations of various pollutants for long and short term exposures and also the recurrence interval, or recovery period between exposure to various levels of pollutants. The end result is anticipated to be a classification matrix of criteria, related to the potential for use, pollutant concentration, duration and frequency for the major polluting determinands. This concept is based on pollutant levels permissible for a given exposure time and return period. The development of these standards requires a considerable amount of eco-toxicity testing, particularly to address the dimension of frequency of recurrence. While this work is being carried out, an interim standard approach has been adopted for use with the existing one year TSR technique. The aim is to propose magnitude and duration values (1 hour and 24 hours) with a one year return period which would not cause mortality in coarse fish.

5. Assessment of Engineering Designs for SSOs

The modelling tools and standards, as described previously will enable engineers and planners to assess quantities, qualities and frequencies of CSO spill and their associated river impact. However, these acceptable water quality planning performance criteria have to be translated into engineering designs for CSO structures. Such structures should be self-cleansing; should achieve the desired hydraulic control; should offer the best

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possible performance in terms of separation of gross, aesthetically polluting solids; and should be free from operational problems. Also when considering rehabilitation schemes, new structures must be capable of integration with existing infrastructure.

In the UK the favoured overflow structure types are the high side weir, the stilling pond and the vortex (Balmforth and Henderson, 1988). The performance of these structures has been extensively investigated at the laboratory model scale. However, few studies have investigated the "as built" field performance. Several evaluation projects are now in hand to address this deficiency, particularly the performance of vortex types. A gross solids monitor, developed by WRc, is being used to assess the gross solids separation efficiency of several designs. Self-cleansing is also being studied.

UK experience with overflows, particularly those which include any form of mechanical plant has lead to a wide divergence of opinion as to the value of any form of pre-spill treatment within the structure. Where necessary, such as on high amenity value receiving waters, overflows should be constructed for ease of access for operational or maintenance activities. This should help to overcome often severe operational difficulties. Spill event and telemetered level sensing instrumentation packages can be highly effective guides to overflow performance and maintenance.

NEW DEVELOPMENTS: SEWER SEDIMENTS RESEARCH

In the five years since the RBM programme was initiated, new areas of investigation have been identified which offer significant potential benefits in assessing and improving the performance of CSOs. First, as part of the overall sewerage rehabilitation process, the performance of CSOs needs to be considered in relation to the local sewage treatment scheme. Sewerage rehabilitation schemes, which incorporate storage may significantly alter the magnitude and pattern of sewage loads received by the treatment plant. The effect this may have on the efficiency of the treatment process needs to be carefully considered.

Further areas of investigation include the integration and optimisation of the sewerage and the sewage treatment systems to fully account for the requirements of the receiving water. This is particularly pertinent to storm flow conditions. Where possible options could include full or partial treatment, in-plant storage or direct overflow. To assist in this integration, a

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dynamic sewage treatment works simulation model (STOAT) is being developed. Also it seems likely that the models, initially developed for rehabilitation scheme planning and design, will lead to future operational models to regulate plant performance to match the varying assimilative capacity of the receiving water course.

Following on from the need to integrate the performance of sewerage and sewage treatment systems, the research programme has recognised that there may be potential economic and environmental benefits in the application of real time control techniques. Such technology offers a means to optimise the performance of the integrated system. As a first step in this direction, research is under way to assess the likely magnitude and cost effectiveness of such benefits.

Perhaps the most significant new development in the RBM programme has been the recognition of the significance of sewer sediment deposits. This has arisen from experience in the development of MOSQITO and the greater understanding of the behaviour of pollutants within sewer systems, which has resulted from the extensive data collection programmes. A recent survey suggests that up to 25,000km of sewers in the UK are affected, to some degree, by in-pipe sedimentation (CIRIA, 1986). Sediment deposits in combined sewers may decrease the level of performance of the system by reducing hydraulic capacity, which may lead to surcharge, flooding and premature operation of storm sewage overflows. In addition, the discharge of pollutants associated with sediment deposits during storm events may result in greater pollution of water courses.

Current sewerage design practise is based on the concept of self-cleansing velocity. However, design methods which incorporate non-cohesive sediment transport theory may be inappropriate for real sewer sediments. Evidence suggests that typically up to 80% of the gross pollution load discharged from a sewer system may be derived from the erosion of in-pipe deposits. Hence, it is necessary to understand the in-sewer processes and mechanisms related to the production of this pollutant load to produce an effective sewer flow quality model.

Therefore, for the hydraulic design and pollution alleviation aspects of sewerage rehabilitation, and also sewerage operations, greater information is needed to define the fundamental nature and characteristics of combined sewer sediment deposits. Sediment observation coupled with sampling for physical and chemical analysis has been used to produce a five category classification of types of combined sewer sediments (Crabtree, 1988). These categories are based on visual appearance and location within a sewerage system. Each category has distinctive characteristics in terms of composition, nature and polluting potential. The categories are:-

TYPE A Coarse, predominantly granular mineral material found in the invert of pipes.

TYPE B Similar in composition to Type A but concreted by the addition of mineral cements, fats and tars.

TYPE C Mobile, fine grained, largely organic sludges found in quiescent zones.

TYPE D Organic pipe wall slimes and zoogloeal biofilms.

TYPE E Fine grained organic and mineral deposits found in storage tanks.

Type C and Type A deposits are considered to be the most significant sources of pollutants. The resuspension of Type A deposits may be the cause of the high pollution loads often associated with extreme rainfall events. Type C deposits are believed to be the source of material discharged during the frequently observed "first foul flush" in many sewerage systems. Type A, Type B and Type E deposits are the most significant in terms of restricting sewer flows and hence their removal is a common operational requirement.

Whilst initial efforts have concentrated on the physical and chemical characteristics of combined sewer sediments it was recognised that real sewer sediments, for example, Type A deposits, contain significant amounts of "dirty" organic material which may stick particles together to give a cohesive deposit. Such a deposit may have a higher critical yield stress and hence require a higher bed shear stress to initiate erosion than for a similar but non-cohesive deposit. Therefore, conventional design criteria may be inappropriate for predicting sewer sediment erosion and the establishment of self-cleansing flow conditions. Other studies have reported that sediment cohesion and consolidation processes are time dependent and also that they exert a significant influence on the erosional behaviour of sewer sediments.

Cohesive sediment transport theory is commonly applied in marine and estuarine engineering and rheological characteristics are commonly used to describe the behaviour of cohesive sediment deposits and, in

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particular, the cohesive strength of a sediment deposit. Rheological characteristics, such as the critical yield stress for erosion, offer parameters to measure the strength of resistance to deformation and flow (erosion) of cohesive materials such as the different types of identified sewer sediment deposits. In particular, information on these properties is required in order to carry out representative experiments to assess the effects of cohesion on the erosion of sediments in laboratory pipe/flume experiments. A preliminary investigation into the rheology of sewer sediments showed such materials to be complex cohesive, non-Newtonian, visco-elastic materials. Materials with similar chemical characteristics and appearance exhibited markedly different values of critical yield stress as shown in Table 1.

The rheological testing results indicate the danger of relating erosional shear stresses to the bulk density of the bed as in the case of non-cohesive sediment transport. For cohesive sewer sediment deposits, the onset of erosion, for a given inter-facial shear stress, is more likely to be related to the rheological properties of the surface layer of the deposit.

Table 1 - Measured values of critical yield stress for sewer sediments

SEDIMENT TYPE	CRITICAL YIELD STRESS (N/m^2)
A	800*
A	620
B	800*
A	400
A	425
C	98
E	200
E	25

* Indicates that the sample had not failed at the maximum instrument reading.

Characterisation of real sewer sediments has also permitted the development of synthetic sewer sediment for use in laboratory flume experiments. Further investigations are required into the magnitude and causes of cohesion in real sewer sediments and the behaviour of such materials in the hydraulic régime of sewer pipes. Current field studies and in situ sensor

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development will provide much of this fundamental data and develop procedures which overcome problems of sampling disturbance in the sediment structure. The results of these studies will be incorporated into the next phase of MOSQITO development (MOSQITO-2, due for release in 1992) and will hopeful significantly increase the reliability of model predictions.

Research is also under way to assess the behaviour and polluting significance of CSO discharged sediments on river quality. Again the results of this work will eventually be incorporated into updated versions of the SPRAT model.

CONCLUSIONS

Five years experience in the assessment of CSO performance and river impact has advanced knowledge considerably. This has largely been due to the integrated and coordinated nature of the UK River Basin Management Programme. There is, however, still much to be achieved. In particular, understanding the characteristics and behaviour of sewer, and sewer derived in-river, sediment deposits has been shown to be crucial to the development of reliable simulation models.

The main tenet of the RBM approach is to develop methodologies to permit the cost-effective transport and treatment of sewage under storm and dry weather flow conditions and equally importantly enable prescribed quality criteria to be achieved in the receiving water. Significant progress has been made in the last five years and there seems every reason to expect similar progress in the next few years.

ACKNOWLEDGEMENTS

This paper is published with the permission of the Director of WRc. However, the views expressed in the paper are those of the authors and not necessarily those of WRc.

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RESEARCH NEEDS IN URBAN HYDROLOGY

by Harry C. Torno,[1] M. ASCE

Introduction

As a part of each Engineering Foundation Conference conducted by the ASCE Urban Water Resources Research Council (UWRRC), it has been the practice to have a session devoted to an examination of current research needs. This has been done in order to provide guidance to the research community in identifying those areas where practicing professionals believe the greatest problems still exist. This Conference was no exception. Midway through the Conference, the participants were each asked to make a list of the two or three research needs that they considered most important. These were compiled by the author, and the compilations formed the basis for a discussion held at the last session of the Conference.

Research Needs

The following is a list of the research needs identified by conference participants, in their order of priority. The number in parentheses indicates the number of "votes" received for each need.

(a) Receiving water impacts, including development of receiving water quality standards (9).

(b) Real-time monitoring techniques, including water quality, flow, and treatment plant operational parameters (6).

(c) Effects of wet-weather flows on treatment plant performance (5).

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(d) Rehabilitation of urban streams - techniques for restoring capacity and aesthetic appeal (4).

(e) Pollutant transport and transformation mechanisms in sewers (4).

(f) Evaluation of the performance of CSO treatment devices, and the costs/benefits of CSO treatment (3).

(g) Effects of infiltrated runoff on the environment (groundwater, water supplies, etc.)(3).

(h) Review/Comparison, on a worldwide basis, of storm and combined sewer regulations and standards (3).

(i) Techniques for source control of runoff-associated pollutants (2).

(j) Development of techniques for using existing rainfall data for design purposes, including the statistical analysis of weather service records and the applications to design(2).

In addition, the following items received one vote each.

o Evaluation of the effectiveness of best management practices (BMP's)

o Service life of sewers and techniques for their rehabilitation

o Effectiveness of stormwater treatment, and appropriate techniques to be used

o Large-scale studies to determine performance and impacts of urban runoff control/treatment systems

o Effectiveness of flow prediction on improvements in real-time control systems performance

o Effects of non-uniform rainfall on system performance

o Quantification of uncertainties in measurements and modeling.

o Evaluation of ecological impacts of combined sewer overflows

The list is similar in many respects to other such lists compiled in the past. As before, receiving water

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impacts head the list, possibly reflecting the relatively low level of knowledge about such waters and the effects on chemical and biological water quality of pollutant discharges into them. Moreover, it reflects the fact that it will be virtually impossible to sample and regulate discharges (establish discharge criteria that will apply to all discharge points - witness the current difficulties in the U. S. in promulgating stormwater discharge regulations), and that we therefore need better knowledge about which parameters to monitor, whether stream biota criteria would be better, and whether appropriate indicator organisms can be found to aid in receiving water quality monitoring.

Two new needs were the next highest in priority. They were research into real-time monitoring techniques, and research on the effects of wet-weather flows on treatment plant performance. Both, in my opinion, reflect the fact that we are beginning to implement new techniques for the control of pollution from storm and combined sewer discharges, and find ourselves lacking basic information on which to evaluate system performance. Studies in Denmark, for instance, suggest that treatment processes, and particularly the final clarifiers, will have to be modified if treatment plants are to treat large volumes of combined sewage. This will require not only research into the processes themselves, and particularly how effective they are in removing other than "conventional" pollutants, but also into the techniques used to measure their performance and make appropriate adjustments to correct operational problems.

A related item was further research into the treatment efficiency of end-of-pipe treatment devices. Specifically, we need to know the ratio

$$\frac{P_1}{P_2}$$

where

P_1 = Annual load with treatment
P_2 = Annual load without treatment

for such parameters as TSS, VSS, BOD, N_{total}, P_{total}, orthophosphate, and selected toxic contaminants.

Another new item on the list is the rehabilitation of urban streams, which means research into the techniques for restoring degraded urban watercourses to either their original condition, or to a condition that is ecologically and aesthetically satisfactory. This includes not only the prevention of unwanted erosion, scour and sediment deposition, but also into methods for regaining some of their aesthetic and ecologic qualities and contributing to water quality enhancement, while at the same time retaining their flood-carrying capacity (which is why the streams were modified in the first place).

It is interesting to note that techniques for controlling urban runoff pollutants at their source received only 2 votes. It was nevertheless my opinion that the sense of the group was that 1) source controls were very desirable, and 2) that more research was needed into practical and socially-acceptable means of implementing those controls.

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NEW SOLUTIONS IN WASTEWATER TREATMENT

by Ursula Kaufmann[1]
and Walter E. Nill, Dipl.Ing.ETH/EPFL[2]

STORMWATER TREATMENT

Treatment of Stormwater has always presented a problem to treatment facilities. Shortly after a heavy rainfall a large volume of polluted water needs to be treated. In most cases the treatment facility can not handle this large flow of water occurring during a short time, and in the past stormwater has been dumped into the backwater without any treatment.

This is especially adverse in a situation where a combined stormwater/sewer system is used and a significant amount of untreated/unfiltered sewer reaches the backwater.

New systems described in this report use a buffer/sedimentation basin to retain the stormwater. A regulated gate assures a constant flow out of the basin to the treatment facility.

Due to the low velocity in the basin a sedimentation of the heavier particles occurs. Floating matter can be retained by separator walls or screens. Overflowing water is free of unaesthetic particles.

Three types of retention/sedimentation basin are used:

1) Simple Buffer Basin.

2) Buffer Basin with protected overflow.

3) Buffer Basin with Screening System.

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SIMPLE BUFFER BASIN:

Stormwater flows to the buffer basin and is collected. The volume of the basin has been calculated based on rainfall amount and area of collection. A regulated gate limits the flow to the treatment facility to a constant value.

The basin acts as a buffer between the stormwater system and the treatment facility. If the basin volume is sufficient, no water needs to be dumped into the backwater.

After all the water in the basin has flown to the treatment facility, the basin is empty and it is cleaned by an automatic dump flush apparatus.

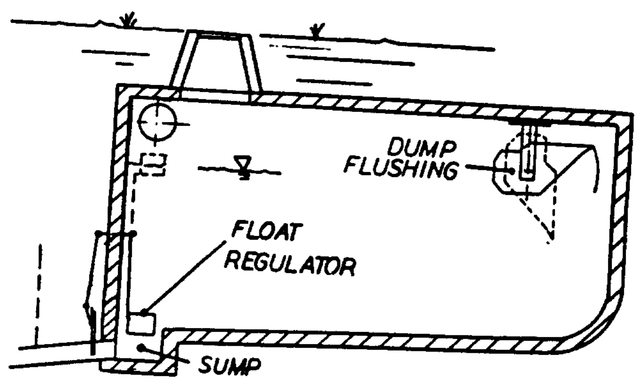

Figure 1: Retention Basin

SELECTION DIAGRAM DUMP FLUSHING

The size of the Dump Flushing Apparatus can be determined based on :

- o Cleaning range [m]
- o Dumping height [m]
- o Slope of basin floor [%]

The example below finds a dump capacity of 700 [l/m]

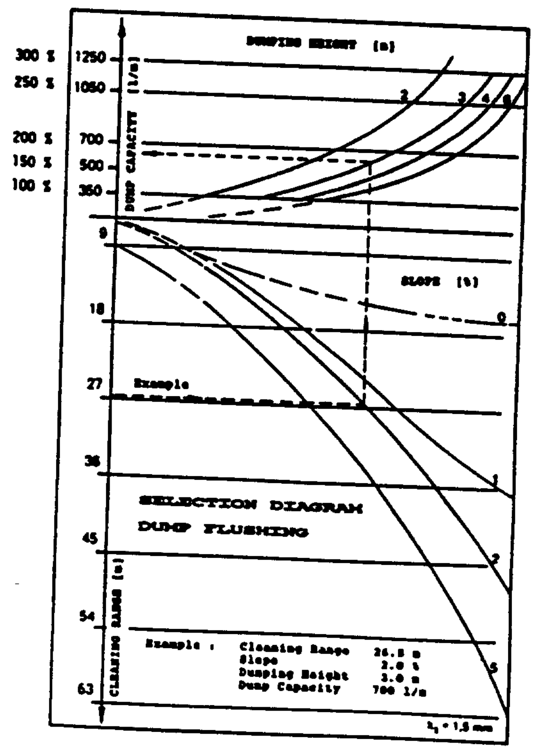

Figure 2 : Selection Diagram for Dump Flushing

FLOAT CONTROLLED REGULATOR GATE

Float controlled regulator gates are widely used to limit the flow rate out of the retention basin.A float inside the retention basin actuates a slide valve on the dry side of the basin.As the water level increases,the gate moves down and reduces the flow.

By optimizing the geometry of the regulator an un-matched linearity can be achieved. The resulting characteristic is by far superior to a characteristic of regulators like the Vortex Valve.

A combination of two slide valves as used in the so-called "Twin Regulator Gate" is virtually self de-clogging.

It is very easy to change the flow rate once the float regulator is installed. In fact the different characteristics shown in Figure 3 were obtained by simply re-adjusting the float controlled regulator to a new flow rate. The basic geometry remeined unchanged.

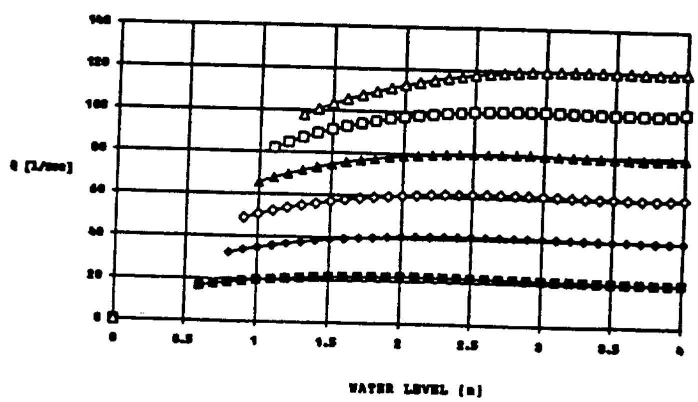

Figure 3 : Characteristics of a float controlled regulator

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FLOAT CONTROLLED REGULATOR GATE

Figure 4 shows different models of a float controlled regulator gate. The gate does not require a hydraulic height difference like other types of regulators.

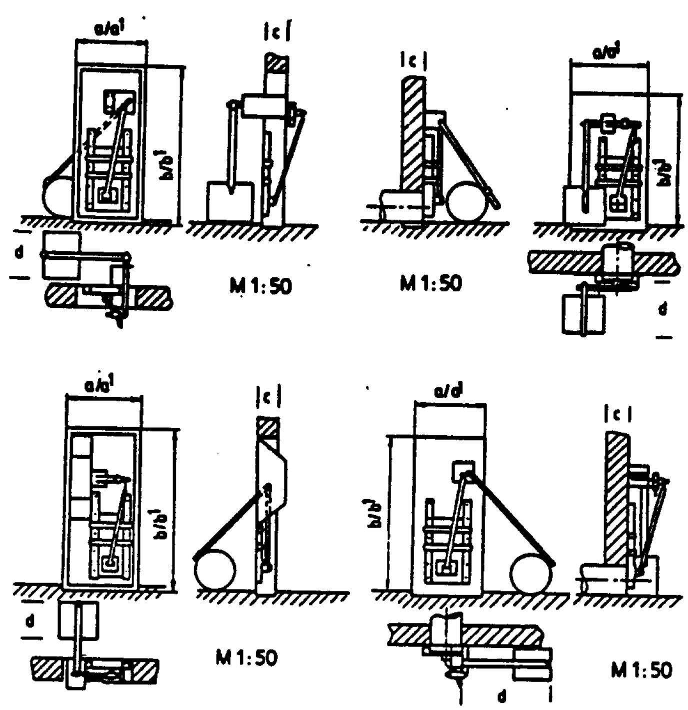

Figure 4: Float controlled regulator gates

BUFFER BASIN WITH PROTECTED OVERFLOW:

Large amounts of stormwater combined with a limited volume of the buffer basin create a situation where some water needs to be dumped.

In the buffer basin the velocity of the water is very slow. Sedimentation of the pollutants based on specific weight will occur.

The overflow is protected by a floating separator wall retaining all floating matter.

The water that is finally dumped into the backwater is free of heavy (specific weight) pollutants and any floating matter.

A regulated gate assures a constant flow to the treatment facility as with the simple buffer basin.

After the basin has been emptied, it is cleaned by the automatic dump flushing apparatus.

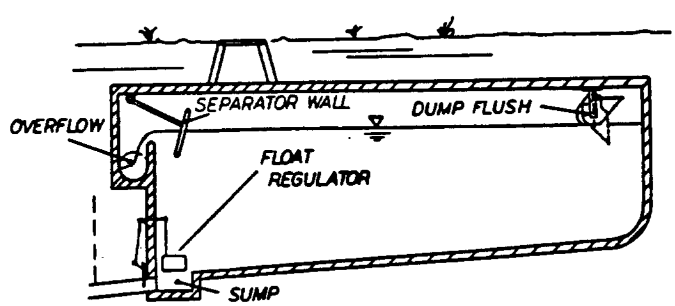

Figure 5 : Retention Basin with Protected Overflow

BUFFER BASIN WITH SCREENING SYSTEM: (Screening System has US Patent)

This basin acts as a sedimentation basin and the overflow is protected by a screen.

The screen retains all floating matter independent of their specific weight. The system is more efficient than a floating separator wall, since anything that does not settle and does not float on the surface is retained as well (paper, napkins, etc.).

Should an overflow situation occur, the excess water is dumped via emergency overflow protected by a floating separator wall.

After the basin has been emptied, the screen is cleaned by dump flushing. The basin is also cleaned by a dump flushing apparatus.

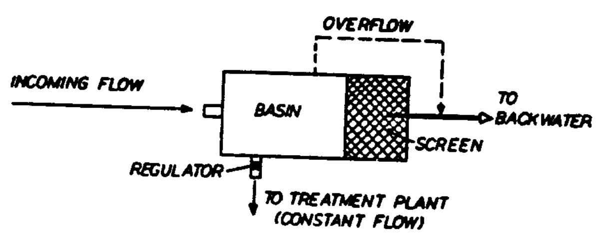

Figure 6 : Diagram of Screening System (US Patent)

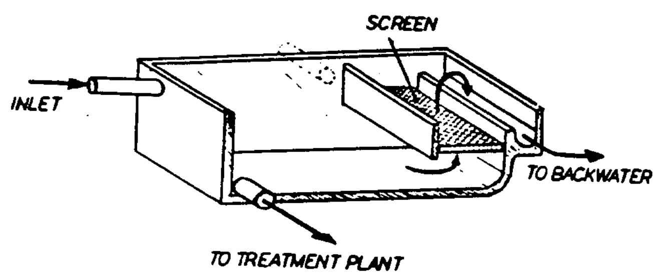

Figure 7: Cutaway of Screening Installation (simplified). (US Patent)

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BUFFER BASIN WITH SCREENING SYSTEM

Figure 8 shows a retention basin with overflow screening and protected emergency overflow. The screen gets cleaned by the automatic Dump Flushing Apparatus. The basin gets cleaned by a second Dump Flushing Apparatus.

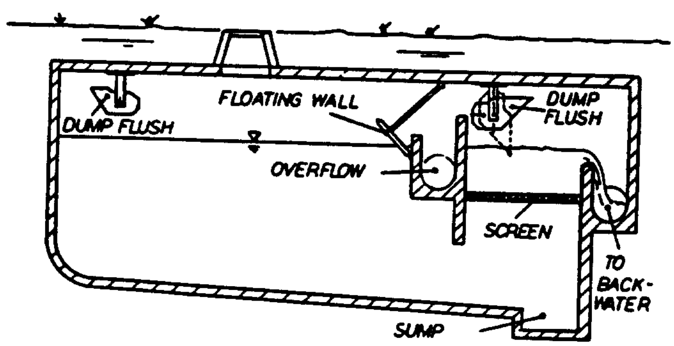

Figure 8: Screening System (US Patent)

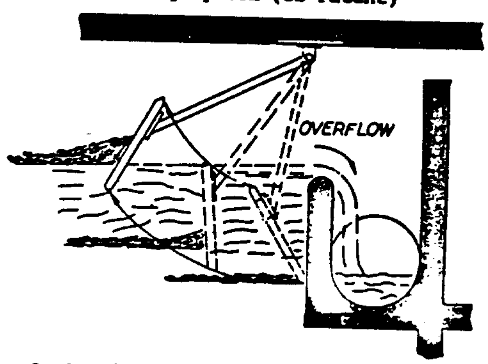

Figure 9: Detail Floating Separator Wall

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SEWER LINE CLEANING

Periodic cleaning of sewer lines can be labor intensive. Lines with low flow rates and/or marginal slopes need to be cleaned frequently to assure proper function.

A new sewer line cleaning apparatus based on a Syphon solves a lot of problems.

Sewer/water is collected in a tank where the Syphon is installed. A float-controlled trigger mechanism triggers the Syphon and the tank is emptied into the sewer line.

As a result the sewer line is flushed periodically with a high flow rate.

The tank can be supplied with fresh water or with waste water from the user.

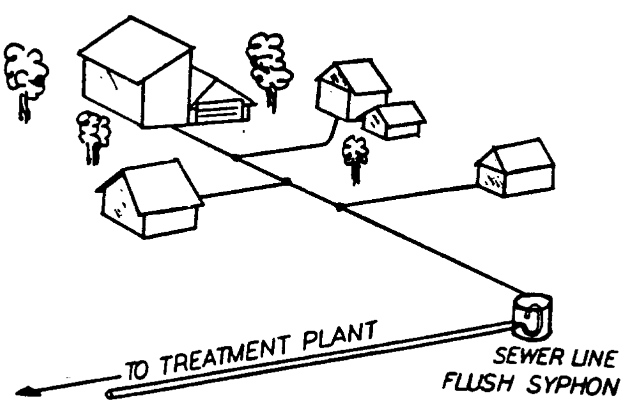

Figure 10 : Remote sewer line cleaning

R0041930

Sewer line cleaning

Figure 11 shows details of the Tank/Syphon of the automatic sewer line cleaning system.

Another system uses a Dump Flush Apparatus similar to those used to clean basins and screens.

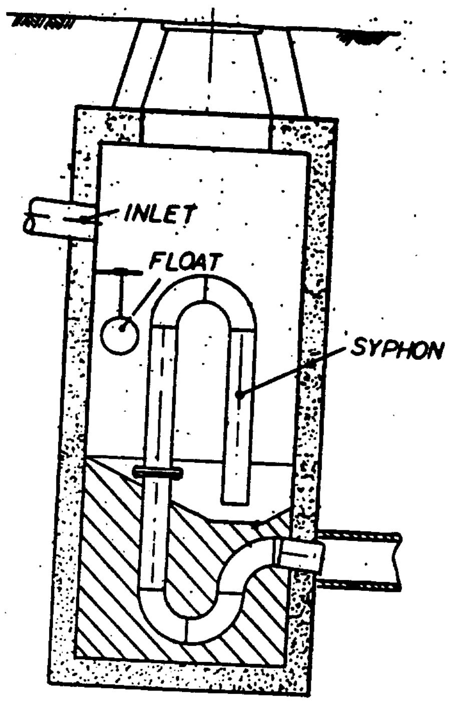

Figure 11: Details of sewer line Flushing Syphon

SUMMARY

The previous pages have introduced new approaches to solve problems in stormwater and sewer treatment.

Stormwater treatment will become more and more important as the pressure to protect our environment increases.

Cleaning of stormwater and sewer installations by conventional methods will be more expensive in the future, and it will become increasingly difficult to find people to do this kind of job.

The technology presented in this report is available today and has been very successfully used for many years in different countries.

Some investments have to be made but they will allow us to get a better grip on our environmental problems.

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SUBJECT INDEX

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April 1995

VOL 12

EPA

Seminar Publication

National Conference on Urban Runoff Management: Enhancing Urban Watershed Management at the Local, County, and State Levels

March 30 to April 2, 1993

The Westin Hotel

Chicago, Illinois

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EPA/625/R-95/003
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Center for Environmental Research Information
Office of Research and Development
U.S. Environmental Protection Agency
Cincinnati, Ohio

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Acknowledgments

This document is the product of the efforts of many individuals. Gratitude goes to each person involved in the preparation and review of this document.

Authors

A special thanks goes to the many authors of the papers presented in this document. Their efforts in preparing papers made this document possible and led to the overall success of the conference.

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Heidi Schultz, Eastern Research Group, Inc., Lexington, MA, directed the editorial review and production of this document.

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Technical Direction and Coordination

Daniel Murray, EPA Office of Research and Development, Center for Environmental Research Information, Cincinnati, OH, coordinated the preparation of this document and provided technical direction throughout its development.

Special Thanks

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Introduction

Background

As stormwater and snowmelt flow across the urban landscape, countless contaminants are carried into our rivers, lakes, and estuaries. The effects of these contaminant discharges on the environment can be severe. Water quality and sediment characteristics can be degraded, threatening the biological integrity of our urban water bodies. In addition to urban runoff quality, the quantity of urban stormwater and snowmelt that reaches urban streams can cause severe physical harm to sensitive ecosystems, including those well beyond urbanized areas.

The proper management of urban watersheds is a challenging and complex task. As urban watersheds are developed, they produce a site-specific mix of pollutants that can adversely affect water and sediment quality. Also, with increased urbanization comes increased impermeability, resulting in higher stormwater flows to streams that can cause streambed and streambank erosion. Urban runoff management is particularly difficult because government jurisdictions rarely coincide with watershed boundaries. So, to overcome these institutional obstacles and implement effective urban watershed management programs, comprehensive and coordinated management strategies are needed.

The National Conference on Urban Runoff Management was held in Chicago, Illinois, from March 30 to April 2, 1993. The purpose of this conference was to bring together national experts in the field of urban watershed management to discuss and share ideas and approaches for effective urban watershed management. This 4-day conference addressed a wide variety of institutional and technical issues, from watershed planning and public information programs to the design and application of best management practices.

Purpose

The purpose of this seminar publication is to make available to a much wider audience the valuable information presented at the National Conference on Urban Runoff Management. This publication comprises 53 papers that were presented at the conference. The papers address a broad spectrum of programmatic and technical topics relating to urban watershed management, including:

- Watershed planning
- Stormwater management programs
- Regulatory issues
- Monitoring, modeling, and environmental assessment
- Design and application of best management practices and controls
- Education and information programs

The papers in this publication represent the collective knowledge and experience of many talented individuals who have developed and are implementing and supporting watershed management programs at the federal, state, county, and local level. As a result, this document will be a valuable resource to regulators, watershed management program personnel, and others interested in developing and implementing a successful urban watershed management program.

Watershed Planning and Program Integration

Eric H. Livingston
Florida Department of Environmental Regulation, Tallahassee, Florida

Abstract

Since passage of the Clean Water Act, federal, state, and local governments together with the private sector have spent billions of dollars attempting to meet the act's goals of restoring and maintaining the chemical, physical, and biological integrity of the nation's waters. While great progress has been made, especially with respect to reducing traditional point sources of pollution, we are faced with a much more complex and difficult challenge: reducing the pollution associated with our everyday activities. Facing the environmental challenges presented by nonpoint sources and stormwater discharges requires a more comprehensive and integrated approach, especially if we are to maximize the environmental benefits in a cost-effective manner. This approach is known as watershed management—the integration, on a watershed basis, of the management of land resources, water resources, social-cultural resources, financial resources, and infrastructure. Implementation of this approach requires a cooperative Watershed Management Team effort involving all levels of government, the private sector, and each citizen.

Besides addressing the need for watershed management, this paper discusses briefly the many components of a comprehensive watershed management program. Key program elements include growth management, land preservation/purchase, wetlands/floodplains protection, erosion and sediment control, stormwater management, wastewater management, watershed prioritization and targeting, inspections and maintenance, research, public education, and dedicated funding sources. Other papers in this publication review the evolution of Florida's watershed management program, with emphasis on successes and failures together with recommendations to improve the environmental effectiveness of the program (e.g., "The Evolution of Florida's Stormwater/Watershed Management Program").

Introduction

When land within a watershed is changed from its natural state to agricultural land and then to urban land, many complex interconnected changes occur to the natural systems within the watershed. These changes can and do have profound effects on the health of these systems as well as their inhabitants. As Earl Shaver describes in his paper, one of the greatest changes is the alteration of the watershed's hydrology, especially the infiltrative capacity of the land. Additionally, the everyday activities of humans within the watershed add many potential environmental contaminants to the watershed that can be easily transported by precipitation and runoff.

Managing stormwater and nonpoint sources of pollution presents many complex challenges to the water resources manager that are somewhat unique and quite different from those encountered when managing traditional point sources of pollution. These challenges include:

- Integrating land-use management, because change in land use creates the stormwater problems.
- Educating the public about how everyday activities contribute to the stormwater/nonpoint source problem and how they must be part of the solution.
- Developing a management framework that is based on the fact that "we all live downstream" and that stormwater flows are not constrained by political boundary lines.
- Obtaining the cooperation and coordination of neighboring political entities that exist within a watershed.
- Not only managing stormwater from new development but retrofitting existing "drainage systems" that were built solely to convey runoff away from developed lands to the nearest water body as quickly as possible.

Secondly, constraints imposed by current stormwater treatment technology, such as treatment efficiency, land needs, and maintenance needs, and by the costs of assessing and solving existing stormwater/nonpoint source pollution problems call for a cooperative and regional framework. Additionally, the proliferation of federal programs and requirements imposed by federal legislation, such as the Federal Clean Water Act and the Coastal Zone Management Act, has caused fragmentation of efforts and created program "turf wars" and even conflicts between programs within the U.S. Environmental Protection Agency (EPA). Other federal programs such as the National Flood Insurance Program, the Section 205 flood control program, and even agricultural crop subsidy programs directly conflict with achieving the goals set forth in various environmental laws and programs. Finally, current environmental management approaches rely on regulatory efforts that attempt to compensate for adverse effects caused by land alteration activities on a particular site. Implementing a watershed management approach helps to overcome all of these challenges and, just as importantly, allows inclusion of planning efforts that can prevent problems. This allows for more extensive use of less expensive nonstructural management practices.

Watershed Management

"Watershed management" is a flexible framework for integrating the management of all resources (land, biological, water, infrastructure, human, economic) within a watershed. Basically, it is the managing of human activities so as to cause the least disruption to natural systems and native flora and fauna. With respect to the management of stormwater and nonpoint sources, the crucial factor is the integration of the management of land use, water/stormwater, and infrastructure. Watershed management has numerous facets, including planning, education, regulation, monitoring, and enforcement, that are performed on a watershed basis.

The watershed management approach discussed in this paper must be flexible. The size of the watershed to be managed can be very large (a river basin) or very small (a subbasin). Selection of watershed size depends on many factors, including ecological systems in the watershed, ground-water hydrologic influences, the type and scope of resource management problems and goals, and the level of resources available. Additionally, the institutional framework for watershed management will vary greatly depending on the legal framework that has been established in state law and local ordinances.

Advantages of Watershed Management

As discussed above, solving our nation's stormwater/nonpoint source problems, especially retrofitting existing "drainage systems" to reduce the pollutant loads they discharge to receiving waters, presents many complex challenges. Correcting these problems will be extremely expensive and technically difficult, and will take a long time. Accordingly, we need to re-evaluate our current approach to stormwater management to shift the emphasis towards more comprehensive, prevention-oriented strategies such as watershed management.

The following comparison illustrates the differences between the usual piecemeal approach to stormwater management and a comprehensive watershed approach (1):

- The usual approach: For existing urban development, the usual approach is to address local stormwater problems without evaluating the potential for the runoff control measure to cause adverse effects in downstream areas. In the case of new urban development, stormwater management responsibilities would be delegated to local land developers, and each would be responsible for constructing stormwater management facilities on the development site to maintain postdevelopment peak discharge rate, volume, and pollutant loads from the site at predevelopment levels. There would be little or no consideration of the cumulative effects of the developments with their individual stormwater systems on either the local government stormwater infrastructure or the downstream lands and waters.
- The watershed approach: This option involves developing a comprehensive watershed plan, known as the "master plan," to identify the most appropriate control measures and the optimal locations to control watershedwide activities. The watershed approach typically involves combinations of the following:
  - Reviewing the watershed and its characteristics to assess problems and potential solutions.
  - Strategically locating a single stormwater management facility (a regional system) to control postdevelopment runoff from several projects within a basin (or from a fully developed basin or subbasin).
  - Providing stormwater conveyance improvements where necessary upstream from the regional facility.
  - Employing nonstructural measures throughout the watershed, such as acquisition of floodplains, wetlands, and natural stormwater depressional storage areas; soundly planned land use; limitations on the amount of imperviousness; grassed swales rather than storm sewers; and roof runoff direction to pervious areas.

While the usual approach to urban stormwater management is relatively easy to administer, it offers several disadvantages. There is a greater risk of negative effects, particularly in watersheds that cover several jurisdictions. Insignificant flood protection benefits result from emphasis on the effects of minor localized flooding. Ineffective runoff control throughout the watershed is caused by the failure to evaluate locational differences in the benefits of stormwater management facilities. Relatively high local costs for facility maintenance are incurred, as are unnecessary costs associated with the use of small-scale structural solutions rather than large-scale nonstructural solutions, which typically are much cheaper.

Included among the possible negative effects of this piecemeal approach to stormwater management are the following:

- It may only partially solve the major flooding problem(s).
- It may solve flooding problems in the upstream jurisdiction but create flooding problems in downstream jurisdictions.
- Randomly located detention basins may actually increase downstream peak flows.
- Maintenance needs and costs associated with numerous onsite runoff controls are very high.
- Significant capital and operation/maintenance expenditures may be wasted.
- The costs of remedial structural solutions likely will be much greater than the cost of a proper management program.

The watershed master planning approach offers significant advantages over the piecemeal approach. It promises reductions in capital and operation/maintenance costs and reductions in the risk of downstream flooding and erosion, particularly in multijurisdictional watersheds. It offers better opportunities to manage existing stormwater problems and the ability to consider and use nonstructural controls. Other benefits include increased opportunities for recreational uses of stormwater controls, potential contributions to local land-use planning, enhanced opportunities for stormwater reuse, and popularity among land developers.

There are some disadvantages to the watershed approach:

- In advance, local governments must conduct studies to locate and develop preliminary designs for regional stormwater management facilities.
- Local governments must develop and adhere to a future land-use plan so that the regional facility is properly designed to capture runoff from the planned amount of development and impervious surfaces.
- Local governments must finance, design, and construct the regional stormwater management facilities before most development occurs and provide for reimbursement by developers over a buildout period that can last many years.
- In some cases, local governments may have to conduct extraordinary maintenance activities for regional facilities that the public feels are primarily recreational facilities that merit protection for water quality.

Another advantage of watershed management is that the resource management goals can be more resource oriented. Prevention practices and programs to protect natural systems and beneficial uses of our water bodies can be stressed. These typically are more cost effective than trying to restore natural systems after they have been adversely affected by human activities that occur within a watershed.

Watershed management allows coordination of infrastructure improvements with point and nonpoint source management programs and, most importantly, provides a vital link between land use and water resources management.

Watershed Management Framework

There is no single approach or institutional framework for establishing a watershed management program. While establishing a watershed management institutional and legal framework would be easiest if we could start with a clean slate, we cannot. There is an existing legal framework in each state, county, and city. These may differ greatly. In some states, there will be a long list of existing laws, rules, and programs that have been set up to respond to earlier state needs. In other states, there will be very few laws, rules, and programs that can form a foundation for establishing watershed management programs. Therefore, one of the keys to opening the watershed management door is flexibility. In some cases, the focus will be on enacting new laws. In other cases, the emphasis will be on revising existing laws (ordinances) to better integrate and coordinate programs and objectives.

Another key to establishing a watershed management framework is patience. Getting state laws or local ordinances enacted or modified is not an easy process. A long-term game plan must be developed and pursued with diligence. Each component of a watershed management program has its own controversies, guaranteeing that public debate will be vociferous on many issues. Therefore, priorities must be established. Typically, priority setting depends on state resource problems and needs, public sentiment, and the degree to which an issue becomes "sexy," thereby receiving coverage by the news media. In many cases, it may take several years to get a particular piece of legislation passed or revised.

To succeed, education of elected officials, state agency managers, and the public must be a priority. Public participation and support are essential in building a consensus. Many of the issues that watershed management programs address are complex and not easily demonstrated. Managers of stormwater and other nonpoint sources of pollution, unlike the managers of traditional point sources of pollution, cannot point to pipes that continuously discharge effluents. Therefore, promoters of watershed management programs must use multimedia presentations to not only educate but also to entertain. You must sell the need for watershed management!

Another key to success is to take advantage of any opportunities that arise. Unfortunately, these opportunities often occur after a natural disaster that results in the loss of property or lives. After Hurricanes Frederick and Andrew struck South Carolina and South Florida, respectively, considerable public debate arose about building codes, land uses, and development within sensitive and susceptible coastal area—whether to allow rebuilding in these areas and whether public programs such as the National Flood Insurance Program should subsidize development in such areas. These debates, especially of the costs and benefits, can be used to help build support for growth management and land acquisition programs. Furthermore, flooding (and in a few locales, water quality problems) can be used to break the "hydro-illogical cycle" and gain support for stormwater management programs and local stormwater utilities.

Finally, in building a watershed management framework, one must establish clear goals for the overall program. Some important goals include:

- Providing opportunities for preventive nonstructural controls in addition to structural controls that can help to mitigate the impacts of human activities within a watershed.
- Establishing clearly defined, holistic natural resource management goals.
- Setting priorities, both in terms of a long-term legislative agenda and by targeting watersheds.
- Encouraging public participation so that everyone "buys in" and feels that they are part of the solution.
- Integrating all available tools and resources into a coordinated, cost-effective, cooperative approach.
- Finding dedicated funding sources outside the main funding stream (also known as "general revenues") so that the watershed management programs do not compete with law enforcement, education, or other high-priority societal needs.

In developing, selling, establishing, and implementing a watershed management framework and associated programs, it is very important to keep in mind "the big Cs of watershed management" (2):

- *Comprehensive* management of people, land use, natural resources, water resources, and infrastructure throughout a watershed.
- *Continuity* of stormwater/watershed management programs over a long period, which is required to correct existing problems and prevent future ones.
- *Cooperation* between federal, state, and local governments; cities and counties; public and private sectors; and all citizens.
- *Communication* to educate ourselves and elected officials about how we are all part of the problem and how we can and must be part of the solution.
- *Coordination* of stormwater retrofitting to reduce pollutant loading and of other natural systems restoration activities with other proposed infrastructure improvements (e.g., road projects) or development/redevelopment projects to maximize benefits and cost-effectiveness.
- *Creativity* in best management practice technology, in funding sources, and in our approach to solving these complex, costly problems.
- *Consistency* in implementing laws, rules, and programs nationally and statewide to assure equity and fairness for everyone.
- *Cash* in large amounts and over a long period to correct existing problems and prevent future ones.
- *Commitment* to solving our current problems and preventing future ones so that we can ensure that our children have a bright future ("Just Say No To Stormwater Pollution").

Watershed Management Program Components

Watershed management involves the integration of management programs addressing the many differing human activities that occur within a watershed. This section discusses briefly many different components or programs that typically are considered a part of watershed management. The following list and discussion of programs is not all inclusive. Other programs addressing specific state or regional needs have been implemented around the country. In developing or implementing programs, it is important to take advantage of information and technology transfer clearinghouses and to communicate with people in other states, cities, and counties who have implemented similar programs.

Each of the various watershed management programs includes common aspects such as planning, holistic goals, science/technical support, implementation (usually with both regulatory and nonregulatory approaches), and extensive public participation. Public participation is needed in all aspects of the program: planning, rule development and adoption, permitting, and inspection/enforcement. Programs must also address how to obtain adequate funding and staffing; how to train staff and the public, especially the regulated community; how to ensure inspection and compliance; and how to ensure long-term operation and maintenance of structural controls. Finally, programs must be evaluated regularly to optimize their environmental effectiveness, cost-effectiveness, and efficiency in providing service. This requires a commitment to monitoring programs that can actually ascertain if the program's goals are being met.

Typically, these programs are implemented following enactment of a state law that requires a state agency to set up a program to address a specific concern. Program implementation via legislative mandate usually helps to ensure that a program has adequate legal authority and staffing/funding support. Some of the programs discussed can and have been established by the passage of a rule by a state agency using its general legislative powers, for example, programs for public education, pollution prevention, monitoring, and prioritizing target watersheds. Given the current scientific data on the pollutants found in stormwater, erosion and sediment control and even stormwater treatment programs can be established using general water pollution control authorities. These programs are very staff/resource intensive, however, requiring legislative approval of budget requests at a minimum.

Common watershed management programs include both planning and regulation. It is important to understand the difference between comprehensive planning and permitting. Both are needed to effectively manage growth and protect the quality of our environment and our citizens' quality of life:

- *Comprehensive planning* allows a community to make decisions about how and where growth will occur in the future. Comprehensive planning asks, is this the right location, is this the right time, and is this the right intensity for the proposed use of the land? Comprehensive planning seeks to prevent problems (social, economic, environmental) before development occurs.
- *Permitting*, on the other hand, asks only, how can we do the best job with this development on this particular site? Permitting is site-specific and seeks only to mitigate the impacts of the land-use decision. There always are inherent limitations in any regulatory program that comprehensive planning can help to overcome. Principal among these limitations is the fact that permitting is piecemeal and does not consider cumulative effects. Therefore, regulation and permitting cannot substitute for planning.

Watershed planning and management programs must include two equal components: the land planning framework and the water planning framework. An example of the hierarchial relationship of these planning frameworks is shown in Table 1.

Table 1. The Land Planning Framework Versus the Water Planning Framework

Land Planning	Water Planning
Land development regulations	Water management regulations
Local compliance plans	State water management plans
Regional policy plans	State water policy
State comprehensive plan	State comprehensive plan

Following is a discussion of many of the program components that typically are part of a watershed management framework. These can be divided into three categories:

- Land planning and management
- Water planning and management
- General resources planning and management

Land Planning and Management Program Components

Land planning and management programs often are called growth management programs. It is important to understand the clear distinctions between growth management, comprehensive planning, and land/environmental regulation:

- *Growth management* looks at broad issues and at the interrelationship of systems—natural systems, infrastructure, land use, and people. It attempts to assess how well we have been providing for the needs of our citizens in the past and, when new people move here, to determine what their needs are and how they will be provided. Growth management encompasses comprehensive planning, natural resource management, public facilities planning, housing, recreation, economic development, and intergovernmental coordination.
- *Comprehensive planning* is a governmental process for inventorying resources, establishing priorities, establishing a vision of where a community wants to go, and determining how to get there. It is a systematic way of looking at the different components of a community, county, region, and state.
- *Regulations* are the specific controls applied to different types of development activities to regulate and minimize their negative impacts. Typically, regulations are administered by all levels of government, federal, state, and local. At the local level, land development regulations are the ordinances that implement the local comprehensive plan.

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State Comprehensive Plan

A state comprehensive plan serves as the base of both the land and water planning pyramids. A State Comprehensive Planning Act would establish goals and policies for each of the plan's various elements and require the state land planning agency to prepare a general state comprehensive plan. Elements in a state comprehensive plan usually include water resources, natural systems, air quality, coastal and marine resources, land and wildlife resources, waste management, public facilities (infrastructure), transportation, mining, agriculture, education, and economic development. If the state's land planning framework includes "regional planning councils" or "regional council of governments," those agencies would be responsible for developing a regional plan. Both the state and regional plans would have to be consistent with the goals and policies set forth in the state comprehensive planning act. These goals and policies, set by the legislature, are to provide guidance to state, regional, and local governments in developing and implementing programs, rules, or ordinances. Consistency must occur from the base of the planning pyramid all the way to its apex. To help ensure consistency and to integrate agency implementation programs with the law's goals and policies, this law can require the preparation of state agency functional plans. These plans can form the basis for agency budget requests, which must be related to the state comprehensive plan's goals and policies.

Growth Management and Land Development Regulation

The Local Government Comprehensive Planning Act (LGCPA), often referred to as the growth management act, establishes the key piece of the natural resources jigsaw puzzle: the direct connection between land-use management and water/natural systems management. Eight states (Oregon, Florida, New Jersey, Maine, Vermont, Rhode Island, Georgia, Washington) have implemented state growth management programs (3). While these programs have elements in common, each state has different implementation requirements. Some states "require" while other states "recommend" local plans, consistency, compliance, etc. An LGCPA should at least address the following components, which are common to each of the eight existing state growth management programs:

- Legislative authority and intent.
- Local comprehensive plans: Required? Voluntary? Schedule? Planning period? Required elements? Minimum requirements?
- Plan implementation: Required? Site planning? Land development regulations?
- Consistency with state goals/policies: Required? Monitoring? Enforcement?
- State review and approval: Required? Which agencies? Administrative process?
- Compliance: Monitoring? Incentives? Disincentives? Citizen enforcement?
- Limitations on the number and type of comp plan amendments: Frequency? Process?
- Regular plan updates and implementation appraisals: Required? Frequency?

Wetlands and Floodplain Protection

Wetlands and floodplains are the "bladder" and "kidneys" of a watershed. They provide a wide range of irreplaceable services at no cost, including maintenance and improvement of water quality; floodwater conveyance and storage; shoreline stabilization; water recharge and supply; sediment control; aquatic productivity; spawning and nursery grounds; habitat for shellfish, fish, waterfowl, endangered species and other wildlife; and open space and recreation. Unfortunately, we have not in the past appreciated these benefits. Instead, we looked on these areas as unproductive, snake-infested mosquito havens with no socially accepted redeeming value. Consequently, only about 40 percent of our nation's original 215 million acres of wetlands remain, largely the result of the conversion of wetlands and floodplains to agricultural lands.

Although Section 404 of the Federal Clean Water Act establishes a wetlands program, its effectiveness in maintaining, protecting, and restoring our nation's wetlands is highly questionable. Not only are nationwide general permits to conduct activities in wetlands relatively easy to obtain, but agricultural and silvicultural activities are largely exempt. Another problem hindering the environmental effectiveness of this federal program is a lack of national consistency. Furthermore, other federal programs (e.g., Section 205 of the 1948 Flood Control Act, National Flood Insurance Program) directly conflict with wetland and water quality protection efforts by promoting alteration and development of these sensitive lands.

A state wetlands protection act can be an important addition to a state's watershed management arsenal to either fill in the gaps of the federal program or to expand the protection of wetlands and floodplains. In developing and implementing a state wetland protection program, it is important to integrate, not duplicate, existing federal programs. Because the current federal wetlands permitting program is administered by the Army Corps of Engineers and EPA, typically the state water quality/environmental management agency is the implementing agency at the state level. Frequently, the "wetlands protection act" is simply a new section within a state's existing environmental laws.

Components that need to be addressed by a state wetlands/floodplain protection act include:

- Defining "wetland." A wetland should be defined by three characteristics: the elevation and duration of flooding, the presence of certain wetland-specific plants, and hydric soil conditions. The law should clearly state that wetlands are considered to be "waters" just like a river, lake, or estuary.
- Establishing a standard method to delineate wetlands. Wetlands represent the transitional edge between waters and uplands. Determining where a wetland ends and the upland begins is neither an easy nor an uncontroversial undertaking. Wetland scientists should be allowed to establish combinations of hydrologic, vegetation, and soil indicators and a process by which to "draw the wetland line."
- Requiring consistant statewide application of the wetland definition and wetland jurisdictional delineation method by all levels of government.
- Establishing wetland protection/management goals and policies that can set the basis for wetland regulations and permitting criteria.
- Creating goals and policies that foster more cost-effective pollution prevention approaches by stressing wetland avoidance rather than mitigation.
- Requiring or encouraging regional mitigation banks rather than onsite mitigation.
- Establishing a fair permitting process that ensures public participation, equity, an appeals process, and decisions based on scientific/technical merit.
- Allowing, with strict pretreatment requirements, the incorporation of certain wetlands into domestic wastewater and stormwater management/reuse systems, provided that the ecological characteristics of the wetland are protected, restored, or enhanced.
- Requiring the annual tracking of wetland losses and mitigation efforts, successes, and failures.
- Providing for assumption, by the state, of the federal Section 404 wetlands program.

State and Local Land Preservation and Acquisition

Regulating and restricting the use of private property are very controversial. The U.S. Supreme Court has ruled several times, however, that state and local governments have the legal authority to do so. In fact, it is the responsibility of government to ensure the health, safety, and welfare of the public. Restricting what can and cannot be done on a particular piece of property helps to maintain property values and to prevent contamination of air, land, water, and human resources. Care must be taken, however, to avoid the "taking of property." One way to help ensure that this goal is met and that extremely crucial or sensitive lands within a watershed are preserved is to implement land acquisition programs.

The federal government has implemented several types of land acquisition programs that have helped to preserve sensitive lands, protect vital wildlife habitats, and establish recreational lands, such as our national parks and national wildlife refuges. Federal budget problems and intense competition for the limited federal land acquisition funds, however, makes it difficult to gain these monies to obtain properties, especially those that do not have national or at least regional significance. Additionally, federal funding programs generally require matching funds from state and/or local governments. Therefore, the establishment of state and local land acquisition programs can greatly increase the ability to purchase and protect sensitive lands and, equally importantly, to capture limited federal funds.

Establishing state or local land acquisition programs requires extensive citizen participation and support. You will be asking the public to tax themselves to raise money to purchase lands, preserve them, and provide recreational opportunities. You must "sell" the program. Catchy phrases and acronyms are helpful. Citizens must see that they or their children will benefit and that the funds will be spent wisely and cost-effectively. Land acquisition programs must avoid conflicts of interest and be administered with great integrity and openness.

A state and local land preservation and acquisition act should contain the following components and considerations:

- Clearly defined program goals and policies. These will form the foundation for determining what types of properties will be purchased and how purchasing priorities will be established. The program's goals and policies should advocate the preservation and restoration of lands that contribute nonstructural environmental benefits. Additional resource management factors that should be considered in purchasing lands include open space and recreational and wildlife benefits.
- Integrated and coordinated federal, state, local, and private land preservation and acquisition programs. This will maximize the ability to leverage funds from various sources. Establishing interconnected wildlife corridors and greenways should be a priority.
- Extensive participation by citizens, private conservation groups, and state and local governments to establish program regulations, administrative procedures, and, most importantly, land-buying priorities.
- The long-term ownership and active land management of the property once it is purchased. Which agency

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will be in charge, an environmental agency? A parks and recreation agency? A fisheries or wildlife agency? A private organization (i.e., Nature Conservancy, Trust for Public Land)? Does a land management plan need to be developed? How will land management be funded?

- Dedicated funding sources. Purchasing large quantities of land and then managing the land, especially with public access and use, requires significant funds over a long period. To obtain sufficient funds, it may be desirable for a state or local government to use its ability to sell bonds. Bonds can raise large amounts of money at one time, which can then be paid off like a mortgage. However, that requires having a source of funds that is stable and predictable over the life of the bond. Fees on real estate transactions (e.g., documentary stamps) and local option sales taxes have been used extensively around the country for this purpose.

Water Resources Planning and Management Programs

In general, the United States is blessed with an abundance of clean water resources. Water generally is available whenever we want it, in whatever quantity we desire and at a very low cost. Consequently, less attention and emphasis have been placed on water resources planning and management, especially from a holistic approach. In the past, water planning and management programs were implemented usually to address a crisis that had arisen. The continuing growth of our nation's population, however, continues to exert ever-growing demands on our vulnerable and limited water resources. Additionally, the need to begin managing unconventional pollution sources such as stormwater and other nonpoint sources requires a re-evaluation of the way we manage water. Accordingly, water resource planning and management programs are receiving increased attention and evaluation.

Within this subcategory of watershed management programs, we include water quantity and quality programs for the protection and management of surface and ground waters, as well as general environmental protection programs. All of these programs usually include both pollution prevention aspects and pollution treatment aspects.

Environmental Protection

Most states have enacted some type of state environmental protection act, typically to control traditional point sources of pollution. Generally, these laws are patterned somewhat after the federal Clean Water Act. These laws get revised frequently as either a new state environmental crisis or concern arises or the Clean Water Act gets amended by Congress. This law is an excellent example of how, over years, an existing law is revised to establish or refine existing or new environmental requirements or programs.

While state environmental protection laws around the country include many common and similar environmental requirements and mandates, there is also considerable variation among states. A major reason for this is that different states approach the same problem differently. For example, some states enact separate erosion and sediment control acts and stormwater management acts. Other states combine these two very important watershed management components. In some states, the law governing the siting and use of onsite wastewater disposal systems is found within a state's general health code law, while in other states it is found within the environmental law. These three watershed management components will be discussed as separate topics even though their legislative authority often is integrated into a state's environmental laws.

State environmental protection laws generally contain such components and considerations as:

- Establishment of the state environmental agency, along with its legal authority and powers and responsibilities.
- Establishment of an "environmental regulation commission," generally composed of citizens appointed by a political body (i.e., governor), which usually holds public workshops and adopts the state's environmental regulations and standards.
- Permitting evaluation criteria, permit fees, and administrative procedures, which typically include a legal, administrative hearing process to appeal permitting decisions.
- Programs, with adequate legal authority/direction and resources (staffing and funding), to address general environmental protection and management of air, land, and water resources (surface and ground water).
- Programs, with adequate legal authority/direction and resources, to minimize the impacts of specific pollution sources such as wastewater and industrial discharges, solid wastes, hazardous wastes, and toxic wastes.
- Pollution prevention programs such as "Amnesty Day," which allows citizens to safely dispose of hazardous or toxic household wastes; used oil recycling centers; waste reduction and assistance programs for industry; "Adopt a Road (Stream, Lake, Bay, Shoreline)" programs; recycling; and "Farmstead Assistance" ("Farm*A*Syst") programs.
- Programs to restore environmentally damaged lands and waters, especially critical areas such as wetlands, floodplains, steep slopes, and eroding lands.
- Programs to monitor the health of the environment and to assess the effectiveness of watershed man-

agement programs. Monitoring programs need to include sampling of the water column, sediment, and biological community. They need to be able to provide information concerning long-term trends in environmental health, as well as the status of the health of selected water bodies or natural systems.

Water Resources Planning and Management

Many states have enacted a water resources act that is distinct and separate from the state environmental protection act, perhaps because the planning and management of water resources is essential to the continued survival of life on our planet and because water is a major determinant of economic development and quality of life. Water resources planning and management must include consideration of both water quantity (water supply, water allocation, flooding) and water quality. A state water resources act needs to be fully integrated with the state environmental protection act. It must ensure that implementation of programs by both the state environmental protection agency and state/regional water resources agency is coordinated, consistent, and complimentary.

A state water resources act creates the framework for water resources planning and management programs to be undertaken by state, regional, and local governments. Using the goals and policies of the state comprehensive planning act, the environmental regulation commission adopts a regulation known as its state water policy. This rule contains general policy statements addressing the myriad water resource topics, such as water supply and conservation, surface water preservation and management, and natural systems preservation and management. It provides guidance for the implementation of all water resource programs and regulations, whether by a state, regional, or local entity. The act could establish regional "water(shed) management districts" which are set up on the basis of watershed boundaries. The districts would conduct regional watershed planning, help coordinate water management efforts undertaken by local agencies to ensure that watershedwide goals are met cooperatively, and operate regulatory and research programs.

A state water resources act should include such program components and considerations as:

- Establishing water(shed) management districts to administer special regional (watershed) water planning and management programs. These districts should provide statutory authorities and be given broad powers to protect, manage, and restore surface- and ground-water resources.
- Setting the institutional relationships between the state environmental agency, regional water management districts, and local governments. Strong oversight of programs, especially regulatory ones, delegated downwards for implementation is essential to ensure program consistency.
- Developing a state water policy to provide guidance for the implementation of all water programs and regulations in the state, which should be adopted as a rule, preferably as part of the state's environmental regulation code. The state water policy must be based on and consistent with the goals and policies in the state planning act. State, regional, and local water regulations and programs must be consistent with the state water policy. Ideally, goals and policies in a local comprehensive plan should also be consistent with the policy.
- Providing the districts with dedicated sources of revenue to ensure long-term, adequate funding of all necessary water resource management programs. Sources used in parts of the country include *ad valorem* assessments (property taxes), fees on water use, permitting fees, and special assessments.

Supplemental Surface Water and Environmental Protection Programs

There are several watershed management component programs that may be established within one of the above two statutes or which may be established in statute separately.

Erosion and Sediment Control Act/Program. Land disturbing activities are among the largest source of sediments and particle-borne pollutants. Preventing erosion and minimizing and capturing sediments, especially from construction sites, are essential parts of any watershed management framework. Since 1972, over 20 states have enacted erosion and sediment control laws and programs.

Establishment of an erosion prevention and sediment control law or program should include the following components and considerations:

- Clearly defined legal authority, goals/performance standards, and responsibilities of the implementing state and/or regional or local agencies.
- Assurance that publicly funded projects, especially highways, must comply with all program requirements, and an encouragement for these projects to serve as models.
- Determination of whether utility construction, agricultural, and forestry projects are to be included in the program.
- Agency responsibilities and relationships. Typically, implementation of an erosion and sediment control program involves a state agency and a regional/local agency such as a soil and water conservation district

or a local government. Delegation of the program from the state to the local agency must involve close oversight to ensure consistency.

- Adequate staffing and other resources to conduct research on the effectiveness of control measures, develop scientifically sound rules, and conduct training and education programs for plan reviewers, inspectors, developers, engineers, and site contractors. A state training and certification program for plan reviewers, inspectors, and contractors is highly recommended because it is very unlikely that public agencies will ever obtain sufficient staffing to conduct inspections of construction sites on a regular basis.
- Mutual integration of the state erosion and sediment program, the state stormwater management program, and the new federal National Pollutant Discharge Elimination System (NPDES) Stormwater Permitting Program.

Stormwater Management Act/Program. Most states have implemented some type of stormwater "drainage" program to ensure that their citizens and their properties are protected from flooding. In some states, special "drainage districts" or "drain commissions" have been established at a regional or local level. Today, however, we know that stormwater is also one of the major sources of pollutant loadings to our nation's rivers, lakes, and estuaries. Stormwater management is evolving slowly from its "drainage" focus to a much more comprehensive, multiple-objective program that addresses stormwater quality and quantity. Stormwater programs must attempt to prevent or minimize stormwater problems associated with new land-use activities but must also develop programs to reduce the pollutant loading discharged from older "drainage systems." This latter objective is extremely difficult and expensive to address. Watershed management approaches are essential. Typically, a state stormwater management program begins by addressing the problems associated with new land uses and then evolves into a more comprehensive, watershed-based program to address the retrofitting of older stormwater systems.

Components and considerations that need to be addressed by a state stormwater management act/program include:

- Clearly defined legal authority, goals/performance standards, and responsibilities of the implementing state and/or regional or local agencies.
- Assurance that publicly funded projects, especially highways, comply with all program requirements, and an encouragement for these projects to serve as models.
- Agency responsibilities and relationships. Typically, implementation of a stormwater management program involves a state agency and a regional/local agency such as a water(shed) management district, soil and water conservation district, or a local government. Delegation of the program from the state to the local agency must involve close oversight to ensure consistency.
- General goals and minimal treatment performance standards (on which best management practice design criteria will be based) based on the state water policy, and a biological or resource based performance standard for reducing the pollutant loading from existing drainage systems.
- Adequate staffing for planning, coordinating, permitting, and enforcement, and resources to conduct research on the effectiveness of control measures; to develop scientifically sound rules; and to conduct training and education programs for plan reviewers, inspectors, developers, engineers, and site contractors.
- A state training and certification program for plan reviewers, inspectors, and contractors. This is highly recommended, because it is very unlikely that public agencies will ever obtain sufficient staffing to conduct inspections of stormwater systems either during construction or afterwards on a regular basis. These programs can be integrated with similar erosion and sediment control programs.
- Integration of the state stormwater management program with the state erosion and sediment control program and with the new federal NPDES Stormwater Permitting Program.
- A mechanism, such as stormwater operating permits, to ensure that stormwater management systems are inspected at least annually to determine maintenance needs and that systems are maintained and operated properly. Ideally, this system is implemented by a local stormwater utility which provides the owner of a properly maintained and operated stormwater system with a stormwater utility fee credit as an economic incentive.
- Statutory authority for the establishment of dedicated funding sources for stormwater management programs at both the state and local level. At the state level, small fees on concrete, asphalt, fertilizer, or pesticides might be considered. At the local level, stormwater utilities are widely used around the country with great success.

Watershed Prioritization and Targeting Act/Program. The ever-growing number of water resources problems along with the financial constraints faced by all levels of government strongly suggest a need for the establishment of watershed prioritization and targeting programs. Many states, often as part of the implementation of stormwater/nonpoint source management programs, have set up such programs (4, 5). Considerations and components of a state watershed prioritization and targeting act/program include:

- Clearly identifying which state, regional, and local agencies will be involved in establishing priority watersheds. Public participation is essential to ensure the cooperation and "buy in" of citizens around the state and within the targeted watershed. Cooperation and joint ventures with private land conservation groups need to be encouraged.
- Providing guidance on what factors will be considered in the prioritization process. These may include requirements such as water bodies being of statewide or regional significance or of a certain level of degradation; the level of local government and citizen support, especially by those land owners that will need to install management practices; and the availability of local matching funds.
- Providing a legal mechanism for the adoption of the "priority list" by the appropriate state, regional, or local agency. Ensuring that the list is reviewed on a regular basis and updated or refined as needed.
- Providing a dedicated source of funds (state, regional, local) to develop and implement a watershed management plan within a realistic time schedule.

Onsite Wastewater Management Act/Program. The nation's rapid population growth and the accompanying move to the suburbs and even more rural areas has led to a tremendous proliferation of the use of onsite wastewater disposal systems (OSDSs). Often considered an inexpensive alternative to centralized wastewater collection and treatment systems, OSDSs can cause or contribute to health and environmental resource problems which are difficult and very expensive to solve. Like many areas of nonpoint source management, OSDS programs need to stress prevention but also be able to correct problems related to the past use and misuse of these systems. Traditionally, state health departments rather than state environmental or water resources agencies have administered OSDS programs. It is increasingly evident, however, that OSDSs are a major contributor to impairment of aquatic systems.

A state onsite wastewater management act/program should include the following components and considerations:

- Clearly defined legal authority, goals/performance standards, and responsibilities of the state, regional, or local entities involved in the implementation of the program.
- Goals and performance standards that not only address traditional health concerns but that also require consideration of the potential environmental effects of OSDSs.
- The adoption of OSDS regulations that govern the types of OSDS systems (e.g., drainfields, mound systems, aerobic units), the siting of systems (e.g., water-table elevation, soil types, setbacks from wetlands/waters), the design and performance of OSDS (e.g., secondary treatment? nitrates ≤10 mg/L?), determination of whether surface discharges will be allowed and under what conditions, inspections during construction and throughout the use of the system, and maintenance.
- Regular inspection (every 2 to 3 years) and maintenance (e.g., pumpout, drainfield) to help ensure that OSDSs continue to function properly. The establishment of OSDS management districts, which have defined service areas, funding sources, and legal authority, is one mechanism that can be used. Another method of ensuring that OSDSs continue to function properly is to require inspections and upgrading/maintenance of systems whenever a property is sold.

General Resources Planning and Management Programs

One of the challenges of implementing watershed management frameworks and programs is their complex, interwoven nature. Many aspects of watershed management transcend the simple classification scheme outlined at the beginning of this section. These include the need for broad-based natural resource management programs and for environmental education programs, especially those integrated into the curriculum of the K–12 education system. In many states, separate agencies have been established that have responsibility for the management of land, fish and wildlife, agriculture, mining, and parks and recreation. Often a state forestry department is responsible for the acquisition and management of state forest lands. The activities and programs of these agencies typically are an essential component of watershed management. Close coordination and cooperation between these agencies and the other "primary" agencies involved in watershed management are needed to ensure that programs do not conflict and to maximize the benefits and cost-effectiveness of all programs.

Additionally, while nearly every natural resources resource management agency has some type of environmental education programs, these typically are narrowly focused, dealing with a particular program. The growing importance of nontraditional pollution sources such as stormwater and nonpoint sources requires the development and implementation of a broad-based environmental curriculum that begins teaching children in kindergarten and continues all the way through their senior year of high school. Each of us must understand the basic interrelationships of the air, land, and water and how our everyday activities can and do contribute to the degradation of our natural systems. We must re-establish the ethic of stewardship, and the best way to accomplish this is through the education of our youth.

Example State Watershed Management Initiatives

Several states have developed and implemented some or many of the watershed management program components discussed above. In recent years, states have begun to try to integrate ongoing programs into a more comprehensive watershed management framework. Within this publication can be found papers that describe or discuss state programs such as Delaware and Florida, regional programs such as the Puget Sound (Washington) Management Program and the San Francisco Bay Program, and local programs such as the Prince George's County (Maryland) and Summit County (Ohio) programs.

One of the ways in which existing programs, especially planning and regulatory programs, can evolve into an integrated watershed approach is demonstrated by the ongoing efforts in North Carolina. The North Carolina Division of Environmental Management (NCDEM) has developed a plan in which basins, not stream reaches, are the basic unit of water quality management. The objectives of North Carolina's Basinwide Water Quality Management Initiative include (6):

- Identify priority problem areas and pollution sources that merit particular pollutant control, using modifications of rules (e.g., basin criteria) and increased enforcement.
- Determine the optimal water quality management strategy and distribution of assimilative capacity for each of the 17 major river basins within the state.
- Prepare, in cooperation with local governments and citizens, comprehensive basinwide management plans that set forth the rationale, approaches, and long-term management goals and strategies for each basin.
- Implement innovative management approaches that protect the state's surface water quality, encourage the equitable distribution of assimilative capacity, and allow for sound economic planning and growth.

The whole-basin initiative is envisioned as a fully integrated approach to water quality assessment and management. It integrates planning, monitoring, modeling, point source permitting and control, nonpoint source control, and enforcement within a basin. NCDEM has rescheduled its NPDES permit activities so that permit renewals within a given basin will occur simultaneously and will be repeated at 5-year intervals.

One of the difficulties in implementing a basin-wide approach is the setting of priorities, the establishment of a rotating schedule among the basins, and the correlation of management needs (monitoring, planning, permitting, enforcement) with staff and resource allocations. North Carolina prioritized and scheduled its 17 basins based on consideration of the nature and extent of known problems, a basin's importance in terms of human use, the availability of data, and staff workload balancing.

For each basin in turn, North Carolina will perform the 15-step process outlined below (6):

1. Compile all existing relevant information on basin characteristics and water quality.
2. Define the water quality goals and objectives for water bodies within the basin. Revise as necessary as more data are obtained.
3. Identify the critical issues (e.g., water supply protection, shellfish harvesting) and current water quality problems within the basin. Determine the major factors and sources (point, nonpoint, habitat degradation) that contribute to the problems.
4. Prioritize the basin's water quality concerns and critical issues. Ensure public participation and input from other government agencies and nongovernment groups.
5. Define the subbasin management units using basin hydrology, physiographic boundaries, problem areas, and critical issues.
6. Identify needs for additional information.
7. Collect additional information.
8. Analyze, integrate, and interpret the information collected. Revisit Steps 2 through 5 in light of the new information.
9. Determine and evaluate the management options for each management unit in the basin.
10. Select final management approaches for the basin and targeted subbasins.
11. Complete the draft whole basin management plan. Perform additional modeling and other analyses to finalize wasteload allocations.
12. Distribute the draft plan for review and comment, and conduct public hearings.
13. Revise the plan as appropriate in response to comments. Ensure adoption of the plan by the state's environmental management commission.
14. Implement the management approaches, including point and nonpoint source controls.
15. Monitor the program's success and update the plan every 5 years.

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The Evolution of Florida's Stormwater/Watershed Management Program

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Abstract

Research conducted during the late 1970s as part of the Section 208 Water Quality Management Program identified pollutant loading from stormwater discharges as the major source of water quality degradation in Florida. This paper reviews the evolution of Florida's stormwater regulatory program, from its initial emphasis on controlling stormwater problems from new development to its current emphasis on reducing pollutant loading from existing development. The philosophical and technical basis for the program are discussed, as are the program's major components. The paper emphasizes how the program is beginning to address the retrofitting of existing "drainage systems."

Developing and implementing a statewide stormwater management program requires several key components. Research must be undertaken to develop statewide rainfall distribution statistics, determine stormwater pollutant loading characteristics, determine the effectiveness of various stormwater treatment practices, and identify key design criteria for each type of best management practice. Education is essential and must be targeted at many different audiences: design engineers, state and local government staff and elected officials, construction personnel, inspectors, maintenance staff, and citizens. Dedicated funding sources at both state and local levels are very important, especially if the program is to achieve the desired environmental benefits and for retrofitting. Most importantly, integration of stormwater regulatory programs with other resource management programs on a watershed basis must occur for maximum environmental results and cost-effectiveness.

Introduction

Florida is blessed with a multitude of natural systems, from the longleaf pine-wiregrass hills of the Panhandle to the sinkhole and sand ridge lakes of the central ridge, the Everglades "River of Grass," and the coral reefs of the Keys. Abundant surface-water resources include over 20 major rivers and estuaries and nearly 8,000 lakes. Plentiful ground-water aquifers provide over 90 percent of the state's residents with drinking water. Add the state's climate and it's easy to see why many consider the Sunshine State a favored vacation destination and why the state has experienced phenomenal growth since the 1970s. Today, Florida is the fourth most populous state, and its population is still growing rapidly, although not at the 900 people per day (300,000 per year) rate that occurred throughout the 1970s and 1980s.

Florida's natural systems, especially its surface- and ground-water resources, are extremely vulnerable and easily damaged. This is partially the result of the state's sandy porous soils, karst geology, and abundant rainfall. The negative impacts of unplanned growth were seen as early as the 1930s, when southeast Florida's coastal water supply was threatened by saltwater intrusion into the fragile freshwater aquifer that supplied most of the potable water for the rapidly expanding population. By the 1970s, it was becoming all too clear that unplanned land-use, development, and water-use decisions were altering the state in a manner that, if left unchecked, could lead to profound, irretrievable loss of the very natural beauty that brought residents and tourists to Florida. Extensive destruction of wetlands, bulldozing of beach and dune systems, continued saltwater intrusion into freshwater aquifers, and the extensive pollution of the state's rivers, lakes and estuaries were only some of the negative impacts of this rapid growth.

Fortunately, Florida's citizens and elected officials became educated about these problems and began developing programs to protect and manage the state's natural resources. Florida began serious and comprehensive efforts to manage its land and water resources and its growth as the environmental movement in the nation and the state gained strength in the early 1970s. Florida's natural resources management programs have evolved over a 20-year period. Collectively, the individual laws and programs enacted during this period can be considered "Florida's Watershed Management Program." In many cases, these laws have been integrated either statutorily with revisions to existing laws or through the adoption of regulations by various state, regional, and local agencies.

The evolution of Florida's watershed management program typically involves the following sequence: 1) concern about a specific "pollutant" or problem creates a resource/environmental management program which usually begins by focusing on "new sources" (site basis); 2) over time, as new sources are controlled and the effectiveness of the program increases, the focus shifts to cleaning up "older sources" (watershed or regional basis); 3) ultimately, the focus shifts to integrating the program with similar ones to eliminate any duplication and to improve efficiency and effectiveness.

Florida's Stormwater Program: The Beginning

Section 208 of the Federal Clean Water Act required the development of areawide water quality management plans to control point and nonpoint sources of pollution. As part of Florida's program conducted during the late 1970s and early 1980s, many investigations were undertaken to assess the impacts of stormwater and the effectiveness of various best management practices (1). These studies demonstrated that stormwater, whether from agriculture, forestry, or urban lands, was the primary source of pollutant loading to Florida's receiving waters. Subsequently, it was concluded that the ability to meet the Clean Water Act objective of fishable and swimmable waters would require the implementation of stormwater programs to reduce the delivery of pollutants from stormwater discharges.

Recognition of this problem, along with the availability of federal funds, led Florida to draft regulations to control stormwater in the late 1970s. The first official state regulation specifically addressing stormwater was adopted in 1979 as part of Chapter 17-4, Florida Administrative Code (FAC). Chapter 17-4.248 was the first attempt to regulate this source of pollution, which, at the time, was not very well understood. Under Chapter 17-4.248, the Florida Department of Environmental Regulation (DER) based its decision to order a permit on a determination of the "insignificance" or "significance" of the stormwater discharge. This determination seems reasonable in concept; however, in practice, such a decision can be as variable as the personalities involved. What may appear insignificant to the owner of a shopping center may actually be a significant pollutant load into an already overloaded stream.

In adopting Chapter 17-4.248, DER intended that the rule would be revised when more detailed information on nonpoint source management became available. About a year after adoption, DER began reviewing the results of research being conducted under the 208 program. DER also established a stormwater task force with membership from all segments of the regulated and environmental communities. A revised stormwater rule, Chapter 17-25, FAC, was developed over 2 years, involving more than 100 meetings between department staff and the regulatory interests, and the dissemination of 29 official rule drafts for review and comment. The rule was adopted by the state's Environmental Regulation Commission (ERC) and became effective in February 1982. The adopted rule required a stormwater permit for all new stormwater discharges and for modifications to existing discharges that were modified to increase flow or pollutant loading.

The stormwater rule had to be implemented within the framework of the federal Clean Water Act. The act establishes two types of regulatory requirements to control pollutant discharges: technology-based effluent limitations, which reflect the best controls available considering the technical and economic achievability of those controls; and water quality-based effluent limitations, which reflect the water quality standards and allowable pollutant loadings set up by state permit (2). The latter approach can be developed and implemented through biomonitoring based on whole effluent toxicity, making it very applicable to stormwater. Florida's tremendous growth, the accompanying creation of tens of thousands of new stormwater discharges, and the lack of data on stormwater loading toxicity made this approach unimplementable, however.

Guidance on the development of stormwater regulatory programs and the role of water quality criteria has been issued by the U.S. Environmental Protection Agency (EPA) (3). The guidance recognizes that best management practices (BMPs) are the primary mechanism to enable the achievement of water quality standards. For the purposes of this paper, a BMP is a control technique that is used for a given set of site conditions to achieve stormwater quality and quantity enhancement at minimal cost. Further, the guidance recommends that state programs include the following steps:

- Design of BMPs based on site-specific conditions; technical, institutional, and economic feasibility; and the water quality standards of the receiving waters.
- Monitoring to ensure that practices are correctly designed and applied.
- Monitoring to determine both the effectiveness of BMPs in meeting water quality standards and the appropriateness of water quality criteria in reasonably ensuring protection of beneficial uses.
- Adjustment of BMPs when it is found that water quality standards are not being protected to a designed level, and/or evaluation and possible adjustment of water quality standards.

Proper installation and operation of state-approved BMPs should achieve water quality standards. While water quality standards are to be used to measure the effectiveness of BMPs, EPA recognizes that there should be flexibility in water quality standards to address the impacts of time and space components of stormwater as well as naturally occurring events. If water quality standards are not met, then the BMPs should be modified, the discharge should cease, or, in some cases, reassessment of the water quality standards should be undertaken.

Rationale for Stormwater Rule Standards

The overriding standards of the stormwater rule are the state's water quality standards and appropriate regulations established in other DER rules. Therefore, an applicant for a stormwater discharge permit must provide reasonable assurance that stormwater discharges will not violate state water quality standards. Because of the potential number of discharge facilities and the difficulties of determining the impact of any facility on a water body or the latter's assimilative capacity, DER decided that the stormwater rule should be based on design and performance standards.

The performance standards established a technology-based effluent limitation against which an applicant can measure the proposed treatment system. Compliance with the rule's design criteria created a presumption that the desired performance standards would be met, which, in turn, provided a rebuttable presumption that water quality standards would be met. If an applicant wants to use BMPs other than those described in the rule, then a demonstration must be made that the BMP provides treatment that achieves the desired pollutant removal performance standard. Actual design and performance standards are based on a number of factors:

- Stormwater management goals: Stormwater management has multiple objectives, including water quality protection, flood protection (volume, peak discharge rate), erosion and sediment control, water conservation and reuse, aesthetics, and recreation. The basic goal for new development is to ensure that postdevelopment peak discharge rate, volume, timing, and pollutant load do not exceed predevelopment levels. BMPs are not 100-percent effective, however, in removing stormwater pollutants, while site variations can also make this goal unachievable at times. Therefore, for the purposes of stormwater regulatory programs, DER (water quality) and the state's regional water management districts (WMDs) (flood control) have established performance standards based on risk analysis and implementation feasibility.
- Rainfall characteristics: An analysis of long-term rainfall records was undertaken to determine statistical distribution of various rainfall characteristics such as storm intensity and duration, precipitation volume, and time between storms. It was found that nearly 90 percent of a year's storm events occurring anywhere in Florida produce a total of 2.54 cm (1 in.) of rainfall or less (4). Also, 75 percent of the total annual volume of rain falls in storms of 2.54 cm or less. Finally, the average interevent time between storms is approximately 80 hr (5).
- Runoff pollutant loads: The first flush of pollutants refers to the higher concentrations of stormwater pollutants that characteristically occur during the early part of the storm, with concentrations decaying as the runoff continues. Concentration peaks and decay functions vary from site to site depending on land use, the pollutants of interest, and the characteristics of the drainage basin. Florida studies (6, 7) indicated that for a variety of land uses the first 1.27 cm (0.5 in.) of runoff contained 80 to 95 percent of the total annual loading of most stormwater pollutants. First flush effects generally diminish, however, as the size of the drainage basin increases and the percent impervious area decreases because of the unequal distribution of rainfall over the watershed and the additive phasing of inflows from numerous small drainages in the larger watershed. In fact, as the drainage area increases in size above 40 ha (100 ac), the annual pollutant load carried in the first flush drops below 80 percent because of the diminishing first flush effect.
- BMP efficiency and cost data: Numerous studies conducted in Florida during the Section 208 program generated information about the pollutant removal effectiveness of various BMPs and the costs of BMP construction and operation. Analysis of this information revealed that the cost of treatment increased exponentially after "secondary treatment" (removal of 80 percent of the annual load) (8).
- Selection of minimum treatment levels: After review and analysis of the above information, and after extensive public participation, DER set a stormwater treatment objective of removing at least 80 percent of the average annual pollutant load for stormwater discharges to Class III (fishable/swimmable) waters. A 95-percent removal level was set for stormwater discharges to sensitive waters such as potable supply waters (Class I), shellfish harvesting waters (Class II), and Outstanding Florida Waters. DER believed that these treatment levels would protect beneficial uses and thereby establish a relationship between the rule's BMP performance standards and water quality standards.

BMP Treatment Volumes and Design Criteria/Guidelines

The current stormwater treatment volumes for various BMPs are set forth in Table 1. Since adoption of the stormwater rule in 1982, the design criteria and treatment volumes have been revised several times as new

Table 1. BMP Treatment Volumes for Stormwater Discharges to Class III Waters

Swales	Infiltration of 80 percent of the runoff generated by a 3-yr/1-hr storm (typically about 5.1 cm [2 in.] of runoff).
Retention	Off-line infiltration of the first 1.25 cm (0.5 in.) of runoff or the volume calculated by 1.25 times the percent imperviousness of the project area, whichever is greater. On-line infiltration must treat an additional 1.25 cm of runoff above the volume required for off-line treatment.
Detention With Filtration	Filtration of detention volume.
Wet Detention	Detention of the first 2.54 cm (1 in. of runoff) or the volume calculated by 2.5 times the percent imperviousness of the project area, whichever is greater.
Wetlands	Same as for wet detention.

Notes: Discharges to sensitive waters must treat 50 percent more stormwater volume and may require infiltration pretreatment.
Discharges to sinkhole watersheds must treat the first 2 in. of runoff (Suwannee River WMD criterion).

information becomes available about the field effectiveness of various types of BMPs.

In addition to the stormwater treatment volumes, other design and performance standards have been set to ensure that BMPs function optimally to attain the stormwater treatment goal and other management objectives (9). These guidelines will be discussed for each of the BMPs currently being used extensively in Florida.

Swales

Swales are defined by Chapter 403, Florida Statutes (FS), as manufactured trenches that:

- Have a top width-to-depth ratio of the cross section equal to or greater than 6:1, or side slopes equal to or greater than 3 ft horizontal to 1 ft vertical.
- Contain contiguous areas of standing or flowing water only following a rainfall event.
- Are planted with or have stabilized vegetation suitable for soil stabilization, stormwater treatment, and nutrient uptake.
- Are designed to take into account soil erodibility, soil percolation, slope, slope length, and drainage area so as to prevent erosion and reduce pollutant concentration of any discharge.

Swale treatment of stormwater is accomplished primarily by infiltration of runoff and secondarily by adsorption and vegetative filtration and uptake (10). Recent investigations have concluded that Florida soil, slope, and water table conditions essentially preclude the use of swales as the sole BMP to treat stormwater (11). Therefore, the greatest utility of swales is as a pretreatment BMP within a BMP treatment train stormwater system. Infiltration pretreatment can be easily accomplished by using raised storm sewer inlets within the swale, or by elevating driveway culverts or using swale blocks to create small retention areas.

Retention

Off-line retention areas, which receive the first flush volume only while the later runoff is diverted to a flood control BMP, are the most effective stormwater treatment practice. Treatment is achieved through diversion and infiltration of the first flush, thereby providing total pollutant removal for all stormwater that is retained on site. To reduce operation needs, increase aesthetics, and reduce the land area needed for stormwater treatment, retention areas should be incorporated into a site's landscaping and open-space areas. Effectiveness of retention areas can be increased and ground-water impacts decreased by:

- Infiltrating the stormwater treatment volume within 72 hr or within 24 hr if the retention area is grassed.
- Grassing the retention area bottom and side slopes, which reduces maintenance and maintains soil infiltration properties.
- Maintaining at least 3 ft between the bottom of the retention area and seasonal high water tables or limerock.
- In karst-sensitive areas, using several small, shallow infiltration areas to prevent formation of solution pipe sinkholes within the system.

Exfiltration trenches typically are used in highly urbanized areas where land is unavailable for retention basins. They consist of a rock-filled trench surrounded by filter fabric in which a perforated pipe is placed. The stormwater treatment volume is stored within the pipe and exfiltrates out of the perforations into the gravel envelope and into the surrounding soil. Pretreatment with catch basins to remove sediments and other debris is essential to prevent clogging. To extend longevity and reduce maintenance, exfiltration systems should always be off-line.

Detention With Filtration

Detention with filtration systems were proposed as an alternative to retention for small projects (less than 8 acres) in those areas of Florida where local conditions, especially flat topography and high water tables, prevent infiltrating the stormwater treatment volume. The filters must consist of 2 ft of natural soil or other suitable fine-textured granular media that meet certain specifications, including:

- Filters must have pore spaces large enough to provide sufficient flow capacity so that the filter permeability is equal to or greater than the permeability of the surrounding soil.
- The design shall ensure that particles within the filter do not move.
- When sand or other fine-textured material other than natural soil is used for filtration, the filter material 1) will be washed (less than 1 percent silt, clay, or organic matter) unless filter cloth is used to retain such materials within the filter, 2) will have a uniformity coefficient between 1.5 and 4.0, and 3) will have an effective grain size of 0.20 to 0.55 mm in diameter.
- Be designed with a safety factor of at least two.
- Will recover the treatment volume (bleed down) within 72 hr.

Filters are placed in the bottom or sides of detention areas, where the filtered stormwater is collected in an underdrain pipe and then discharged. Experience has shown that these filters are very difficult to design and construct. Operation is also difficult because of low hydraulic head, and maintenance is nearly impossible. It is not a question of if a filter will clog, only when it will clog. In addition, filters are designed to remove particulate pollutants and do not remove dissolved pollutants such as phosphorus or zinc. Therefore, filtration systems are not recommended for use except under very special conditions and where a full-time maintenance entity such as a local government will assume such responsibilities.

Wet Detention

Wet detention systems consist of a permanent water pool, an overlying zone in which the stormwater treatment volume temporarily increases the depth while it is stored and slowly released, and a shallow littoral zone (biological filter). In addition to their high pollutant removal efficiencies (12), wet detention systems can also provide aesthetic and recreational amenities, a source of fill for the developer, and even "lake front" property, which brings a premium price.

Wet detention criteria are listed in Table 2. These have been developed to take full advantage of the biological, physical, and chemical assimilation processes occurring within the wet detention system. If the system is designed as a development amenity, the use of pretreatment BMPs integrated into the overall stormwater management system is highly recommended to prevent algal blooms or other perturbations that would reduce the aesthetic value. Raised storm sewers in grassed areas such as parking lot landscape islands, swale conveyances, and perimeter swale/berm systems along the detention lake shoreline are techniques that have been used frequently.

Table 2. Wet Detention Guidelines

1. Treatment volume as per Table 1.
2. Treatment volume slowly recovered in no less than 120 hr with no more than half of the volume discharged within the first 60 hr following the storm:
   - Volume in the permanent pool should provide a residence time of at least 14 days.
   - At least 30 percent of the surface area shall consist of littoral area with slopes of 6:1 or flatter that is established with appropriate native aquatic plants selected to maximize pollutant uptake and aesthetic value.
   - Littoral zone plants shall have a minimum 80 percent survival rate and coverage after 2 years. Cattails and other undesirable plants shall be removed.
   - The littoral zone is concentrated near the outfall or in a series of shallow benches ending at the outfall.
   - Side slopes should be no steeper than 4:1 out to a depth of 2 ft below the level of the permanent pool.
   - Maximum depth of 8 to 10 ft below the invert of the discharge structure is recommended. Maximum depth shall not create aerobic conditions in bottom sediments and waters.
   - The flow length between inlets and outlet should be maximized; a length-to-width ratio of at least 3:1 is recommended. Diversion barriers such as baffles
   - An oil and grease skimmer shall be designed into the outlet structure.
   - If the system is planned as a "real estate lake," pretreatment by infiltration is recommended.
   - Inlet areas should include a sediment sump.

Wetland Treatment

Wetland treatment was authorized by the 1984 Henderson Wetlands Protection Act, which allows stormwater treatment in wetlands that are connected to other state waters by a constructed ditch or by an intermittent water course that flows in direct response to rainfall, thereby causing the water table to rise above ground surface. Not only does this take advantage of natural treatment mechanisms but it gives another economic value to wetlands—an incentive to the developer to use, not destroy, the wetland—and it revitalizes ditched and drained wetlands by providing water.

Wetlands may be viewed as nature's kidneys—they store stormwater, dampen floodwaters, transform pollutants, and even retain pollutants, thereby providing natural stormwater treatment (13). Care must be taken, however, to protect the numerous assimilation mechanisms within the wetland plants and sediments. In addition, the wetland hydroperiod—the duration that water stays at various levels—must be protected or restored because it determines the form, function, and nature of the wetland. Therefore, pretreatment practices to attenuate

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stormwater volume and peak rate and to reduce oil, grease, and especially sediment are essential. The BMP treatment train concept must be used to provide pretreatment, which normally includes a pretreatment lake that is constructed adjacent to the wetland.

The following guidelines are presented for incorporating wetlands into a stormwater management system:

- The treatment volume is per Table 1, with the treatment volume slowly recovered in no less than 120 hr with no more than half of the volume discharged within the first 60 hr following the storm.
- Stormwater must sheet flow evenly through the wetland to maximize contact with the wetland plants, sediments, and microorganisms. Spreader swales, distribution systems, and level spreaders between the pretreatment lake and the wetland have been used extensively.
- Swales should be used for stormwater conveyance throughout the development.
- The hydroperiod must be protected or restored.
- Treatment volume capacity of the wetland is determined by the storage volume available between the normal low and high elevations. These elevations are determined by site-specific indicators such as lichen and moss lines, water stain lines, adventitious root formation, plant community zonation, hydric soils distribution and rack/debris lines.
- Erosion and sediment control during construction is essential because only a few inches of sediment deposited in the wetland will destroy the wetland filter.
- Inflow/outflow monitoring, sediment metal levels, and vegetative transect monitoring are required to help evaluate the effectiveness of these systems and the impacts of stormwater additions to wetlands.

Administration of the Stormwater Rule

Under the Florida Water Resources Act of 1972, DER, a water quality agency, serves as the umbrella administering agency delegating authority to five regional WMDs whose primary functions historically have been related to water quantity management. Therefore, a second objective in developing the stormwater rule was to coordinate the water quality considerations of DER's stormwater permits with the water quantity aspects of the districts' surface water management permits.

In addition, the delegation of the stormwater permitting program allows for minor adjustments to stormwater rule design and performance standards to better reflect regional conditions. Florida is a very diverse state, with major variations in soils, geology, topography, and rainfall that can directly affect the usability and treatment effectiveness of a BMP. Such problems can be minimized if districts adopt slightly different design and performance standards which are approved by DER before implementation.

Both DER's and the districts' stormwater rules essentially require a new development to include a comprehensive stormwater management system. The system should be viewed as a "BMP treatment train" in which a number of different BMPs are integrated into a comprehensive system that provides aesthetic and recreational amenities in addition to traditional stormwater management objectives.

The Challenge Ahead

The implementation of Florida's stormwater treatment requirements has been very effective in helping to reduce the stormwater pollutant loading from new development. As a result, the biggest stormwater management problem facing Florida is how to reduce pollutant loadings discharged by older systems, especially local government master systems constructed before the stormwater rule was implemented. These systems were designed solely for flood protection and rapidly deliver untreated stormwater directly to rivers, lakes, estuaries, and sinkholes.

Establishing a stormwater program to retrofit existing systems presents many technical, institutional, and financial dilemmas. The unavailability and cost of land in urbanized areas make conventional BMPs infeasible in most instances. Current state laws and institutional arrangements promote piecemeal, crisis-solving approaches aimed at managing stormwater within political boundaries, yet stormwater follows watershed boundaries. Land-use planning and management must be fully integrated into the stormwater management scheme. Retrofitting is also prohibitively expensive, and many local governments are already short of funds. Therefore, solving our existing urban stormwater problems requires comprehensive, coordinated, creative approaches and technology.

Following is a brief discussion of some of the essential elements of a comprehensive long-term effort to reduce pollutant loadings from older stormwater systems.

Watershed Management

A watershed approach that integrates land-use planning with the development of stormwater infrastructure is essential. After all, it is the intensification of land use and the increase in impervious surfaces within a watershed that create the stormwater and water resources management problems. Consequently, a watershed management team effort, involving state and local governments together with the private sector, is necessary. In fact, local governments are the primary team member because they determine zoning and land use, issue building permits and inspect projects, and have code enforcement powers that can help to ensure that stormwater systems are properly operated and maintained.

Local governments need to identify and map the existing natural stormwater system: the creeks, wetlands, flood plains, drainageways, and natural depression areas. Once mapped, these areas need to be zoned for conservation or low-intensity uses compatible with the functions provided by the natural system. The existing constructed stormwater system must also be mapped, and essential characteristics such as pipe size, drainage areas, and invert elevations must be determined. This information should then be fully integrated with the existing and future land-use plan for the watershed and a master stormwater management plan developed and implemented. The Growth Management Act of 1985, which requires all local governments to adopt comprehensive plans addressing current and future land use with infrastructure needs, establishes a base structure that could promote a watershed management approach.

Treatment Requirements for Older Systems

Numerous problems inherent in a highly urbanized area prevent the application of new development stormwater treatment standards from being imposed on older systems. Instead, a "watershed loading" concept is proposed which considers the beneficial uses of the receiving waters and the total stormwater load that can be assimilated by the receiving waters. The actual treatment level would depend on the watershed's total allowable loading, which is based on citizen desires for certain beneficial uses of the receiving water. The amount of load reduction needed to restore or maintain the desired beneficial uses of the receiving waters is known as the pollutant load reduction goal (PLRG).

Selective Targeting

The extremely high cost of retrofitting older urban stormwater systems also implies a need for careful evaluation of pollutant reduction goals. A long-term (25 to 40 years) plan based on prioritization of watersheds such that existing systems are selectively targeted for modification is needed to ensure that citizens receive the greatest benefit (pollutant load reduction, flood protection) for the dollar. The upgrading of older systems must also be coordinated with other already planned infrastructure improvements such as road widenings. An excellent example of this approach is the Orlando Streetscape Project. While downtown streets were torn up for this downtown renovation, the existing stormwater system was modified by the addition of off-line exfiltration systems to reduce pollution loads to downtown lakes.

Nonstructural BMPs and source controls also must be used extensively to reduce stormwater pollution from already developed areas. Improved street sweepers that pick up the small particles (<60 microns) that contain high concentrations of metals and other pollutants could also prove valuable in reducing stormwater loadings, especially from downtown business districts where other BMPs usually are infeasible. Education programs for the general public and for professionals involved in stormwater management also are vital. Citizens must understand how their everyday activities contribute to stormwater pollution. For example, citizens should not discard leaves, grass clippings, used motor oil, or other material into swales or storm sewers. Getting youth and citizen groups involved in storm sewer stenciling projects ("Dump No Wastes, Drains To Lake") is an excellent way of reducing dumping of potential pollutants into these conveyances. Even more importantly, comprehensive training and certification programs are needed for those in the private and public sectors who design, construct, inspect, operate, and maintain stormwater management systems.

Funding

The cost of providing needed stormwater infrastructure improvements to address current and future flooding and water quality problems is gigantic. Yet local governments are already struggling financially, and traditional revenue sources such as property taxes cannot be relied on to pay for stormwater management. Instead, a dedicated source of revenue based on contributions to the stormwater problem is needed. The stormwater utility can provide this. The city of Tallahassee implemented Florida's first stormwater utility in October 1986, and over 50 local governments have followed this example.

Innovative BMPs

The infeasibility of using traditional BMPs to reduce stormwater pollutant loads in highly urbanized areas means that creative and innovative BMPs are needed. For example, alum injection within storm sewers was used in Tallahassee to reduce stormwater loadings to Lake Ella (14). A sonic flow meter measures storm sewer flow, causing a flow-proportional dose of aluminum sulfate to be injected and mixed with the polluted stormwater. As the alum mixes with the stormwater, a small floc is produced which attracts suspended and dissolved pollutants by adsorption and enmeshment into and onto the floc particles. The floc then settles to the lake's bottom sediments, gradually blanketing and incorporating into the sediments and thereby reducing internal recycling of nutrients and metals. Other advantages of alum injection include excellent pollutant reduction (>85 percent) and relatively low construction and operations costs, especially for the highly urbanized areas. This type of system has been installed at several locations in Florida with exceptional treatment efficiencies.

Porous concrete consists of specially formulated mixtures of Portland cement, uniform open-graded coarse aggregate, and water. When properly mixed and installed, porous concrete surfaces have a high percentage of void space which allows rapid percolation of rainfall and runoff. Porous concrete is being used widely in Florida, especially for parking lots, and could be an important BMP to reduce stormwater loadings in highly urbanized areas. Recent field investigations of porous concrete parking areas that have been in place for up to 12 years revealed that the infiltration capacity of the concrete has not decreased significantly, a major concern (15). Further information about the use, design, and construction of porous concrete surfaces is available (15).

Regional stormwater systems that manage stormwater from several developments or an entire drainage basin offer many advantages over the piecemeal approach that relies on small, individual onsite systems. They provide economies of scale in construction, operation, and maintenance. Regional systems can also help manage stormwater from existing and future land uses and will be a central part of any retrofitting program. The use of regional systems is another good reason for a watershed management approach that fully integrates land use and stormwater management.

The Southeast Lakes Program—A Model

Many of the above elements of a watershedwide master stormwater planning approach are being implemented by the city of Orlando. The city has adopted an excellent local stormwater ordinance and developed a fine community education program and a prioritized urban lake management program (16). One of the most innovative programs is the Southeast Lakes Project, which is designed to correct flooding problems and to reduce stormwater pollutant loads to 15 urban lakes and 58 drainage wells that currently convey untreated stormwater to an aquifer. A corrective watershed management plan was cooperatively developed by the city, its consultants, DER, and the St. Johns River WMD. The project was initiated not because of enforcement of water quality standards but because of a loss of beneficial uses and local citizen desires and perceptions. Modifications to the existing stormwater systems will be made over a 10-year period, with treatment requirements based on "net environmental improvement" and total watershed load.

One of the most important aspects of the project is the use of innovative BMP designs that promote multiple objectives and take advantage of city-owned properties. At Al Coith Park, a spreader swale will be built on the park's perimeter. When it rains, runoff will enter and fill the swale, overtopping the sidewalk berm and sheet flow across the grassed parkland where it will percolate into the ground. At Lake Greenwood, the surrounding city-owned land is being converted into an urban wetland and expanded lake. The wetland and lake is a complex treatment train that incorporates many BMPs into a very aesthetically pleasing stormwater system and park that even includes reuse of stormwater to irrigate the park and adjacent city-owned cemetery. Near the Citrus Bowl, a packed-bed wetland filter has been installed that will treat water from Lake Clear during times of no rainfall. In addition to improved stormwater management, citizens are receiving the added benefits of recreation and open space. In addition, the retrofitting project has stimulated redevelopment and renovation of existing properties, thereby providing citizens with economic benefits as property values rise.

Chronologic Evolution of Florida's Watershed Management Program

Following is a chronology of the establishment and revision of Florida statutes and programs that are considered cornerstones of the state's overall watershed management efforts. As such, this chronology traces the evolution of Florida's watershed management program.

1970

Chapter 370, FS, created the Coastal Coordinating Council, which was the first state effort at integrating state/regional programs in the protection and use of coastal resources. Initial efforts from 1970 to 1975 focused on a comprehensive resource-based coastal protection program.

1972

A package of land and water planning, regulation, and acquisition programs was created:

- Chapter 380, FS: This creates the Developments of Regional Impact (DRI) and Areas of Critical State Concern (ACSC) land planning and management programs.
- Chapter 373, FS: The Florida Water Resources Act establishes the state's five regional WMDs; designates the Department of Pollution Control as the oversight agency for the WMDs; requires the development of a state water plan; and allows for the regulation of the water resource. WMDs financed by *ad valorem* property taxing authority of up to 1 mil ($1/$1000 value) which is set in the Florida Constitution. NWFWMD millage capped at 0.05 mil.
- Chapter 259, FS: The Land Conservation Act establishes a program, commonly known as the Environmentally Endangered Lands Program, which authorizes the state to purchase critical and sensitive lands; envisioned as a 10-year program investing $200 million and funded by the sale of state bonds.

1973

In Chapter 403, FS, the Florida Environmental Protection Act renames the Department of Pollution Control as the Department of Environmental Regulation and broadens its powers, duties, and programs. This law is the state's general environmental protection act. It is amended almost annually as new environmental concerns and needs arise and as existing programs evolve.

1975

Chapter 163, FS, the Local Government Comprehensive Planning Act and the state's first growth management legislation, was recommended by the first Environmental Land Management Study Committee (ELMS I). The law requires all cities and counties to prepare comprehensive plans which are submitted for review to the state's land planning agency, the Department of Community Affairs, which in turn sends the plans to other state agencies for review and comment. However, the LGCPA contains no "teeth." Local governments are under no statutory requirement to revise their plans by incorporating the comments and recommendations made by the state reviewing agencies. Furthermore, they are not required to pass land development regulations to implement their plans.

1976

Implementation by EPA and the states of Section 208 of the 1972 Clean Water Act occurs, requiring the development of Areawide Water Quality Management Plans. This was the first national program directed at the assessment and control of nonpoint sources of pollution. In Florida, millions of federal grant dollars allows the DER and 12 "Designated Area Agencies" to undertake extensive research on nonpoint source impacts, sources, controls, control effectiveness, and costs. These data provide the scientific basis for the development and implementation in 1982 of a statewide rule that requires treatment of stormwater for new development and redevelopment projects.

1978

Chapter 380, FS, is amended, adding Part II, the Florida Coastal Management Act, which requires establishment of a program based on existing statutes and rules to serve as a basis for receiving federal approval under the Federal Coastal Zone Management Act of 1972. After approval of the program by the National Oceanic and Atmospheric Administration, Office of Coastal Zone Management, federal grants fund many initiatives to better protect and manage coastal resources. One particular initiative establishes an estuarine watershed management program with emphasis on sediment mapping. This project leads to the development of innovative, reliable coastal sediment sampling, analytical, and assessment techniques.

1979

The first components of the state's Areawide Water Quality Management Plan, the Agriculture Nonpoint Source Plan and the Silviculture Nonpoint Source Plan, are submitted to and approved by EPA. These call for a non-regulatory approach with a regulatory backstop if BMPs required by farm conservation plans are not implemented or if the forestry BMPs required by the state's adopted *Silviculture BMP Manual* are not followed.

Chapter 17-4.248, FAC, the state's first stormwater rule, is adopted by the state ERC as a rule of DER. This rule is intended as a temporary regulation until ongoing research on BMP design and effectiveness is completed. The rule's adoption is controversial, but data collected during from 208 program studies conclusively show that stormwater runoff, especially from urban land uses and highways, is a "pollutant" and therefore should be controlled. Florida's continuing rapid growth makes it imperative that treatment of stormwater, using BMPs, be required for new stormwater discharges that would be "a significant source of pollution."

Chapter 253, FS, is amended to establish the Conservation and Recreation Land (CARL) Trust Fund, which provides additional funding for the purchase of Environmentally Endangered Lands and other lands deemed appropriate and in the public interest by the Governor and Cabinet.

1981

Through action taken by the Governor and Cabinet, the Save Our Coasts land acquisition program is established. The program proposes to spend $200 million over 10 years to purchase coastal lands such as beaches, shorelines, and sensitive areas. Funding is provided by the sale of state bonds backed by documentary stamps as authorized in Chapter 375, FS, which sets policy on how the Land Acquisition Trust Fund is to be administered.

Chapter 373, FS, is amended with the creation of the Save Our Rivers land acquisition program. Administered by the WMDs, this program proposes to spend $320 million over 10 years to purchase wetlands, floodplains, and other lands necessary for water management, water supply, and the conservation and protection of water resources.

1982

Chapter 17-25, FAC, is adopted by the ERC after 2 years of rule adoption workshops and 29 official rule drafts. The rule is technology based rather than water quality based, although the state's water quality standards remain as a backstop should a stormwater discharge be causing violations. A performance standard of 80 percent average annual load reduction is recommended, based on BMP effectiveness and cost data, to establish equity with minimum treatment levels for point source discharges. The rule creates design criteria for various types of BMPs, including retention, detention with filtration, and wet detention. The rule creates "general permits" for certain types of BMPs (i.e., retention, detention with filtration) if they are built to the design criteria. Implementation of the rule is delegated to the South Florida WMD, allowing stormwater treatment requirements to be merged with stormwater quantity (flood control) requirements in one permit.

1984

Chapter 403, FS, is revised to create Section IX, which is known as the Henderson Wetlands Protection Act. This legislation expands the authority of the DER to protect wetlands; establishes administrative procedures to allow landowners to obtain legally binding "wetland lines"; allows the DER to consider fish and wildlife habitat, endangered species, and historical and archaeological resource and other relevant concerns in wetland permitting; allows the use of certain wetlands for incorporation into domestic wastewater and stormwater management systems; transfers wetland regulation for agriculture and forestry activities to the WMDs; and requires the WMDs to protect isolated wetlands and consider fish and wildlife habitat requirements.

The Southwest Florida Water Management District (SWFWMD) receives delegation of the stormwater rule.

In the late 1970s and early 1980s, an extensive appraisal of Florida's growth management system was undertaken, which concluded that the existing system was not working. Shaped by the *Final Report of the Governor's Task Force on Resource Management* (1980) and the second Environmental Land Management Study Committee (ELMS II), a totally new blueprint for managing growth emerged. The ELMS II Committee recommended a comprehensive package of integrated state, regional, and local comprehensive planning; reforms to the DRI law; and coastal protection improvements. The state legislature responded between 1984 and 1986 by enacting several laws. For example, Chapter 186, FS, the State and Regional Planning Act, mandates that the Governor's Office prepare a state comprehensive plan and present it to the 1985 state legislature. It also requires the preparation of regional plans by the state's 11 regional planning councils and provides them with $500,000 for plan preparation.

1985

Chapter 187, FS, the State Comprehensive Plan, originally is envisioned to be a leadership document—the foundation of the entire planning process—with strong, measurable, and strategic goals that will set the course for Florida's growth over the next 10 years. Each state agency is to prepare an agency functional plan, based on the state plan, on which its budget appropriations will be made. Unfortunately, one of the most important elements of the state plan, the development and adoption of a capital plan and budget, is never prepared. However, the plan contains important goals and policies in 25 different areas, including water resources, coastal and marine resources, natural systems and recreation, air quality, waste management, land use, mining, agriculture, public facilities, and transportation.

Important and relevant goals include:

- Ensure the availability of an adequate water supply.
- Maintain the functions of natural systems.
- Maintain and enhance existing surface- and groundwater quality.

Important and relevant policies include:

- Eliminate the discharge of inadequately treated wastewater and stormwater.
- Protect natural systems in lieu of structural alternatives, and restore modified systems.
- Promote water conservation and the use and reuse of treated wastewater and stormwater.
- Establish minimum flows and levels for surface waters to ensure protection of natural systems.

1985 to 1986

Chapter 163, FS, is amended with enactment of the Local Government Comprehensive Planning and Land Development Regulation Act of 1985. This law requires all local governments to prepare local comprehensive plans and implementing regulations, which must be consistent with the goals and policies of the state and regional plans. Numerous state and regional agencies review the local plans and submit their objections, recommendations, and comments to the Department of Community Affairs for transmittal to the local government. This time the local plans must be revised to incorporate the objections, recommendations, and comments. Furthermore, local governments face sanctions from the state that could result in the loss of state funding if adopted local plans are not consistent with the state and regional plans.

Florida's revised growth management system is built around three key requirements: consistency, concurrency, and compactness. The consistency requirement establishes the "integrated policy framework," whereby the goals and policies of the state plan frame a system of vertical consistency. State agency functional plans and Regional Planning Council regional plans must be consistent with the goals and policies of the state plan while local plans are required to be consistent with the goals and policies of the state and appropriate regional plan. Local land development regulations (LDRs) must also be consistent with the local plans goals and policies. Horizontal consistency at the local level also is required to ensure that the plans of neighboring local governments are compatible. Consistency is the strong cord that holds the growth management system together.

Concurrency is the most powerful policy requirement built into the growth management system. It requires state and local governments to abandon their long-standing policy of deficit financing growth by implementing a "pay as you grow system." Once local plans and LDRs are adopted, a local government may approve development only if the public facilities and services (infrastructure) needed to accommodate the impact of the proposed development can be in place concurrent with the impacts of the development. Public facilities and services subject to the concurrency requirements are roads, stormwater management, solid waste, potable water, wastewater, parks and recreation, and, if applicable, mass transit. Level of service standards acceptable to the community must be established for each type of public facility.

Compact urban development goals and policies are built into the State Comprehensive Plan and into regional plans. Such policies as separating rural and urban land uses, discouraging urban sprawl, encouraging urban in-fill development, making maximal use of existing infrastructure, and encouraging compact urban development form the basis for this requirement.

1986

Chapter 403.0893, FS, is created as the only surviving section of a stormwater management bill that was developed over a 10-month period. The bill was an attempt to put into statute a cost-effective, timely process to retrofit existing drainage systems to reduce the pollutant loadings discharged to water bodies. Only the section creating explicit legislative authority for local governments to establish stormwater utilities or special stormwater management benefit areas is enacted.

The St. Johns River WMD adopts Chapter 40C-42, FAC, and the Suwannee River WMD adopts Chapter 40B-4, FAC. Adoption of these two stormwater management regulations and the addition of staff to implement these programs allows DER to delegate administration of its stormwater treatment rule to these WMDs, which, in turn, allows DER's stormwater quality permit to be combined with the districts' stormwater quantity permit.

1987

Chapter 373, FS, is revised to add a new section, the Surface Water Improvement and Management (SWIM) Act, which establishes six state priority water bodies. It directs the WMDs, under DER supervision, to prepare a priority water body list and develop and adopt comprehensive watershed management plans to preserve or restore the water bodies. It provides $15 million from general revenue sources and requires a match from the WMDs. The act does not establish a dedicated funding source, making the program dependent on uncertain annual appropriations from the legislature.

1988

Chapter 17-43, FAC, the SWIM rule, is adopted by the ERC. It sets forth factors to consider in the selection of priority water bodies, specifies the format for SWIM plans to ensure some consistency, and establishes administrative processes for the development and adoption of SWIM plans by the WMDs and for their submittal to DER for review and approval.

The State Nonpoint Source Assessment and Management Plan, prepared pursuant to Section 319 of the federal Clean Water Act, is submitted to EPA and approved. This qualifies the state for Section 319 nonpoint source implementation grants, which are used for BMP demonstration projects and to refine existing nonpoint source management programs. The delineation of the state's ecoregions (based on river systems), selection of ecoregion reference sites, and modification of EPA's Rapid Bioassessment Protocols and metrics for use in Florida are initiated.

1989

Chapters 373 and 403, FS, are revised as part of the 1989 stormwater legislation. The legislation clarifies the stormwater program's multiple goals and objectives; sets forth the program's institutional framework, which involves a partnership between DER, the WMDs, and local governments; defines the responsibilities of each entity; addresses the need for the treatment of agricultural runoff by amending Chapter 187, FS, to add a policy in the Agriculture Element to "eliminate the discharge of inadequately treated agricultural wastewater and stormwater"; further promotes the watershed approach being used by the SWIM program; attempts to integrate the stormwater program, SWIM program, and local comprehensive planning program (but does not succeed); establishes State Water Policy, an existing but little-used DER rule, as the primary implementation guidance document for stormwater and all water resources management programs; and creates the State Stormwater Demonstration Grant Fund as an incentive to local governments to implement stormwater utilities and provides $2 million.

1990

Chapter 17-40, FAC, State Water Policy, undergoes a total revision and reorganization so that it can be used as guidance by all entities implementing water resource management programs and regulations. Section 17-40.420 is created and includes the goals, policies, and institutional framework for the state's stormwater management program.

DER is designated as the lead agency with responsibility for setting goals for the program, for providing overall program guidance, for overseeing implementation of the program by the WMDs, and for coordinating with EPA, especially with the advent of the new National Pollutant Discharge Elimination System stormwater permitting program.

WMDs are the chief administrators of the stormwater regulatory program (quantity and quality); they are responsible for preparing SWIM watershed management plans, which include the establishment of stormwater PLRGs; they provide technical assistance to local governments, especially with respect to basin planning and the development of stormwater master plans.

Local governments are the frontlines in the stormwater/watershed management program because they determine land use and provide stormwater and other infrastructure. They are encouraged, but not required, to set up stormwater utilities to provide a dedicated funding source for their stormwater program. Their stormwater responsibilities include preparation of a stormwater master plan to address needs imposed by existing land uses and those needs to be created by future growth; operation and maintenance activities; capital improvements of infrastructure; and public education. They are encouraged to set up an operating permit system wherein stormwater systems are inspected annually to ensure that needed maintenance is performed.

Important goals include:

- Preventing stormwater problems from land-use changes and restoring degraded water bodies by reducing the pollution contributions from older stormwater systems.
- Retaining sediment on site during construction.
- Trying to ensure that the stormwater peak discharge rate, volume, and pollutant loading are no greater after a site is developed than before.

Important minimum treatment performance standards include:

- 80 percent average annual load reduction for new stormwater discharges to most water bodies.
- 95 percent average annual load reduction for new stormwater discharges to Outstanding Florida Waters, which are a special class of exceptionally high-quality water bodies.
- Reducing, on a watershed basis, the pollutant loading from older stormwater systems as needed to protect, maintain, or restore the beneficial uses of the receiving water body.

Chapter 375, FS, is amended with the creation of Preservation 2000, a 10-year land acquisition program with a goal of spending $300 million per year. The legislation divided available annual funding among seven programs: CARL, Save Our Rivers (SOR), Florida Communities Trust, State Parks, State Forests, State Wildlife Areas, and Rails to Trails. The program is funded the first year by state bonds backed by an increase in the documentary stamp fee. Unfortunately, a long-term dedicated funding source is not identified, making the program subject to annual legislative appropriations. Between 1972 and 1991, the state's land acquisition programs have invested over $1.5 billion to buy over 1.2 million acres. Equally important, as a result of the state land acquisition programs, 14 Florida counties have created local programs that currently commit up to $600 million for land conservation. Revenue sources for these local land acquisition programs include local option sales tax, impact fees, added property taxes, and local bonds.

1991

Chapter 40C-42, FAC, is completely revised by the St. Johns River WMD to modify the design criteria for stormwater treatment BMPs so that they will achieve the minimum treatment levels set in State Water Policy. Stormwater reuse becomes essential for developments discharging to Outstanding Florida Waters.

Chapter 40C-44, FAC, is adopted by the St. Johns River WMD to regulate certain agricultural pumped discharges (formerly regulated as industrial wastewater) and establishes design and performance criteria for these agricultural stormwater management systems.

The SWFWMD initiates development of an agricultural stormwater management program for certain types of agricultural activities including row crops and citrus. The program includes regulatory incentives to obtain technical assistance from U.S. Department of Agriculture, Soil Conservation Service, or other qualified individuals to prepare and implement a farm-specific resource management plan that contains certain required BMPs.

1992

DER and the WMDs, in response to increasing demands on the state's waters and the increasing number of water quantity and quality problems, begin the development of district water management plans. collectively these district plans, together with the DER's plan, will create the state water management plan. These plans are based on the goals and policies set in State Water Policy and in the state comprehensive plan. For each of four major areas (water supply, water quality, flood protection, natural systems protection), four key planning steps will occur:

- Resource assessment to identify current or anticipated problems.
- Examination of options.
- Declaration of policy.
- Designation of implementation strategies.

Section 314 Federal Clean Lake Program Lake Assessment Grant is obtained to initiate the delineation of lake ecoregions, select lake ecoregion reference sites, and test/validate lake bioassessment sampling protocols and metrics.

1993

Chapters 373 and 403, FS, are revised extensively as part of the DER/Department of Natural Resources merger to create the Department of Environmental Protection (DEP) and as a part of the Environmental Permit Streamlining bill. The goals of the streamlining bill are to eliminate duplication, especially in permitting; increase administrative and environmental effectiveness by increasing delegation of programs from DEP to the WMDs; and ensure greater program consistency and integration. Key specific actions of the bill include:

- Moving the "Wetlands Protection Act" from Chapter 403 to Chapter 373, FS, thereby delegating the wetland resource permits to the WMDs except for certain projects that require other types of DEP permits.
- Merging the existing surface water/stormwater management permit with the wetland resource permit to create an environmental resource permit.
- Redefining wetlands based on their hydrology, vegetation, and soils, and requiring the development of a single wetland delineation method that will be used by the DEP, WMDs, and local governments.

Recommendations of the third Environmental Lands Management Study Committee (ELMS III) are enacted into law (with a 180-page act), thereby amending several state laws. The act seeks to strengthen the state planning process by:

- Requiring the Governor to biannually review and analyze the state comprehensive plan and recommend any necessary revisions.
- Requiring the Governor to prepare a new growth management portion of the state comprehensive plan. This is to provide a more detailed and strategic state policy guidance for state, regional, and local governments in implementing the state plan. It is to identify urban growth centers; set strategies to protect identified areas of state and regional environmental importance; and provide guidelines for determining where urban growth is appropriate and should be encouraged. The growth management document must be adopted by the legislature. However, to what extent local comprehensive plans, state agency strategic plans, and regional policy plans must be consistent with the state plan is unknown—to be recommended by the Governor and adopted as law by the 1994 legislature.

The act also provided greater flexibility and less requirements in local comprehensive plans for small cities (≤5,000) and counties (≤50,000); streamlined the plan amendment process by limiting the types of revisions requiring state review and approval; strengthened the local plan evaluation and appraisal process; terminated or made optional the development of regional impact (DRI) process in certain areas and revised the DRI process; and authorized local option gas tax of up to 5 cents.

Discussion and Recommendations

Florida has established a wide variety of laws, regulations, and programs at the state, regional, and local level to protect, manage, and restore the state's incredibly valuable yet vulnerable natural resources, especially its water resources. There is no doubt that these programs have been effective in helping to reduce adverse impacts on natural resources resulting from the state's rapid and continuing growth over the past 20 years. Even with the implementation of these programs, however, many of Florida's natural resources have been severely strained or degraded. Some of these adverse effects can be attributed to activities that occurred before the implementation of modern watershed management programs, such as the channelization of the Kissimmee River and the creation of the vast drainage canal network south of Lake Okeechobee, both of which are contributing to the decline of Lake Okeechobee, the Everglades, and Florida Bay. Other adverse impacts, though, are directly related to the state's rapid growth and development during the last 20 years. These include water supply problems, water quality problems, declining habitat, and impacts on endangered species such as the manatee and the Florida panther.

Why are these adverse impacts still occurring given the wide range of watershed management programs that have been implemented in Florida? What could be done to reduce these effects and possibly restore already degraded areas? Following is a list of program deficiencies and recommendations to correct them:

- While the statutes enacted by the legislature may be helpful, insufficient resources have been provided to the governmental entities that are to implement the programs. The state's reliance on sales tax as it primary means of raising "general revenues" means that state revenues are tied closely to economic conditions. Relying on such sources during a recession, especially when population growth is still occurring, means that the state budget is nearly always in crisis. Dedicated sources of funding are needed if watershed management programs are going to compete for limited state resources and have adequate resources to actually achieve their intended benefits.

- The statutes and programs are not fully integrated, leaving gaps in both land planning and water planning programs. In particular, there is a need to better integrate water and land planning and regulatory programs. The local government growth management program needs to be more closely connected to state and regional water management programs. The requirements set forth in State Water Policy and in the district/state water management plans need to be used by local governments in their land-use planning programs. These local plans need to be consistent among all state, regional, and local programs.
- Greater emphasis needs to be placed on ensuring the long-term maintenance and operation of stormwater management systems. Because these systems are a part of the local infrastructure, local governments need to take a more active role in this area. Establishing stormwater operation permits as part of a stormwater utility funded program is an excellent way of providing an economic incentive to a land owner to maintain and operate an onsite stormwater management system properly.
- Greater emphasis needs to be placed on erosion and sediment control on construction sites and on utility installation projects. A major deficiency is ensuring the regular inspection of erosion prevention and sediment control practices. Implementation of a training and certification program for inspectors and contractor supervisors, similar to the Certified Construction Reviewer Program in Delaware, is needed.
- Retrofitting existing drainage systems to reduce their pollutant loading is one of the biggest, most difficult, and most expensive challenges the state has ever faced. One of the major problems in meeting this challenge is the need to develop new stormwater treatment techniques that are not land intensive. Funding of demonstration projects and for research of new techniques in needed.
- While Floridians are among the most educated citizens in the country with respect to water resources and stormwater management issues, more education is needed to help gain citizen support for watershed management programs. The state's environmental education program needs to focus on establishing a comprehensive natural resources management curriculum that begins in kindergarten and continues all the way through high school. Additionally, because of the large number of people who are moving to Florida, especially retirees, continuous education programs are needed to educate these people about the vulnerability and importance of Florida's natural resources.

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The State of Delaware Sediment Control and Stormwater Management Program

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Institutional Philosophy

Before submitting proposed legislation regarding stormwater management or sediment control, representatives of the State of Delaware Department of Natural Resources and Environmental Control (DNREC) conducted an extensive educational program to document the serious nature of water quantity and quality problems that exist statewide. This problem documentation was successful in that elected officials, affected industries, and the general public acknowledged the need for a comprehensive approach to sediment control and stormwater management. The statewide legislation was unanimously approved in four committees and on the floor of both the state senate and the house of representatives. The local conservation districts were instrumental in their support of the legislation. In addition, the regulations detailing the legislative requirements were approved with no negative comments after an extensive educational process and with the assistance of a regulatory advisory committee.

A basic premise of the program is that sediment control during construction and stormwater quantity and water quality control postconstruction are all components of an overall stormwater management program that functions from the time that construction is initiated through the lifespan of the constructed project (Figure 1). Program implementation was initiated on July 1, 1991, and the initial emphasis of the program is to prevent existing flooding or water quality issues from worsening. The intent is to limit further degradation until more comprehensive, watershed-specific approaches, as detailed in the state legislation and regulations, can be adopted.

Program Structure

The structure of the sediment and stormwater management program is based on the premise that ultimate program responsibility must rest with the state. In the case of Delaware, the state agency responsible for program implementation is DNREC. DNREC is the ultimate approval authority. Local conservation districts and jurisdictions, however, may request delegation of four program components:

- Sediment control and stormwater management plan approval.
- Inspection during construction.
- Postconstruction inspection of permanent stormwater facilities.
- Education and training.

The sediment control and stormwater management plan review and approval process must be completed before any building or grading permits are issued. Criteria for plan review and approval are contained in state regulations, and design aids and handbooks have been developed or approved by DNREC. One important distinction of the Delaware program is that the delegated local agency handles day-to-day inspection responsibilities.

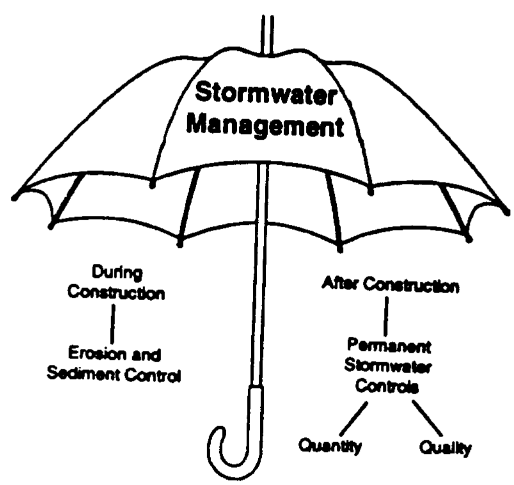

Figure 1. Stormwater management.

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Projects for which site compliance cannot be achieved are transferred to the state, where progressive, aggressive enforcement is carried out. State enforcement options include civil and criminal penalty provisions.

Control Practices

Site control practices (Figures 2 and 3) are grouped into two categories: temporary practices during construction and permanent practices for postconstruction runoff. Sediment control practices, designed for temporary site control, must comply with the *Delaware Erosion and Sediment Control Handbook*. This handbook details numerous practices that are available for use depending on applicability. The plan review process ensures that the sediment control practices are located appropriately.

In addition to the traditional structural controls that the handbook contains, the regulations have several requirements that are important to providing overall site control. Site stabilization must be accomplished if the disturbed areas are not being actively worked for a period in excess of 14 days. In addition, unless modified for a specific type of project, no more than 20 acres may be disturbed at any one time to facilitate phasing of a project.

The regulations specifically require that water quality must achieve an equivalent removal efficiency of 80 percent for suspended solids. From a permanent stormwater management standpoint, initial consideration for control must be a pond that has a permanent pool of water. These wet ponds also have an extended detention requirement placed on them in addition to peak flow control of larger storms. Ponds having a normal pool are preferred over either normally dry extended detention ponds or infiltration practices due to their documented performance records and the ability of wet ponds to reduce downstream nutrient loadings. Wet ponds, if properly designed, also can be an amenity to the community where they are placed. A major emphasis is being placed on constructed wetlands as a primary stormwater treatment system in upland areas. The Delaware program does not encourage the use of existing wetlands for stormwater treatment.

Another option for site control is the use of infiltration practices. These practices are allowed but not encouraged due to their potential for clogging and concern over

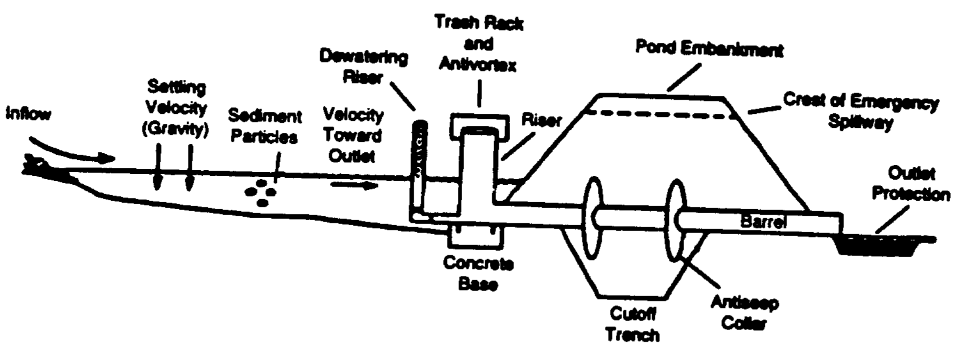

Figure 2. Sediment pond (to be converted to permanent stormwater management facility).

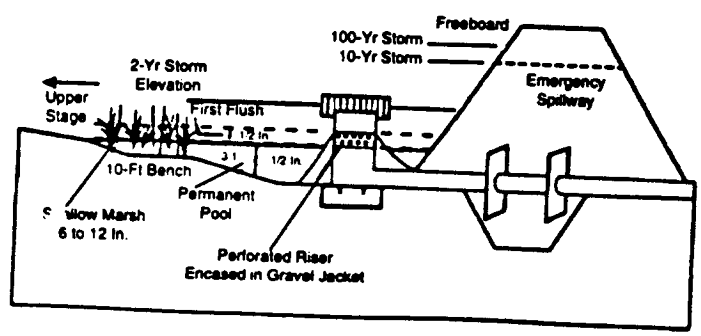

Figure 3. Extended detention pond.

ground-water pollution. Experience in other jurisdictions has demonstrated the potential that infiltration practices have for clogging. Where infiltration practices are used, upslope and downslope impacts in the event of clogging are carefully considered during the plan review process. Infiltration of stormwater runoff is a necessary component of an overall stormwater management program, but critical safeguards relating to filtering of stormwater and ground-water pollution concerns must be considered before design approval.

Filtration of runoff also must be a program component either as a stand-alone practice or in conjunction with other practices, primarily infiltration. Common filtration practices generally rely on vegetative filtering of runoff over filter strips or through swale systems. On highly impervious sites, vegetative filters often are not feasible; in these situations, a sand filter design may be appropriate for initial water quality treatment (Figure 4). Several variations in sand filter designs may be applicable from site to site, but defined design criteria must be followed if the system is to be effective at pollutant removal.

Unique Features

Several features of the Delaware program are unique. The regulations clearly require that stormwater management practices achieve an 80-percent reduction in suspended solids load after a site has been developed. The only other state to present a similar performance criteria is Florida. The 80-percent figure was selected based on a review of documented stormwater practice performances around the country. That level of performance can be achieved with present technology application. Long-term removal rates in excess of 80 percent may require extraordinary measures such as water reuse, which may be required on a local basis but which is not practical from a statewide perspective.

The concept of delegation of program components is fairly unique with respect to program implementation. In Delaware, each aspect of program implementation may be delegated, with DNREC acting as a safety net in the event that a conservation district or a local government fails to adequately implement an aspect of the program. The initial concept of delegation was developed in Maryland for inspection of sediment control; the concept was expanded in the Delaware law and regulations to encompass all aspects of program implementation. The actual interaction of state and local program implementers has quickly become a partnership effort, with the state providing technical expertise and educational training while the conservation districts and local governments provide for actual program implementation.

A major way in which the Delaware program is unique is in the use of privately provided inspectors (Certified Construction Reviewers). The land developer on larger projects (over 50 acres in size or where the state or delegated inspection agency requires) must provide sediment control and stormwater inspectors to assist the appropriate governmental inspection agency. These inspectors must attend and pass a DNREC course on inspection, inspect active construction sites at least once a week, and submit an inspection report to the developer/contractor and the inspection agency on their findings and recommendations. The inspection agency still must periodically inspect the site to ensure the adequacy of site controls, but the designated inspector reduces the frequency of inspection for the inspection agency. Failure to accurately record site conditions or failure to notify either the contractor/developer or inspection agency of site deficiencies may jeopardize the desig-

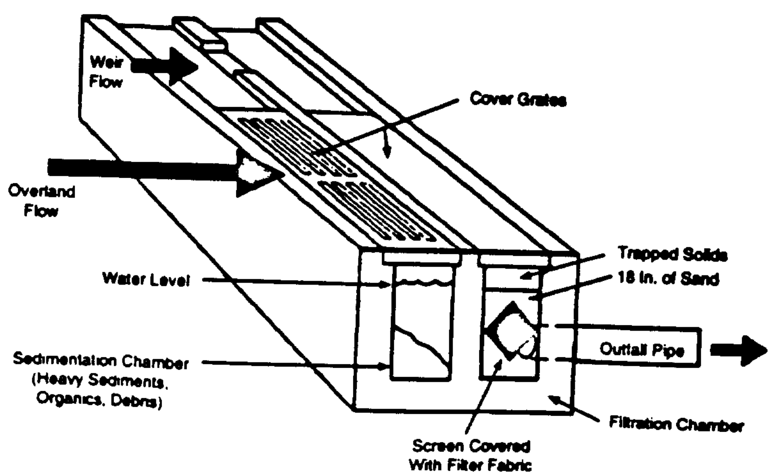

Figure 4. Sand filter design.

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nated inspector's certification, which could be grounds for enforcement action against the contractor/developer.

Another important concept that is becoming increasingly popular among states implementing sediment control programs is the requirement that contractors must have a responsible individual(s) certified as having attended a DNREC course for sediment control and stormwater management. The Delaware course lasts approximately 4 hours and attempts to acquaint contractors with the importance of good site erosion and sediment control and stormwater management, as well as with their responsibilities under the law. The contractor certification program is extremely popular with contractors and reduces the "we-they" problems that often exist in regulatory programs.

Evolution

The program discussed above represents the initial phase of program implementation in Delaware. The next step relates to addressing stormwater management from a watershed perspective. The sediment and stormwater regulations contain a Designated Watershed concept that allows for the design and construction of practices on a watershed basis that, when coupled with land-use planning, wetland restoration, and other nonstructural practices, reduces existing flooding problems or improves existing water quality. The expectation is that one watershed will be designated in each county to serve as a model for other watersheds. These watersheds will be studied from a hydrologic, water quality, and stream habitat and diversity standpoint, and alternative land uses and stormwater controls will be considered along with their impact on water quality. Based on the results of the watershed study, a recommended approach for watershed protection will be developed in conjunction with local government officials that presents a blueprint for future resource protection in these Designated Watersheds.

Funding is another area that must be addressed if the initial program is to be expanded. The state law and regulations provide a framework for expanding traditional funding mechanisms with more innovative types of funding. The regulations contain significant information on the consideration of stormwater utilities (user fees) as an alternative to permit fees or general funding. The stormwater utility is expected to accompany the Designated Watershed concept as a mechanism to fund the watershed studies, planning, design, implementation of practices, and the maintenance of completed stormwater management structures.

One area that has not been satisfactorily addressed at this time is the maintenance of residential stormwater management structures. Commercial stormwater management structure maintenance is not expected to present a significant problem, because one entity is generally responsible for overall site maintenance; residential stormwater management structure maintenance, however, is not so easily assured. At this time, residential maintenance is generally the responsibility of a community association, but eventually that responsibility must become a public responsibility if maintenance is to be assured. If that shift of responsibility is to occur, a dedicated funding source, such as a stormwater utility, will have to be implemented.

The issue of land use and its relationship to water quantity and water quality needs to evolve if resource protection is to be accomplished. Significant effort will be expended in educating local government officials on the importance of wetlands, open space, greenways, cluster development, and other options to conventional "cookie cutter" zoning. The Designated Watershed approach will provide specific details on the benefits of alternative land-use approaches and their impacts on water quality and aquatic resources.

An effective stormwater management program must be multifaceted in its approach and implementation. It must cross conventional lines that are based on an erroneous assumption that total resource protection can be provided through the implementation of structural controls that are considered only after entire site utilization has been maximized. Land-use limitations, dedicated open space, vegetated buffer areas, and reduced impervious areas are all components of an overall resource protection strategy. The implementation of a structural control strategy alone will only reduce the rate of resource decline. That type of program needs to be implemented as a first step, but programs should recognize the need for continued evolution for true resource protection to occur.

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Section 6217 Coastal Nonpoint Pollution Control Program: Program Development and Approval Guidance

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Abstract

In recognition of the fact that over half of the nation's population lives in coastal areas and that nonpoint source pollution remains a significant limiting factor in attaining coastal water quality goals, Congress enacted Section 6217 of the Coastal Zone Act Reauthorization Amendments of 1990 (CZARA). Section 6217 establishes a requirement that states with federally approved coastal zone management programs develop and implement coastal nonpoint pollution control programs to address nonpoint sources affecting coastal waters.

These coastal nonpoint programs are to be implemented through changes to state nonpoint source pollution programs approved by the U.S. Environmental Protection Agency (EPA) under Section 319 of the Clean Water Act and through changes to state coastal zone management programs approved by the National Oceanic and Atmospheric Administration (NOAA) under Section 306 of the Coastal Zone Management Act. The central purpose of Section 6217 is to strengthen the links between federal and state coastal zone and water quality management programs and thereby enhance state and local efforts to manage land uses that affect coastal water quality. States are to achieve this by implementing 1) management measures in conformity with guidance published by EPA under Section 6217(g) of CZARA, referred to as the (g) guidance or the management measures guidance, and 2) additional management measures developed by states where necessary to achieve and maintain water quality standards.

In addition to the (g) guidance, NOAA and EPA have jointly produced program development and approval guidance that outlines the requirements for state coastal nonpoint programs. The program guidance outlines the process by which states will develop their programs and submit them for approval. It also includes the criteria by which EPA and NOAA will evaluate state coastal nonpoint programs.

This paper provides an overview of the program development and approval guidance by briefly describing the elements of the program development process and the necessary components for an approvable state program. Included in this description are coastal zone boundary modification recommendations; identification of nonpoint sources to be addressed; implementation of management measures; additional management measures/critical areas; enforceable policies and mechanisms; program coordination, public participation, and technical assistance; and the program approval process.

Overview

As part of the Coastal Zone Act Reauthorization Amendments of 1990 (CZARA), Congress enacted a new Section 6217, entitled "Protecting Coastal Waters." This new section requires states with federally approved coastal zone management programs to develop and implement coastal nonpoint pollution control programs (referred to here as coastal nonpoint programs).[1] These coastal nonpoint programs are to build and expand upon existing efforts to control nonpoint pollution by state coastal zone management and nonpoint source control agencies.

Section 6217(g) of the statute requires the U.S. Environmental Protection Agency (EPA), in consultation with the National Oceanic and Atmospheric Administration (NOAA), the U.S. Fish and Wildlife Service, and other federal agencies, to publish and periodically update "guidance for specifying management measures for sources of nonpoint pollution in coastal waters." This

[1] The term "state" refers to states, territories, and commonwealths having coastal management programs approved under Section 306 of the Coastal Zone Management Act. There are currently 29 such programs.

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technical guidance, or (g) guidance, was published on January 19, 1993. A companion guidance document, entitled *Coastal Nonpoint Pollution Control Program: Program Development and Approval Guidance*, was also released on the same date. Though the program guidance was not required by the statute, NOAA and EPA developed the guidance in an effort to identify clearly the necessary elements for an approvable state coastal nonpoint program.

The statute sets out a two-tiered process for implementing management measures. First, states are to implement technology-based management measures throughout the Section 6217 management area. Second, states must implement additional management measures where water quality standards are not attained or maintained. The states are to determine these additional measures. The program guidance further explains the justification necessary to exclude any nonpoint source category or subcategory from the first tier of a state coastal nonpoint program and sets out the components each state program should include. The program guidance provides for a threshold review process that allows states to work with NOAA and EPA to evaluate their existing nonpoint programs and identify gaps that need to be filled. Finally, the program guidance establishes a process for submitting programs to NOAA and EPA for approval and a schedule for program development, approval, and implementation.

The focus of this paper is the "nuts and bolts" of each state coastal nonpoint program. Each program will vary due to unique differences in both state physiographic features and government structure. Even so, the basic components of a state coastal nonpoint program need to include those elements identified in the statute and discussed in the program guidance.

Statutory Requirements

Section 6217 requires that several elements be included in each state coastal nonpoint program in order to receive NOAA and EPA approval. These basic statutory requirements, excerpted from the program guidance, appear below. State programs must:

- Be closely coordinated with existing state and local water quality plans and programs developed pursuant to Sections 208, 303, 319 and 320 of the Clean Water Act, and with state coastal zone management programs.
- Provide for the implementation, at a minimum, of management measures in conformity with the guidance published under Section 6217(g) to protect coastal waters generally.
- Provide for the implementation and continuing revision from time to time of additional management measures that are necessary to attain and maintain applicable water quality standards and protect designated uses with respect to:
  - Land uses that, individually or cumulatively, may cause or contribute significantly to a degradation of 1) coastal waters not presently attaining or maintaining applicable water quality standards or protecting designated uses or 2) coastal waters that are threatened by reasonably foreseeable increases in pollution loadings from new or expanding sources.
  - Critical coastal areas adjacent to coastal waters that are failing to attain or maintain water quality standards or that are threatened by reasonably foreseeable increases in pollutant loadings.
- Provide for technical and other assistance to local governments and the public to implement additional management measures.
- Provide opportunities for public participation in all aspects of the program.
- Establish mechanisms to improve coordination between state agencies and between state and local officials responsible for land-use programs and permitting, water quality permitting and enforcement, habitat protection, and public health and safety.
- Propose to modify state coastal zone boundaries as the state determines is necessary to implement NOAA recommendations under Section 6217(e), which are based on findings that modifications to the inland boundary of a state coastal zone are necessary to more effectively manage land and water uses to protect coastal waters.

Program Development

The Section 6217 Management Area

The statute requires that NOAA conduct a review of each state's existing coastal zone boundary to determine whether or not the area encompassed by the boundary includes the land and water uses that have "significant" impacts on the state's coastal waters. The impact of land and water uses on coastal waters is considered both "individually and cumulatively." In cases where NOAA finds that modifications to the inland boundary of a state's existing coastal zone are necessary to more effectively manage land and water uses, NOAA is required to recommend a modification to the existing coastal zone. Although expressed in terms of a recommendation that a state modify its coastal zone boundary, NOAA's recommendation also defines what NOAA and EPA believe should be the geographic scope of that state's coastal nonpoint program, i.e., the "6217 management area."

NOAA conducted a review of each state's coastal zone boundary, using existing national data to evaluate land

and water uses within the state. The national data included information on such parameters as population, land area, harvested crop land, and soil loss from crop land. Information was compiled for each state and summarized in a draft document entitled *National Summary: State Characterization Reports.*

In evaluating indicators of nonpoint source pollution, NOAA analyzed data for areas within the state's existing coastal zone and for areas within and outside of coastal watersheds. NOAA used the smallest U.S. Geological Survey mapping unit as a definition of the coastal watershed. In cases where indicators suggested that nonpoint pollution beyond the coastal watershed might have a significant impact on coastal waters, NOAA assessed the need to further extend the boundary to encompass these land and water uses. The area finally recommended by NOAA for inclusion (both the land area encompassed by the existing coastal zone boundary and any area landward of the existing boundary) constitutes the 6217 management area.

NOAA recently provided recommendations to states for modifying their existing coastal zone boundaries. These boundary recommendations generally conform with the state coastal watershed boundaries, except in cases where indicators of nonpoint pollution beyond the coastal watershed appear significant. In such cases, NOAA recommends that an additional area landward of the coastal watershed be included in the 6217 management area. In addition to the boundary recommendations, NOAA issued a set of draft criteria that states may use in developing their response to the boundary modification recommendation. The final boundary determination will be accomplished through the state response to the NOAA recommendation and a public review and comment process at the state level. States have the option of either extending their existing coastal zone boundary inland or exercising other state authorities within the 6217 management area.

Identification of Nonpoint Sources To Be Addressed

The basic premise of Section 6217 is that technology-based controls should be implemented for all nonpoint sources that, either individually or cumulatively, have significant impacts on coastal waters. There need not be a demonstration that an individual source has an impact on water quality. In this sense, Section 6217 is akin to the technology-based approach of the point source program under the Clean Water Act. For program approval, states are to implement management measures throughout the 6217 management area for all nonpoint source categories (e.g., agriculture) and subcategories (e.g., confined animal facilities) identified in the management measures guidance. States also may include management measures for other sources (e.g., mining) not identified in the guidance if the state determines such measures are necessary to protect coastal waters generally.

The program guidance provides for exclusions of nonpoint source categories and subcategories under certain circumstances. If the state can demonstrate that the source is neither present nor anticipated in the 6217 management area, the source may be excluded. States also may exclude sources that do not, individually or cumulatively, present significant adverse effects to living coastal resources or human health. It should be noted that the burden of proof is on the state to demonstrate that the application of the management measures to the remaining sources will protect coastal waters generally. In other words, if a state wishes to exclude a particular nonpoint source category from management measures implementation, the state must demonstrate that the nonpoint category does not (and is not reasonably expected to) present significant adverse effects to living coastal resources or human health.

For either type of exclusion, the state must provide documentation of the rationale and data used to justify the exclusion. The program guidance includes certain factors that may be considered in exclusions. They are as follows:

- Pollutant loadings or estimates of loadings from the sources.
- Intensity of land use.
- Ecological and human health risk associated with the source.

NOAA and EPA will review the information provided by the state to determine if the category or subcategory may be excluded from the coastal nonpoint program.

Implementation of the (g) Management Measures

State programs need to provide detailed information on how each of the management measures will be implemented. The program guidance includes a description of the information to be included in the coastal nonpoint program for each nonpoint category and subcategory. This information includes the scope, structure, and coverage of the state program; the designated lead agency and supporting agencies that will implement the program; a program implementation schedule with milestones; enforceable policies and mechanisms to ensure management measure implementation; interagency coordination mechanisms; a process to identify practices to implement the management measures; operation, maintenance, and inspection procedures to ensure continuing performance of the measures; and monitoring activities to evaluate the effectiveness of the measures.

States may already have programs in place that can be incorporated into the coastal nonpoint program. States need to provide information on how these existing programs can be used to implement the management measures and identify where necessary changes will be made. For example, a state may have a program that requires local ordinances for erosion and sediment control. Because the program guidance requires "enforceable policies and mechanisms" at the state level, the state would have to show some means of ensuring local implementation of erosion and sediment control. This could be in the form of backup state enforcement or some other state oversight of local programs.

Where states do not have existing programs to address a given nonpoint category or subcategory, they will have to develop new authorities and programs to ensure implementation of the management measures. This may include developing new state authority. Both existing and new programs need to be incorporated into the coastal nonpoint program.

Additional Management Measures/Critical Areas

The program guidance requires states to implement additional management measures under two conditions:

- Where coastal water quality remains impaired even after implementation of the (g) measures.
- In areas whose function is critical to water quality.

States must first identify waters that are threatened or impaired as a result of nonpoint pollution impacts. Land adjacent to these waters plays a particularly important role in attaining or maintaining water quality. There may be situations where new and expanding land uses could result in further impacts to threatened or impaired waters from nonpoint sources, beyond those controlled by the (g) measures. The purpose of additional management measures in this case is pollution prevention to avoid water quality problems that might otherwise develop.

Additional management measures also are required for coastal waters that are not attaining or maintaining applicable state water quality standards or protecting designated uses. There are two instances where states will need to implement additional management measures due to water quality impairments. First, if a state has identified waters that are failing to meet water quality standards and determines that existing pollution prevention activities and/or the implementation of the (g) measures will not be adequate to achieve water quality standards, the state will have to implement additional measures for those waters at the time of program approval. The second is following implementation of the (g) measures and monitoring to evaluate effectiveness of the (g) measures. If a state determines that water quality impairments (as a result of nonpoint sources) exist even after implementation of the (g) measures, the state will have to implement additional management measures.

Enforceable Policies and Mechanisms

Besides the provisions for state coastal nonpoint programs found in Section 6217, CZARA also amended Section 306 of the Coastal Zone Management Act (CZMA) to require that (before approving a coastal zone management program) NOAA finds "... the management program contains enforceable policies and mechanisms to implement the applicable requirements of the coastal nonpoint pollution control program of the state required by Section 6217..." (Section 306(d)16). The CZMA also includes a definition of "enforceable policy": "[t]he term 'enforceable policy' means state policies which are legally binding through constitutional provisions, laws, regulations, land use plans, ordinances, or judicial or administrative decisions, by which a state exerts control over private and public land and water uses and natural resources in the coastal zone."

The program guidance outlines a variety of both regulatory and nonregulatory approaches that a state may design to meet the requirement for enforceable policies and mechanisms. Examples of regulatory approaches include permit programs, local zoning requirements, and state laws. Nonregulatory approaches could include economic incentives (such as cost-share programs) or disincentives (such as taxes or user fees). Nonregulatory approaches must be backed by enforceable state authority to ensure management measure implementation.

Several existing state programs to control nonpoint sources are backed by state laws. In other cases, state requirements are delegated to local authorities for implementation or rely on state funds, which provide cost-share monies for implementing practices. For a state coastal nonpoint program to be approvable, the state needs to demonstrate that these programs are ultimately subject to state enforcement authority. An example of how this might work for a cost-share program that is currently voluntary is for the state to back up the voluntary program with a "bad actor" provision in state law. In cases where participation in the voluntary program does not result in implementation of the management measures, the state would have the ability to penalize the "bad actors" or those who failed to take advantage of the voluntary opportunity.

Traditional regulatory approaches could offer more direct state oversight of management measures implementation. A state could issue general permits for specific source categories that include certain criteria that must be met by all those who meet the category definition. Conditions on the general permit would allow tailoring of requirements for site-specific circumstances. Issuance of individual permits (such as those issued by many states for septic systems) could also be used for a specific entity.

Program Coordination, Public Participation, and Technical Assistance

The program guidance requires several other program elements, including provision for administrative coordination, public participation, and technical assistance. These elements are critical to successful implementation of coastal nonpoint programs because they provide necessary linkages between state, regional, and local governments; between government agencies and the public; and between government agencies and affected user groups. Such linkages ensure the involvement of a variety of players and, if well developed, build strong support for programs from the grass-roots level to the state capitol.

Administrative coordination is inherent in the involvement of state coastal zone management agencies and state water quality agencies as equal partners in the development of coastal nonpoint programs. These ties need to be further enhanced through the involvement of other state agencies (such as state forestry, state agriculture, and state health departments) and with local governments who will be instrumental in implementing programs at the ground level. Such relationships can be further defined and solidified through memoranda of agreement, joint permitting processes, cross training of staff, and interagency committees.

Public participation is an integral part of the coastal nonpoint program because public support is necessary to ensure effective program development and implementation. The program guidance requires that states must provide opportunities for public participation in all aspects of the coastal nonpoint program. Specifically, each state needs to demonstrate that its program has undergone public review and comment before submittal to NOAA and EPA for approval.

Technical assistance is particularly important in providing regional and local governments with needed direction on how to implement the provisions of state coastal nonpoint programs. The statute outlines a variety of technical assistance areas, including "assistance in developing ordinances and regulations, technical guidance, and modeling to predict and assess the effectiveness of such measures, training, financial incentives, demonstration projects, and other innovations to protect coastal water quality and designated uses." Technical assistance also will be necessary for affected user groups and the public. The program guidance also includes assurances that NOAA and EPA will continue to provide technical assistance to states as they develop and implement their programs.

Program Submission and Approval

States have 30 months from the publication of the final (g) guidance to develop their coastal nonpoint programs. The final (g) guidance document was published on January 19, 1993, giving states until July 19, 1995, to submit their programs (see timeline below). During this period, states have opportunities to meet with NOAA and EPA and discuss their progress on program development. The program guidance establishes a threshold review process whereby NOAA and EPA conduct an initial review of a state's program to address key issues and decision points. Threshold review is voluntary but provides an opportunity for states to identify gaps in their programs early in the process, giving a better idea of what to expect when the program is finally submitted for approval. It also helps focus limited resources where they can be used in the most efficient and effective manner.

In addition to threshold review, the program guidance sets out a conditional approval provision for state programs that are submitted without all of the necessary elements for final approval. NOAA and EPA recognize (under limited circumstances) that a state may submit a program for which all necessary enforceable policies and mechanisms are in place but that the state may need additional time to develop state, regional, or local authorities to implement the state requirements. Under such circumstances, NOAA and EPA may grant conditional approval of a state program for a period of 1 year. Final approval of the program would depend on the state's ability to demonstrate that all necessary enforceable policies and mechanisms are in place. A conditional approval will not affect the date by which states must achieve full implementation of the (g) measures. Full implementation still must proceed and be completed within 3 years of the first federal approval action, whether that approval is conditional or not.

Summary

Table 1 presents a timeline for coastal nonpoint program development, approval, and implementation.

Table 1. Coastal Nonpoint Program Development, Approval, and Implementation

Date	Process
January 1993	Final (g) measures and program approval guidance issued
January 1993	Coastal nonpoint program development: threshold review (optional), formal/informal
July 1995	States submit final Section 6217 coastal nonpoint programs
January 1996	EPA/NOAA complete review of state programs (program approval)
January 1996	State begins implementation of (g) measures
January 1999	Full implementation of (g) measures
January 2001	Completion of 2-year monitoring period
January 2004	Full implementation of additional management measures

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Compliance With the 1991 South Carolina Stormwater Management and Sediment Reduction Act

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Abstract

The 1991 Stormwater Management and Sediment Reduction Act is comprehensive legislation intended to address the management of stormwater runoff from a watershed perspective. The Act establishes a statewide program making requirements consistent across political boundaries. It gives local governments several options to address specific problems though the creation of stormwater utilities or designated watersheds. Considerations are made for citizen complaints and input into program development and operation.

Introduction

Stormwater management and sediment reduction is an integral part of nonpoint source pollution control. Amendments to the federal Clean Water Act in recent years have emphasized stormwater management and sediment control as basic parts of National Pollutant Discharge Elimination System (NPDES) permitting. Several states recognized erosion and sediment control as a major problem in the early 1970s. States had used different approaches, ranging from comprehensive statewide regulatory legislation (e.g., North Carolina) to the voluntary approach of enabling legislation to allow local governments to enact ordinances to regulate erosion and sediment control on the local level. Traditionally, stormwater management was not part of enabling legislation or statewide programs.

In the early to mid 1980s, some states began to incorporate stormwater management into these programs. The Clean Water Act amendments strengthened the case for attaching the stormwater management issue to the erosion and sediment control programs. To date, several states have implemented combined programs.

South Carolina passed enabling legislation in 1971 to allow local governments to pass ordinances to regulate erosion and sediment control. This approach met with very little success; only 22 local ordinances were passed in 22 years. In 1983, the Erosion and Sediment Reduction Act was passed to regulate state-owned lands. This act was to set an example for local programs. The act exempted the South Carolina Department of Highways and Public Transportation by requiring them to establish a program of their own.

In 1991, the South Carolina General Assembly recognized the increasing problems from years of mismanagement of stormwater runoff. On May 27, 1991, Governor Carroll Campbell signed the 1991 Stormwater Management and Sediment Reduction Act. Pursuant Regulation 72-300 became effective June 26, 1992.

Requirements of the Act

The 1991 act sets minimum standards for program development for control of sediment and water quantity statewide. The act allows local governments to establish stormwater utilities and designated watersheds. It also mandates a statewide regulatory program for stormwater management and sediment reduction.

The intent is to delegate program components to local governments or conservation districts. There are four components to the program: plan review, inspection, enforcement, and education and training. Criteria for delegation of each component is set forth in the regulations. Any or all of the components may be delegated. The delegation is valid for 3 years. The South Carolina Land Resources Conservation Commission provides oversight of the local program to ensure its proper operation. In the event that delegation is not requested, the commission operates the program within that jurisdiction or until a local entity requests delegation. The local government has first right of refusal to request delegation. If the local government chooses not to request delegation, the local conservation district may request the delegation.

The commission retains jurisdiction of certain activities to the exclusion of all others. The commission will permit activities by persons with eminent domain, the federal government, and all local governments.

Requirements for Individual Site Development

Minimum standards are established for individual site development. There are important dates that should be recognized when determining specific requirements for site development. The effective date of the act was May 27, 1992. The effective date of Regulation 72-300 was June 26, 1992. All sites with land-disturbing activities that affect 5 acres or more and that began on or after October 1, 1992, are required to permit through this program regardless of local program status. Beginning July 1, 1993, any land-disturbing activity starting on or after that date in the fifteen most populated counties as listed in Section 72-303 must permit through the program. Additional counties are phased in for 1994 and 1995. Size limits have been set for land disturbances from 0 to 2 acres as a reporting requirement following guidance in 72-307(H). Permits for land disturbances of 2 to 5 acres are required under the guidelines of 72-307(I). Land disturbances greater than 5 acres must follow Section 72-307.

Site-Specific Requirements

The site-specific requirements have some general similarities to the federal Clean Water Act requirements for construction. One of the major differences addresses the quantity of water released. These regulations are broken into different parts according to the stage of the land-disturbing activity.

Postconstruction requirements include both quantitative and qualitative controls. For quantity control, post-development release rates for the 2-year/24-hour and 10-year/24-hour design storms are controlled to the 2-year/24-hour and 10-year/24-hour predeveloped release rates. Quality controls for the first flush are implemented where ponds are the proposed method of control. A wet pond requires capture of the first half inch of runoff volume from the impervious areas site. This flow can be mixed with the clean permanent pool volume and discharged over 24 hours. A dry pond requires that the first 1 inch of runoff volume from impervious areas is captured and released over 24 hours. The first flush must be separated from the additional flow into the dry basin.

Where ponds are not the proposed method of control, nonstructural controls are required. Riparian vegetation strips, grass waterways, sand filters, and other measures to meet postconstruction water quality concerns are acceptable alternatives.

During construction, the requirement is qualitative, dealing exclusively with control of offsite discharge of sediment. A performance standard of 80 percent removal (total suspended solids in versus total suspended solids out) or an efficiency of an effluent standard of 0.5 mL/L peak effluent settable solid concentration, whichever is most lenient, must be achieved. Sites with 10 disturbed acres draining to a single point are required to have a sediment basin. Otherwise, a combination of structural and nonstructural practices may be used. There is no sampling requirement to prove compliance with these standards. Plans are developed using modeling techniques to predict performance of this standard for the 10-year/24-hour design storm.

A construction sequence, one of the most important requirements, is required as part of the overall plan. The sequence, which is developed by the project designer, contains all site activities, from installing tree protection to final landscaping and paving. Close compliance with the construction is required. The contractor must follow this sequence, with modifications allowed for unforeseen circumstances; however, the sequence is not normally modified.

Inspection and Enforcement

Site inspection is of primary importance to operations of this program. Without inspection, the program is doomed to failure. Weekly unannounced site inspections are made on each site. Further, a set of approved plans is required to be held on site.

Enforcement provisions in the act provide for fines of up to $1,000 per day. Also, stop-work orders may be issued. These enforcement provisions are used when violations occur and cooperation is not received to correct the problem. There are no criminal penalties associated with violations of this act.

Enforcement actions require that the owner be notified by certified mail of any violation. Land-disturbing activities commencing without a permit are subject to an immediate stop-work order. Violations are cited in the inspection report, with a copy given to the designated day-to-day contact and a copy mailed to the owner. If corrective action is not taken within the specified time frame, a certified letter is mailed to the owner. This letter outlines the corrective action required and the penalties to be assessed.

Citizen Complaint Process

A citizen may file a complaint concerning any portion of program operation or site-specific regulation. The complaint is filed with the implementing agency for action. If satisfaction is not achieved, a hearing may be requested. This hearing must follow procedures listed in the South Carolina Administrative Procedures Act. If satisfaction is not achieved in this hearing, the complaint may be appealed in the court system.

Florida's Growth Management Program

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Abstract

Between 1970 and 1990, Florida's population nearly doubled, from 6,791,418 to 12,937,926. Recognizing that this rapid growth—up to 900 people per day—could overwhelm the state's social, economic, and environmental resources, the Florida legislature twice passed growth management acts. This paper reviews the history of growth management in Florida, with emphasis on the differences between the 1975 and 1986 legislation. The state's current growth management program and process is described, focusing on the institutional framework and the relationship to the state's water quality management program. The role of various state and regional resource management agencies in the review and approval of local government comprehensive plans and the implementing land development regulations is discussed, including specific areas of Florida's growth management program that are essential to the management of water resources. The paper also presents examples of goals within the State Comprehensive Plan that can form the foundation for watershed management and the maintenance and restoration of water resources. Lessons learned in the implementation of Florida's growth management program are reviewed, with recommendations made to improve the program's environmental effectiveness.

Introduction

Florida's citizens and political leaders accepted the notion that the strong and sustained growth that Florida enjoyed after World War II was an unmixed blessing that would ensure economic health with no negative effects. It was assumed that growth not only paid for itself but also produced surplus revenues for state and local governments. Florida's public policy toward growth during the 1950s and 1960s could best be described as "Build now, worry later."

During this period, Florida grew at a phenomenal rate with the population rising from 2,771,305 in 1950 to 6,791,418 in 1970 and to 12,937,926 in 1990. Today, Florida is the fourth most populous state and is still growing rapidly, although not at the rate of 900 people per day (300,000 per year) that occurred throughout the 1970s and 1980s.

The negative impacts of unplanned growth were seen as early as the 1930s, when southeast Florida's coastal water supply was threatened by saltwater intrusion into the fragile freshwater aquifer that supplied most of the potable water for the rapidly expanding population. By the 1970s, it was becoming all too clear that unplanned land use and development decisions were altering the state in a manner that, if left unchecked, could lead to profound, irretrievable loss of the very natural beauty that brought residents and tourists to Florida. Extensive destruction of wetlands, bulldozing of beach and dune systems, continued saltwater intrusion into freshwater aquifers, and the extensive pollution of the state's rivers, lakes, and estuaries were only some of the negative impacts of this rapid growth.

What Is Growth Management?

Florida is one of eight states to have implemented a growth management program (1). Understanding Florida's growth management system requires a clear understanding of the distinctions between growth management, comprehensive planning, and land/environmental regulations:

- *Growth management* looks at broad issues and at the interrelationship of systems: natural systems, infrastructure, land use, and people. It attempts to assess how well we have provided for the needs of our citizens in the past and on how to determine and provide for the needs of new citizens. Growth management encompasses comprehensive planning, natural resource management, public facilities planning, housing, recreation, economic development, and intergovernmental coordination.
- *Comprehensive planning* is a governmental process for inventorying resources, establishing priorities, establishing a vision of where a community wants to

go, and determining how to get there. It is a systematic way of looking at the different components of a community, county, region, and state.

- *Regulations* are the specific controls applied to different types of development activities to regulate and minimize their negative impacts. Typically, regulations are administered by all levels of government, federal, state, and local. At the local level, land development regulations are the ordinances that implement the local comprehensive plan.

Comprehensive Planning Versus Regulation

Comprehensive planning allows a community to make decisions about how and where future growth will occur. Comprehensive planning asks, Is this the right location? Is this the right time? Is this the right intensity for the proposed use of the land? Comprehensive planning seeks to prevent problems (social, economic, environmental) before development occurs.

Permitting, on the other hand, asks only, How can we do the best job with this development on this particular site? Permitting is site-specific and seeks only to mitigate the impacts of the land-use decision. Limitations are always inherent in any regulatory program, and comprehensive planning can help to overcome them. Principal among these limitations is the fact that permitting is piecemeal and does not consider cumulative effects. Therefore, regulation and permitting cannot substitute for planning. Both are needed to manage growth effectively and to protect quality of life.

Growth Management in Florida, Chapter 1

Florida began serious and comprehensive efforts to manage its growth as the environmental movement in the nation and the state gained strength. In 1972, the Florida legislature enacted the first modern package of land and water planning, regulation, and acquisition programs. This package included:

- Chapter 373, Florida Statutes (F.S.), establishing the state's five regional water management districts, requiring the development of a state water plan, and allowing for the regulation of the water resource.
- Chapter 403, F.S., establishing the state's Department of Environmental Regulation and its powers and duties.
- Chapter 259, F.S., establishing the Environmentally Endangered Lands program, which authorized the state to purchase critical and sensitive lands.
- Chapter 380, F.S., creating the Developments of Regional Impact (DRI) and Areas of Critical State Concern (ACSC) programs.

In 1975, at the recommendation of the first Environmental Land Management Study Committee (ELMS I), the Legislature enacted the state's first growth management legislation. Chapter 163, F.S., the Local Government Comprehensive Planning Act (LGCPA), required all cities and counties to prepare a comprehensive plan. These plans were submitted for review to the state's land planning agency, the Department of Community Affairs (DCA), which in turn sent the plans to other state agencies for review and comment.

Despite the legislature's good intentions, the growth management legislation passed in the 1970s contained fatal flaws. First, the LGCPA contained no "teeth." Local governments were under no statutory requirement to revise their plans by incorporating the comments and recommendations that the state agencies involved in the review of the local comprehensive plans had made. Furthermore, they were not required to pass land development regulations to implement their plans. Most importantly, state and local officials never recognized that substantial new funding would have to be provided to make the program work. Funding was essential for the mandated planning, for supporting the costs of infrastructure, and for implementing strategies to manage growth. Finally, the law did not require local governments to ensure that public facilities and services kept up with the demands imposed by population growth. As Florida's population continued to boom in the 1980s, this failure to connect the costs of growth with land-use decisions and population increases resulted in billions of dollars of backlog in public facilities and services, increased strain on existing facilities, and an ever-increasing deficit in the quality of life for Floridians.

Growth Management in Florida, Chapter 2

In the late 1970s and early 1980s, an extensive appraisal of Florida's growth management system was undertaken; the appraisal concluded that the existing system was not working. Shaped by the Final Report of the Governor's Task Force on Resource Management (1980) and the second Environmental Land Management Study Committee (ELMS II), a totally new blueprint for managing growth emerged. The ELMS II recommended a comprehensive package of integrated state, regional, and local comprehensive planning, reforms to the DRI law, and coastal protection improvements. The legislature responded by enacting the following growth management framework:

- *The State and Regional Planning Act of 1984* (Chapter 186, F.S.) mandated that the Governor's Office prepare a state comprehensive plan and present it to the 1985 legislature. It also required the preparation of regional plans by the state's 11 regional planning councils and provided $500,000 for plan preparation.

- *The 1985 State Comprehensive Plan* (Chapter 187, F.S.) originally was envisioned to be a leadership document—the foundation of the entire planning process—with strong, measurable, and strategic goals that would set the course for Florida's growth over the next 10 years. Each state agency was to prepare an agency functional plan, based on the State Comprehensive Plan, upon which its budget appropriations would be made. Unfortunately, one of the most important elements of the State Plan—the development and adoption of a capital plan and budget—was never prepared.
- *The Local Government Comprehensive Planning and Land Development Regulation Act of 1985* (Chapter 163, F.S.) required all local governments to prepare local comprehensive plans and implement regulations consistent with the goals and policies of the state and regional plans. Numerous state and regional agencies reviewed the local plans and submitted their objections, recommendations, and comments to the Department of Community Affairs for transmittal to the local government. This time, the local plans had to be revised to incorporate the objections, recommendations, and comments. Furthermore, local governments faced sanctions from the state that could result in the loss of state funding if adopted local plans were not consistent with the state and regional plans.

Florida's revised growth management system is built around three key requirements: consistency, concurrency, and compactness:

- The *consistency* requirement established the "integrated policy framework," whereby the goals and policies of the State Plan framed a system of vertical consistency. State agency functional plans and regional planning council regional plans had to be consistent with the goals and policies of the State Plan, while local plans had to be consistent with the goals and policies of the state and appropriate regional plan. Furthermore, the individual elements of each local plan must be internally consistent, a requirement that has the power to make local plans into coherent, meaningful, balanced documents for guiding the future of a community. Local land development regulations (LDRs) must also be consistent with the local plan's goals and policies. Horizontal consistency at the local level also is required to ensure that the plans of neighboring local governments are compatible. Consistency is the strong cord that holds the growth management system together.
- *Concurrency* is the most powerful policy requirement built into the growth management system. It requires state and local governments to abandon their long-standing policy of deficit financing growth by implementing a "pay as you grow system." Once local plans and LDRs are adopted, a local government may approve a development only if the public facilities and services (infrastructure) needed to accommodate the impact of the proposed development can be in place concurrent with the impacts of the development. Public facilities and services subject to the concurrency requirements are roads, stormwater management, solid waste, potable water, wastewater, parks and recreation, and, if applicable, mass transit.
- *Compact* urban development goals and policies are built into the State Comprehensive Plan and into regional plans. Policies such as separating rural and urban land uses, discouraging urban sprawl, encouraging urban in-fill development, making maximum use of existing infrastructure, and encouraging compact urban development form the basis for this requirement.

Synopsis of the 1985 Growth Management Process

Content of Local Comprehensive Plans (2)

The plans are prepared in accordance with the minimum requirements set forth in Rule 9J-5, Florida Administrative Code (FAC), "Minimum Criteria for Review of Local Government Comprehensive Plans and Determination of Compliance."

Who Prepares the Plan?

The local government may designate itself as the local planning agency (LPA) or designate a LPA by ordinance to prepare the plan and recommend it to the local government for adoption. Procedures assuring maximum public input and participation must be implemented by the local government and the LPA.

What Is Included in the Plan?

Plans shall consist of materials, written or graphic, including maps, as are appropriate for the prescription of goals, objectives, principles, guidelines, and standards for the orderly and balanced future economic, social, physical, environmental, and fiscal development of the area. The plan must contain the nine required elements and, if the local government population exceeds 50,000, a Mass Transit Element and an Aviation and Port Element.

What Are the Required Plan Elements?

These elements must be internally consistent and economically feasible. Each element consists of data analysis along with the setting of goals and policies to achieve desired results. The elements include:

1. *Capital Improvements Element*, which must consider the projected need and location of public facilities over the next 5 years:

a) This element must contain a component with principles for construction of new public facilities or for increasing capacity of existing facilities.

b) A component must also be provided outlining principles for correcting existing public facility deficiencies.

c) The element must set forth standards to ensure availability and adequacy of public facilities.

d) It must establish the acceptable levels of service for all facilities.

2. *Future Land Use Element*, which must include a future land use map. The map and policies of this element must be based on studies, data, and surveys that determine the projected population changes, show the distribution and amount of land for each land use type (e.g., residential, commercial, industrial) needed to accommodate the growth, show the availability of public services, address renewal of blighted areas, and eliminate nonconforming uses.

3. *Traffic Circulation Element*, showing existing and proposed transportation routes needed to achieve the desired level of service based on future population and land uses.

4. *Public Services/Facilities Element*, which establishes the level of service for wastewater, solid waste, stormwater, and potable water. An analysis must be undertaken to determine whether existing facilities are providing current residents with the desired level of service, and whether these facilities can meet the demands for service created by projected future development; to identify any existing or future service deficiencies; to determine strategies and schedules for correcting these deficiencies; and to insert these needed infrastructure improvements into the Capital Improvements Element.

5. *Conservation Element*, to provide principles and guidelines for the conservation, use, and protection of natural resources, including air, water, recharge areas, wetlands, estuarine marshes, soils, beaches, floodplains, rivers, bays, lakes, wildlife and marine habitat, and other natural and environmental resources.

6. *Recreation and Open Space Element*, which must establish a level of service for recreational facilities, set forth how these will be met as the population grows, and ensure public access to beaches.

7. *Housing Element*, with standards and principles to be followed to ensure the provision of housing for existing residents and provide for future growth. It must also include provisions for adequate sites of future housing for low and moderate income persons, for mobile homes, and for group homes.

8. *Coastal Management Element*, which must be prepared by those jurisdictions having a coastline. This element is to set forth policies to maintain, restore, and enhance the overall quality of the coastal zone environment, including wildlife; to protect human life against the effects of natural disasters; and to limit public expenditures that subsidize development in high-hazard coastal areas.

9. *Intergovernmental Coordination Element*, to coordinate the plan with those of adjacent local governments, school boards, special districts, etc.

The Plan Adoption and Review Process

Local plans are submitted to the DCA at a rate of 10 to 15 per month in accordance with the schedule and dates set out in Rule 9J-5, FAC.

The local government sends the proposed plan to DCA for review and written comment. DCA in turn sends copies to other state agencies for review and comment within 45 days. Within 45 days after receiving comments from these other agencies, the DCA issues an Objections, Recommendations, and Comments (ORC) Report, which summarizes the comments received from all of the reviewing agencies. The local government has 60 days to revise the plan, hold a public hearing, and formally adopt it.

Upon adopting the revised plan, the local government sends the adopted plan to DCA. DCA has 45 days to review and issue a legal Notice of Intent to find the plan "in compliance" or "not in compliance." The term "in compliance" means consistent with the State Comprehensive Plan, the Regional Plan, and Rule 9J-5, which sets forth minimum criteria.

If the local plan is found to be not in compliance, the following process occurs:

- A formal Chapter 120, F.S., Administrative Hearing is held, at which the local government can show by a preponderance of evidence that the plan is in compliance. A Final Order upholding or overturning DCA's determination of compliance is sent to the Governor and Cabinet.
- If the plan is not in compliance, the Governor and Cabinet can either specify remedial actions to bring the plan into compliance or impose sanctions on the local government, resulting in the loss of state revenue sharing funds, loss of state funds for road improvements, and loss of eligibility for some grant programs.

If the local plan is found to be in compliance:

- A legal notice of intent is published in a local newspaper.
- Within 21 days, any affected party may file a petition for a formal Chapter 120 hearing to appeal DCA's compliance decision.

- After the hearing, a final order is issued that either upholds or overturns the DCA compliance determination. If overturned, the Governor and Cabinet again can either specify remedial actions or impose sanctions.

Plan Adoption and Approval Status

As of August 1993, a total of 186 local comprehensive plans were in compliance, while 30 were not in compliance. Another 212 plans had been brought into compliance through a negotiated compliance agreement between the DCA and the local government, and 29 plans that were not in compliance have a pending compliance agreement that has not been signed (3). Of the 259 local comprehensive plans determined to be not in compliance, the compliance issues that caused the findings to be made are summarized in Table 1 (4).

The Plan Amendment Process

Chapter 163 limits amendments to an adopted comprehensive plan to only twice a year. These amendments must be adopted following the same procedure as when the plan was first adopted. The plan amendment review process is similar to the original plan review process, involving the following steps:

1. The land owner submits a request for plan amendment to the local government. Usually this must include certain data and information to help the local government determine the potential impacts of the proposed amendment.
2. The local government holds a public hearing to determine whether to adopt the proposed plan amendment.
3. Proposed plan amendments are submitted to the DCA for review to ensure consistency with state and regional plans and with Rule 9J-5. DCA transmits the amendment to other state agencies for their review and comment within 30 days. DCA has a total of 45 days to review the amendments; incorporate comments, objections and recommendations from other state agencies; and send the ORC Report to the local government.
4. The local government conducts a public hearing where it can adopt, adopt with modifications, or not adopt the amendment.

Table 1. Compliance Issues

Compliance Issue	Number	Percentage
Natural resource protection	198	76
Level of service standard	183	71
Land use	163	63
Concurrency management system	128	49
Affordable housing	89	34
Financial feasibility	84	32
Coastal management	59	23
Intergovernmental coordination	56	22
Land development regulation	21	8

Implementing the Plan: Adopting Land Development Regulations

A key feature of the 1985 growth management legislation is the requirement that local governments adopt LDRs within 1 year after submission of the revised plan to DCA for formal review. LDRs are defined in Chapter 163, F.S., as "ordinances enacted . . . for the regulation of any aspect of development." They are an exercise of the general governmental police power for the protection of the public health, safety, and welfare. LDRs must address, at a minimum, the following areas:

- Subdivisions.
- Implementation of land-use categories included in the land-use element and map (zoning), along with regulations to ensure the compatibility of adjacent land uses and to provide for open space.
- Protection of potable water wellfields.
- Stormwater management (quantity and quality).
- Protection of environmentally sensitive land.
- Signage.
- Public facilities and services to meet or exceed the established level of service standards.
- Onsite vehicular and pedestrian traffic flow and parking.

The LDRs must be adopted by ordinance, and the adoption process must comply with the notice and public hearing process set forth in Florida law. Finally, the LDRs must be combined into a single land development code.

Unlike local plans, LDRs do not undergo comprehensive state review and approval. The DCA may review and take action on individual LDRs under only two circumstances. The first is for "completeness review," in which the DCA must have reasonable grounds to believe that a local government has totally failed to adopt any of the required LDRs. "Reasonable grounds" means that DCA has received a letter(s) from a party or parties stating facts that show the local government has failed to adopt one or more of the required LDRs. DCA can then require a local government to submit its LDRs for review. DCA then enters into a period of review and consultation with the local government to determine whether the local government has complied with statutory requirements. If DCA determines that a local government has failed to adopt one or more required LDRs, it notifies the local government within 30 days. The local government then must adopt the LDRs and submit them to DCA. If the local government fails to adopt the LDRs, DCA institutes action in circuit court to require adoption of the required LDRs.

The second type of state review is to assure that the LDRs "implement and are consistent with the local comprehensive plan." This review looks more closely at the actual content and substance of the ordinances. This review can only be initiated by a "substantially affected person" (citizen), however, and it cannot be initiated by the DCA. A consistency challenge must occur within 12 months after the final adoption of the LDR. The substantially affected person must petition DCA to initiate a Chapter 120 administrative hearing. If DCA reviews the information in the petition and determines that the LDRs are not consistent with the plan, then DCA requests an administrative hearing. If DCA reviews the information in the petition and determines that the LDRs are consistent with the plan, then the affected party can request an administrative hearing. If the Final Order from the administrative hearing finds the LDR is inconsistent, then the Governor and Cabinet determine what types of sanctions will be imposed on the local government.

Comprehensive Plans and the Protection of Natural Resources

A main purpose of the comprehensive planning program is to maintain, restore, and protect Florida's very valuable, vulnerable natural resources. The goals and policies set forth in the State Comprehensive Plan along with the requirements in Rule 9J-5, which set forth specific objectives and policies that must be included in each plan element, provide the basis for the protection of natural resources.

Within the State Comprehensive Plan, goals and policies that specifically address minimizing impacts of various activities on natural resources and the general conservation, protection, and proper use and management of natural resources are found within the Water Resources, Coastal/Marine Resources, Natural Systems and Recreation Lands, Air Quality, Waste Materials, Land Use, Mining, Agriculture, Public Facilities, Conservation, and Transportation Elements. The following are examples of these goals and policies.

For the Water Resources Element, the goal is to "assure the availability of an adequate supply of water . . . and . . . maintain the functions of natural systems and the overall present level of surface and ground-water quality. Florida shall improve and restore the quality of waters not presently meeting water quality standards." Policies include:

- Protect and use natural water systems in lieu of structural alternatives, and restore modified systems.
- Establish minimum seasonal flows and levels for surface waters to ensure protection of natural resources, especially marine, estuarine, and aquatic ecosystems.
- Discourage the channelization, diversion, or damming of natural riverine systems.
- Encourage the development of a strict floodplain management program to preserve hydrologically significant wetlands and other natural floodplain features.
- Protect surface and ground-water quality and quantity.
- Eliminate the discharge of inadequately treated wastewater and stormwater runoff into waters of the state.

Coastal/Marine Resources policies include:

- Accelerate public acquisition of coastal and beachfront land to protect coastal and marine resources.
- Avoid spending state funds that subsidize development in high-hazard coastal areas.
- Protect coastal and marine resources and dune systems from the adverse impacts of development.

For the Natural Systems and Recreational Lands Element, the goal is to protect and acquire unique natural habitats and ecosystems and to restore degraded natural systems. Policies include:

- Protect and restore the ecological functions of wetlands systems to ensure their long-term environmental, economic, and recreational value.
- Promote restoration of the Everglades system and of the hydrological and ecological functions of degraded or disrupted surface waters.
- Implement a comprehensive planning, management, and acquisition program to ensure the integrity of Florida's river systems.

Agriculture policies include:

- Eliminate the discharge of inadequately treated agricultural wastewater and stormwater runoff to surface waters.
- Conserve soil resources to prevent sedimentation of state waters.

Rule 9J-5 contains many minimum requirements for goals, objectives, and policies that are directly related to the conservation, protection, and proper use and management of natural resources. The following are some examples.

Public Facilities policies include:

- Correct existing facility deficiencies and coordinate the extension of, or increases in the capacity of, facilities to meet future needs.
- Maximize the use of existing facilities to discourage urban sprawl.

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- Regulate land use and development to protect the functions of natural stormwater features and natural ground-water aquifer recharge areas.

Conservation policies include:

- Conserve, appropriately use, and protect the quantity and quality of water, minerals, soils, native vegetative communities, fisheries, wildlife, and wildlife habitat.
- Protect air quality, native vegetative communities, and water quality.
- Protection and conservation of the natural functions of soils, fisheries, wildlife habitats, surface waters, ground waters, and beaches and shorelines.

Growth Management in Florida, Chapter 3

After several years of living with and implementing the 1985 growth management law, numerous issues were arising that suggested that the program needed fine tuning. On one side were people who thought that the program and process were hindering economic development, stepping on private property rights, and becoming cumbersome administratively. Others felt that the program was not adequately protecting social, economic, and environmental resources. In 1991, the third Environmental Land Management Study Committee (ELMS III) was formed to provide recommendations to the 1993 legislature on ways to further improve and refine Florida's growth management laws. The Committee's report included the following conclusion (5):

> Florida's growth management process is not in a state of disrepair, but it needs some immediate attention. More importantly, it needs executive leadership to protect the substantial investment that has been made so that it will not be lost, or worse, become a liability. Decisions that are made over the next 12 to 18 months will determine whether our efforts will be able to deliver the promises made. The tools for managing future growth and change are in place. The challenge is whether these tools and our leadership can respond when asked to perform.

The Committee's Final Report and Recommendations formed the basis for a new planning and growth management act which passed by overwhelming margins in both the house and the senate in the closing days of the 1993 session. Among the provisions of the 180-page law are some major changes relating to state planning, regional planning, the DRI process, local planning and concurrency, and infrastructure funding as explained below (6).

State Planning

One of the biggest criticisms of Florida's growth management system is the lack of strong leadership at the state level. The State Comprehensive Plan originally was envisioned as a leadership document with strong, measurable, and strategic goals that would set a course for the state's growth and guide the development and implementation of state programs. State agency and program budgeting decisions, however, never were changed to incorporate the State Plan's requirements. Furthermore, key components of the State Plan—the capital plan and budget—never were developed or adopted. These omissions have resulted in a lack of a cohesive, integrated, comprehensive vision of Florida's future as well as a lack of financial resources to implement the program and to correct existing infrastructure deficiencies.

The 1993 Growth Management Act strengthens the state planning process in two ways. First, it requires the Governor's Office to review and analyze the State Comprehensive Plan biannually and submit a written report recommending revisions or explaining why no revisions are necessary. Second, the act requires that a new Growth Management Element be prepared and submitted to the 1994 legislature. The element must be strategic in nature; provide guidance for state, regional, and local actions necessary to implement the State Plan; identify metropolitan and urban growth centers; establish strategies to protect identified areas of state and regional environmental significance; and provide guidelines for determining where urban growth is appropriate and should be encouraged.

Regional Planning

The 1993 Growth Management Act greatly changes the role and powers of the regional planning councils. The regional planning councils are charged with planning and coordinating intergovernmental solutions to multi-jurisdictional growth-related problems, with no regulatory authority. Regional policy plans will now be required to address only affordable housing, economic development, emergency preparedness, regionally significant natural resources, and regional transportation, and these plans will no longer be a basis for determining the consistency of local plans.

The DRI Process

The act provides for the termination of the DRI process in large jurisdictions (counties greater than 100,000 population) when they adopt specific intergovernmental coordination mechanisms. The law also greatly revises the DRI process in those counties and cities that retain the process. Fewer projects will be considered DRIs, the regional planning councils will be allowed to address only state and regional resources or facilities, and the review process is expedited for projects that are consistent with the local comprehensive plan.

Local Planning

The act makes several very substantial changes in the local planning process, especially with respect to the plan amendment review process, sanctions, intergovernmental coordination, and evaluation and appraisal reports. The plan amendment review process is streamlined, with DCA issuing an ORC Report for a proposed amendment only if a regional planning council, affected person, or local government requests it or if DCA decides to conduct such a review. All adopted plan amendments will be reviewed by DCA for compliance with state laws. The law greatly changes and strengthens the evaluation and review reporting requirements. The DCA is directed to adopt a rule establishing a phased schedule for the submittal of evaluation and appraisal reports no later than 6 years after local plan adoption and then every 5 years thereafter.

Concurrency and Infrastructure Funding

The act codifies DCA's existing concurrency management rule and policies, thereby providing specific legislative guidance on this critical component of the planning process. To avoid conflicts with other state planning goals, the act authorizes local governments to provide an exception from transportation concurrency requirements in areas designated for urban in-fill development, urban redevelopment areas, existing urban service areas, or certain downtown revitalization areas. The act authorizes local governments to adopt a "pay and go" system for transportation concurrency if the local plan includes a financially feasible capital improvement plan to upgrade transportation facilities and establishes an impact fee or other system requiring the developer to pay its fair share of needed transportation facilities. Unfortunately, while ELMS III recommended a 10-cent statewide gas tax increase to provide infrastructure funding, the legislature only authorized local governments to increase the local option gas tax by up to 5 cents.

Recommendations

Based on experience with Florida's growth management programs over the past 15 years, the following recommendations are made to streamline the process and enhance protection of Florida's natural resources.

The program and its requirements must recognize the inherently different growth management needs of highly urbanized areas or rapidly growing areas and separate them from the planning needs of rural areas, especially those with very slow growth rates. Flexibility, with consistency, is the key.

Rural local governments, especially in those areas experiencing growth, have the most to gain from comprehensive planning. Hopefully, they can avoid the mistakes that have been made in central and southern Florida where unplanned growth adversely affected social, economic, and environmental resources. Rural local governments, however, need extensive technical assistance and funding to develop and implement sound comprehensive plans.

Probably the greatest hindrance to solving Florida's existing growth management problems and preventing future growth from exacerbating them is the implementation, at both state and local levels, of dedicated funding sources. At the state level, the Growth Management Program, the Surface Water Improvement and Management Program, the State Stormwater Demonstration Grant Program, and the Preservation 2000 Land Acquisition Program are underfunded and depend on annual legislative appropriations. Dedicated funding sources such as increases in documentary stamp taxes or the placement of small fees on products such as concrete, asphalt, fertilizer, pesticides, and water use or even electric bills could generate sufficient funding levels to ensure that these programs succeed. At the local level, impact fees, gasoline taxes, and the establishment of stormwater utilities (already implemented by over 50 local governments) are essential if funds sufficient to pay for needed infrastructure improvements are to be raised.

The state's land planning and water planning frameworks need to be better integrated. In particular, the Department of Environmental Regulation and the five regional water management districts need to be the lead agencies involved with water management issues. Greater consistency and integration is needed between local comprehensive plans and requirements set forth in State Water Policy, Chapter 17-40, FAC. Currently, local comprehensive plans only are required to "consider" State Water Policy rather than to be "consistent with."

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Stormwater and the Clean Water Act: Municipal Separate Storm Sewers in the Moratorium

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Abstract

Urban stormwater and related pollutant sources have been shown to be major sources of water quality impairment. Section 402(p)(6) of the Clean Water Act requires the U.S. Environmental Protection Agency to identify additional stormwater sources to be regulated to protect water quality under Phase II of the National Pollutant Discharge Elimination System (NPDES) program. Mitigating water quality impairment associated with urban runoff requires comprehensive efforts with special emphasis on comprehensive approaches to stormwater management for new development. Municipal governments in urbanized areas appear to be critical institutions for making many of the day-to-day decisions necessary to address problems associated with stormwater, including measures to minimize the risks to water resources associated with stormwater from areas undergoing urbanization. In addition, municipalities have the police power needed to implement some components of stormwater programs and the ability to collect funds to be used in program implementation. This paper looks at the use of NPDES permits for discharges from municipal separate storm sewers systems in urbanized areas as a tool for defining the federal/state/municipal relationship for addressing stormwater management.

Environmental Background

Urban stormwater discharges have been shown to be a major cause of impairment of surface water resources. The *National Water Quality Inventory 1990 Report to Congress* provides a general assessment of surface water quality based on biennial reports submitted by the states under Section 305(b) of the Clean Water Act (CWA). The report indicates that of the rivers, lakes, and estuaries that the states assessed, roughly 60 to 70 percent are supporting the uses for which they were designated. Urban lands, however, only account for 2 percent of lands in the United States (1). The report indicates that urban runoff is a major source of impairment for 53 percent of impaired estuary acres, 36 percent of impaired ocean coastal miles, 29 percent of impaired lake acres, 6 percent of impaired Great Lake shoreline, and 9.6 percent of impaired river miles. The report also indicates that combined sewer overflows, which are a mixture of urban runoff, sanitary sewage, and industrial process discharges, are sources of impairment for 4 percent of impaired estuary acres, 3.6 percent of impaired ocean coastal miles, 7.5 percent of impaired Great Lakes shoreline, and 2.8 percent of impaired river miles. Urban runoff affects receiving waters in or near urban population centers and therefore may limit the uses and values of the waters closest to the most people.

Surface water resources are affected by two characteristics of urban runoff: 1) elevated pollution concentrations and loadings and 2) changes in flow patterns that accompany urbanization. The nature of the receiving water determines whether increased pollutant loadings or changes to natural flow patterns or a combination of both are causes of impairment. For example, slower moving rivers, streams, lakes, and estuaries can be more sensitive to increased pollutant loadings than to changes in flow patterns. Conversely, faster moving streams, such as those found in hilly or mountainous areas, can flush pollutants but may be sensitive to dramatic changes in flow patterns. A good comparison of these impacts is provided by Pitt, who compares impacts in Coyote Creek (San Jose, California), a stream with relatively slow flows, with impacts in Kelsey and Bear Creeks (Bellevue, Washington), streams with high flows and good flushing capabilities (2, 3).

Sources of Pollutants in Urban Stormwater

Pollutants discharged from municipal separate storm sewer systems originate from a variety of diffuse sources. EPA has identified four major classes of sources that contribute pollutants to discharges from municipal separate storm sewer systems (4):

- Nonstormwater sources
- Residential and commercial sources
- Industrial sources
- Construction activities

Nonstormwater Sources

Although separate storm sewers are primarily designed to remove runoff from storm events, materials other than stormwater find their way into and are ultimately discharged from separate storm sewers. For example, in Sacramento, California, less than half the water discharged from the stormwater drainage system was directly attributed to precipitation (5). Nonstormwater discharges to storm sewers come from a variety of sources, including:

- Illicit connections and cross connections from industrial, commercial, and sanitary sewage sources.
- Improper disposal of wastes, wastewaters, and litter.
- Spills.
- Leaking sanitary sewage systems.
- Malfunctioning septic tanks.
- Infiltration of ground water contaminated by a variety of sources including leaking underground storage tanks.
- Wash waters, lawn irrigation, and other drainage sources.

For a more complete description of nonstormwater discharges to storm sewers, see U.S. EPA (6).

Table 1 provides a summary of several studies involving problems with nonstormwater discharges. These case studies illustrate the wide range of pollutants that can enter storm sewers from nonstormwater discharges,

Table 1. Summary of Nonstormwater Discharge Problems

Study Site	Comments
Jones Falls Watershed, Baltimore City and County, MD	During the NURP study of the Jones Falls Watershed, 15 illicit connections were discovered in portions of the watershed. The illicit connections were grouped into four types: direct discharges from residences; leakage from cracked or broken sewer lines; decades-old overflows from the sanitary sewer; and sanitary sewage pumping station malfunctions. Elevated levels of pathogens, TSS, ammonia, TKN, total nitrogen, COD, and TOC were identified.
Tulsa, OK	A physical inspection was conducted of 120,000 ft of storm sewer 48 in. and larger serving a drainage area of approximately 12 square miles. Thirty-five potential nonstormwater discharges were observed. Twenty-three of these were observed and/or suspected sanitary sewer connections, four were potable water discharges, and eight were of unknown origin. In addition, 12,900 ft of sanitary sewer was laid within the storm sewer, where the storm sewer served as a conduit. Most illicit connections were associated with development that occurred before 1970. Other documented observations were structural defects (900 ft of pipe showed signs of structural defects), pipe cross through (176 total), and debris buildup.
Washtenaw County, MI	Inspection of 1,067 businesses, homes, and other buildings was conducted, with 154 of the buildings (14%) identified as having illicit connections, including connections in restaurants, dormitories, car washes, and auto repair facilities. About 60% of the automobile-related businesses inspected had illicit discharges. A majority of the illicit connections discovered had been approved connections when installed. Pollutants that were detected included heavy metals, nutrients, TSS, oil and grease, radiator fluids, and solvents.
Fort Worth, TX	Twenty-four outfalls in a 10-mile radius were targeted for end-of-pipe observations. The success of the program was judged by a decline in the number of undesirable features at the target outfalls from an average of 44 undesirable observations per month in 1986 (522 total) to an average of 21 undesirable observations per month in 1988. The Fort Worth investigation indicated problems associated with allowing septic tanks, self-management of liquid waste by industry, and construction of municipal overflow bypasses from the sanitary sewer to the storm drains. These problems were attributed to the inability of the publicly owned treatment works to expand as rapidly as urban growth occurred. During a 30-month period, problems detected included 133 hazardous spills, 125 incidents related to industrial activity, 265 sanitary sewer line breaks, and 21 bypass connections of the sanitary sewer to the storm sewer. Highlighted cases included a 20-gal/min flow from a cracked sanitary sewer from a bean processing plant to a storm drain and an illicit connection of a sanitary sewer line from a 12-story office building to a storm sewer. Most industrial pollution enters the storm sewer system from illegal dumping, storm runoff, accidental spills, and direct discharges. Metals were not detected in dry-weather discharges but were found in significant levels in receiving water sediment. City officials state that the high metal concentrations in sediment are consistent with otherwise unexplained serious reported fish kills.

Table 1. Summary of Nonstormwater Discharge Problems

Study Site	Comments
Seattle, WA	The city of Seattle has detected improper disposal and illicit connections from industrial sites by investigating sediment in storm sewers. One storm drain outfall representing a major source of lead to the Duwamish River was traced back to a former smelter that crushed batteries to recover lead. Lead concentrations in the sediment were high enough to allow the city to send it to an operating smelter to be refined. Another storm drain contained high levels of creosote, pentachlorophenol, copper, arsenic, and PCBs, which (except for the PCBs) were traced back to a wood treatment facility. Contaminated sediments removed from the storm drain (30 yd^3) contained 145 lb of contaminants. Sediments removed from storm drains in another industrial area contained very high levels of PCBs (about 1 lb PCBs/70 yd^3 sediment).
Upper Mystic Lake, NY	The NURP study for the Mystic Lake Watershed project identified contamination of stormwater runoff and subsequently surface water contamination of surface waters by sanitary discharges as a major problem in the watershed that contributed large quantities of phosphorus, certain metals, and bacteria. Interactions at 19 manholes that served both sanitary and storm sewer lines were identified as the major contributor of pollutants.
Bellevue, WA	The NURP report for Bellevue recorded 50 voluntary citizen reports of illegal dumping and other nonstormwater discharges during a 27-month period. The incidents reported were varied and resulted in at least two significant fish kills. Of the citizen reports, 25% involved improper disposal of used oil to the storm sewer. Other reports involved spills; illicit connections of floor drains, septic tank pipes, and a car wash; chemical dumping; and concrete trucks rinsing out into catchbasins or streams.
Ann Arbor, MI	Studies in 1963, 1978, and 1979 found that discharges from the Allen Creek storm drain contained significant quantities of fecal coliform, fecal streptococci, solids, nitrates, and metals. Of the 160 businesses dye-tested, 61 (38%) were found to have improper storm drain connections. Chemical pollutants including detergents, oil, grease, radiator wastes, and solvents were causing water quality problems. Monitoring of the storm drainage system during storm events indicated a decrease in the concentration of 32 of 37 chemicals monitored after the improper connections were removed.
Medford, OR	Fecal coliform tests at storm drain outfalls in city parks were used to detect four leaking sewer lines, which either were located above the storm lines or saturated the ground with effluent, which entered the nearby storm drains, an agricultural equipment wash rack, and a house with sanitary lines plumbed to the storm drain. In addition, in one of the oldest sections of town a large storm drain bored in the early 1900s also contained the sanitary sewer line. Under manholes, the sanitary line was only a trough. Even minor clogs or breaks resulted in a spillover of effluent in the storm drain below.
Toronto, Ontario	Dry weather sampling of discharges from 625 storm drains in the Humber River Watershed. About 10% of the outfalls were considered significant sources of nutrients, phenols, and/or metals, while 30 of the outfalls had fecal coliform levels >10,000/100 mL. Investigations identified 93 industrial and sanitary sewage illicit connections. Problems included residential connections of sanitary sewage to the storm sewers and yard runoff from a meat packing plant to a storm drain.
Grays Harbor, WA	Dry weather sampling of 29 outfalls of separate storm drains indicated that discharges from six of the outfalls had abnormally high pollutant levels with suspected illicit connections. The area under consideration had originally been served by combined sewers. Earlier efforts to separate the system had been incomplete, with some residences discharging sanitary sewage to the storm drain.
Seward, NY	Sewage from septic tanks with clogged drainfields in clay soils flowed into open storm sewers. The open storm sewers posed health risks to neighborhood children and lowered property values.
Norfolk Naval Station, VA	The Norfolk Naval Shipyard was originally built in 1767 and has had numerous additions since that time. It has an extensive network of underground pipes that includes both separate storm sewers and sanitary/industrial sewers. In response to a lawsuit, officials at the shipyard conducted dye-testing of sanitary facilities throughout the shipyard, which led to the identification and elimination of 25 cross connections of sanitary and industrial waste to the separate storm sewer system.
Sacramento, CA	The city of Sacramento is currently undertaking a project to identify pollutant discharges and illegal connections into the stormwater drainage systems. Recent studies identified acute toxicity in stormwater, and revealed that less than half the water discharged from the drainage system was not directly attributable to precipitation. Mass loading estimates of copper, lead, and zinc discharged by the drainage system were several times higher than the estimated pollutant loads of these metals from the Sacramento Regional Treatment Plan secondary effluent.
Hazardous waste case studies	Cases of onsite waste disposal where pollutants were added to runoff that eventually ended up in drainage systems and other cases where a generator dumped wastes directly down a drain were common. Of the 36 cases of illegal dumping investigated in a GAO report, 14 cases investigated involved disposal of hazardous waste directly to, or with drainage to, a storm sewer, flood control structure, or the side of a road. An additional 10 sites involved disposal to the ground, landfills (other than those receiving hazardous wastes), and trash bins, which can then result in added pollutants to subsequent stormwater discharges.

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including pathogens, metals, nutrients, oil and grease, metals, phenols, and solvents. Removal of these non-stormwater pollutant sources often provides opportunities for dramatic improvement in the quality of discharges from separate storm sewers.

Residential and Commercial Runoff

Residential and commercial activities are the predominate land uses in most urbanized areas (UAs), typically occupying between 55 to 85 percent of the total area. Major pollutants associated with residential and commercial runoff include heavy metals, oxygen demanding materials, bacteria, nutrients, floatables, organics, pesticides, polynuclear aromatic hydrocarbons (PAHs), and other toxic organic pollutants.

From 1978 through 1983, the U.S. Environmental Protection Agency (EPA) provided funding and guidance to the Nationwide Urban Runoff Program (NURP) to study the nature of runoff from commercial and residential areas. The NURP study provides insight into what can be considered background levels of pollutants in runoff from residential and commercial land uses. Sites used in the NURP study were carefully selected so that they were not affected by pollutant contributions from construction sites, industrial activities, or illicit connections. Data from several sites had to be eliminated from the study because of elevated pollutant loads associated with these sources.

Data collected in NURP indicated that on an annual loadings basis, suspended solids in discharges from separate storm sewers draining runoff from residential and commercial areas are approximately an order of magnitude or more greater than in effluent from sewage treatment plants receiving secondary treatment. In addition, the study indicated that annual loadings of chemical oxygen demand (COD) is comparable in magnitude with effluent from sewage treatment plants receiving secondary treatment.

Table 2 compares annual pollutant loadings for three metals—zinc, lead, and copper—from urban runoff from the Metropolitan Washington UA, from a sewage treatment plant that provides advanced treatment and that serves about 2 million people (the Blue Plains sewage treatment plant), and from major industrial process wastewater discharges located in Maryland and Virginia.

When analyzing annual loadings associated with urban runoff, it is important to recognize that discharges of urban runoff are highly intermittent, and that the short-term loadings associated with individual events will be high and may have shockloading effects on receiving water.

Pollutant loadings for urban stormwater are based on the "Simple Method" developed by the Washington Metropolitan Council of Governments (7). Pollutant concentrations used in this model were based on those published in U.S. EPA (8). The values for leaa were reduced by 75 percent to account for assumed reductions due to reductions in the use of lead in gasoline.

Pollutant loadings for direct dischargers in the Toxics Release Inventory are as reported in Cameron (9). The Toxics Release Inventory contains data on toxic chemical releases by industrial facilities that use 10,000 lb or more of specified toxic chemicals and does not include all releases from all industrial facilities in a state.

Industrial Runoff

A number of studies indicate that runoff from industrial land uses has relatively poorer water quality than other general land uses (8, 10-13). In general, a greater variety and larger amounts of toxic materials can be used, produced, stored, or transported in industrial areas. Industrial activities that can provide a significant source of pollutants to stormwater from industrial sites include loading and unloading, outdoor storage, outdoor processes, illicit connections or management practices, and waste disposal practices. In addition, many heavy industrial areas have a large degree of imperviousness, which results in high volumes of runoff. Atmospheric deposition and spills and leaks associated with material transport can contribute to significant levels of toxic constituents in runoff to areas surrounding or in close proximity to heavy industrial activity.

Table 2. Annual Pollutant Loadings (In Pounds) In Stormwater From Selected Pollutant Sources

Pollutant	Urban Stormwater From Metropolitan Washington	Blue Plains POTW[a]	All MD and VA Direct Industrial Discharges In 1987 Toxic Release Inventory
Zinc	480,000	137,000	132,000
Lead	132,600	5,500	31,300
Copper	113,000	21,000	127,000
Nitrogen	30,000,000	12,000,000	Not available
Phosphorus	1,200,000	113,000	Not available
BOD5	9,500,000	1,400,000	Not available

[a]Blue Plains POTW loadings estimates based on EPA Permit Compliance System (PCS) data for 1989.

Runoff From Construction Activities

The amount of sediment in stormwater discharges from construction sites can vary considerably, depending on whether the discharges are uncontrolled or whether effective management practices are implemented at the construction site. Sediment loads from uncontrolled or inadequately controlled construction sites have been reported to be on the order of 35 to 45 tons/acre/year. Sediment loads from uncontrolled construction sites are typically 10 to 20 times that of agricultural lands, with sediment loads as high as 100 times that of agricultural lands and typically 1,000 to 2,000 times that of forest lands. Over a short period, construction sites can contribute more sediment to streams than was previously deposited over several decades.

Changes to Flow Patterns: Physical Impacts

Urbanization can result in dramatic changes to the natural flow patterns of urban streams and wetlands. In undeveloped watersheds, most rainfall infiltrates into the ground and recharges ground-water supplies. Urbanization alters the natural vegetation and natural infiltration characteristics of a watershed, which results in much higher peak flows and reduced base flows in urban streams. Increased peak flows can result in stream bank erosion, streambed scour, flooding, channelization, and elimination or alteration of habitat (14). Increases in peak flows can also create the need to modify stream channels through a variety of engineered structures, such as retaining walls, rip-rap, and channel dredging.

Increased imperviousness and loss of wetlands and natural flow channels also decrease the amount of rainwater available for ground-water recharge. Reduced ground water levels reduce base flows in streams during dry weather periods, which impairs the aquatic habitat, impairs riparian wetlands, and makes receiving streams more sensitive to other pollutant inputs and sedimentation.

Development Patterns

In the United States, population patterns typically do not follow the political boundaries of municipalities. Prior to 1950, many large core cities annexed additional fringe areas as populations of the urban center increased. The trend of core cities increasing in area through annexation has largely stopped in most major UAs. In most states, smaller "suburban" local governments surrounding the core city are retained or created.[1] Thus, today most urban centers are composed of a large core city surrounded by several smaller "suburban" municipalities.

Every 10 years, the Bureau of Census defines UAs to characterize the population and development patterns of large urban centers of 50,000 or more. UAs are composed of a central city (or cities) with a surrounding closely settled area. The population of the entire UA must be greater than 50,000 persons. The closely settled area outside of the city, the urban fringe, must have a population density generally greater than 1,000 persons per square mile (just over 1.5 persons per acre) to be included. The boundaries of UAs are based on population patterns, not political boundaries; therefore, they do not include significant portions of rural land.

The Bureau of Census has defined 396 UAs in the United States based on the 1990 Census. These UAs have a combined population of 158.3 million, or 63.6 percent of the nation's total population;[2] however, these areas only account for 1.5 to 2 percent of the land surface of the country. Most increases in population occur in urban fringe or suburban municipalities rather than in core cities.[3]

Clean Water Act Requirements

In 1972, the CWA was amended to provide that the discharge of any pollutants to waters of the United States from a point source is unlawful, except where the discharge is authorized by an NPDES permit. The term "point source" is broadly defined to include "any discernible, confined and discrete conveyance, including but not limited to any pipe, ditch, [or] channel, ... from which pollutants are or may be discharged." (Congress has specifically exempted agricultural stormwater discharges and return flows from irrigated agriculture from the definition of point source.) Although the definition of point source is very broad, prior to 1987, efforts under the NPDES program to control water pollution have focused on controlling pollutants in discharges from

[1]The patterns and functions of local governments in suburban fringe areas vary from state to state. In some states, such as Maryland, Virginia, Florida, and California, and, to a lesser degree, a number of southern states and Texas, large urban populations outside of core cities are in unincorporated portions of counties. In these cases, the county government conducts the major functions of local government. However, in most States, including New England, mid-Atlantic, Great Lake, midwestern, and most western states, the primary form of local government for many municipal functions is not a county but either an incorporated place or a minor civil division. (These terms are defined in Table 3.)

[2]The Census Bureau defines urban populations more broadly than UAs. Urban populations include the populations of UAs and any other dense population of 2,500 or more people. The 1990 Census indicates that 28.8 million people who lived outside of UAs were classed as urban populations. The Bureau of Census classified populations that are not classified as urban (including UAs) as rural. The 1990 Census indicates that 61.6 million people were classified as living in rural areas.

[3]The 1990 Census indicates that the total population of the United States increased by 22.1 million between 1980 and 1990. Of this growth, 86 percent (19 million) was in Census-designated UAs. Cities with a population of 100,000 or more accounted for 22 percent of this growth (4.9 million), while suburban areas surrounding these areas grew by 11.5 million (52 percent of the national total). Another 12 percent of the national growth (2.6 million) occurred in UAs that did not have a core city of 100,000 or more.

publicly owned treatment works (POTWs) and industrial process wastewaters. The major exception to this are the 10 effluent limitation guidelines that EPA has issued for stormwater discharges: cement manufacturing (40 CFR 411), feedlots (40 CFR 412), fertilizer manufacturing (40 CFR 418), petroleum refining (40 CFR 419), phosphate manufacturing (40 CFR 422), steam electric (40 CFR 423), coal mining (40 CFR 434), mineral mining and processing (40 CFR 436), ore mining and dressing (40 CFR 440), and asphalt emulsion (40 CFR 443).

As part of the Water Quality Act of 1987, Congress added Section 402(p) to the CWA to require EPA to develop a comprehensive, phased program for regulated stormwater discharges under the NPDES program. Under the first phase of the post-1987 program, EPA is to develop requirements for:

- Stormwater discharges associated with industrial activity.
- Discharges from large municipal separate storm sewer systems (systems serving a population of 250,000 or more) and medium municipal separate storm sewer systems (systems serving a population of 100,000 to 250,000).
- Discharges that are designated by EPA or an NPDES-approved state as needing an NPDES permit because the discharge contributes to a violation of a water quality standard or is a significant contributor of pollutants to waters of the United States.

Section 402(p)(1) of the CWA creates a temporary moratorium on the requirement that point source discharges of pollutants to U.S. waters must be authorized by an NPDES permit for other stormwater discharges.[4] Under the moratorium, EPA is prohibited from issuing NPDES permits for discharges composed entirely of stormwater that are not specifically exempted from the moratorium (the discharges listed above to be addressed during the first phase of the program) prior to October 1, 1994.[5] Before this time, EPA, in consultation with the states, is required to conduct two studies on stormwater discharges. The first study is to identify those stormwater discharges or classes of stormwater discharges for which permits are not required prior to October 1, 1994, and to determine, to the maximum extent practicable, the nature and extent of pollutants in such discharges. The second study is to establish procedures and methods to control stormwater discharges to the extent necessary to mitigate impacts on water quality.

Based on the two studies, EPA is required to issue regulations by no later than October 1, 1993, that designate additional stormwater discharges to be regulated to protect water quality and establish a comprehensive program to regulate such designated sources. The program must, at a minimum:

- Establish priorities.
- Establish requirements for state stormwater management programs.
- Establish expeditious deadlines.

The program may include performance standards, guidelines, guidance, management practices, and treatment requirements, as appropriate.

The 1987 amendments to the CWA made significant changes to the permit requirements for discharges from municipal separate storm sewers. Section 402(p)(3)(B) of the CWA provides that NPDES permits for such discharges:

- May be issued on a system- or jurisdictionwide basis.
- Shall include a requirement to effectively prohibit non-stormwater discharges into storm sewers.
- Shall require controls to reduce the discharge of pollutants to the maximum extent practicable, including management practices, control techniques and system, design and engineering methods, and such other provisions as the Director determines appropriate for the control of such pollutants.

Initial Implementation

On November 16, 1990, EPA published the initial NPDES regulations under Section 402(p) of the CWA (see 55 FR 47990). The November 16, 1990, regulations:

- Defined the initial scope of the program by defining the terms "stormwater discharge associated with industrial activity" and large and medium "municipal separate storm sewer systems."
- Established permit application requirements.
- Established deadlines.

The regulatory definitions of large and medium municipal separate storm sewer systems specifically identified 173 incorporated cities and 47 counties, and allowed for additional designations of adjacent municipalities on a case-by-case basis. EPA estimates that 400 additional municipalities with a combined population of about 16 million people have been designated by EPA and authorized NPDES states, and that 23 cities with a population of 100,000 or more (and a combined population of 8.6 million people) have been excluded from stormwater

[4] The Conference Report for the 1987 amendments to the CWA provides that after the moratorium ends on October 1, 1994, "*all* municipal separate storm sewers are subject to the requirements of Sections 301 and 402" (emphasis added) (15).

[5] The 1987 amendments to the CWA originally provided that the moratorium on other stormwater discharges (Water Resources Development Act) expire on October 1, 1992. Under the amendments, EPA was required to issue additional regulations to address these sources.

requirements due to large populations served by combined sewer systems.

The November 16, 1990, regulations were based on 1980 Census data. Data from the 1990 Census indicates that 30 additional cities have a population of more than 100,000, and five of the cities listed in the November 16, 1990, regulations no longer have a population of 100,000 or more. In addition, the 1990 Census indicates that 12 additional counties have an unincorporated, urbanized population of 100,000, and two counties listed in the November 16, 1990, regulations no longer have an unincorporated, urbanized population of 100,000.

The November 16, 1990, regulations also established requirements for a comprehensive, two-part permit application for discharges from large and medium municipal separate storm sewer systems. The major objectives of the permit application requirements are to ensure that municipalities develop comprehensive municipal stormwater management programs that address water quality, and to begin to implement these programs.

The permit application requirements for discharges from municipal separate storm sewer systems represent a new approach to addressing pollutant sources under the NPDES program. NPDES permit application requirements for other types of discharges traditionally focused on sampling end-of-pipe discharges. Permit applications for discharges from municipal separate storm sewer systems place a lesser emphasis on discharge sampling for a number of reasons, including the large number of discharge points commonly associated with municipal systems and the recognition that many municipalities were only initiating efforts to reduce pollutants in stormwater discharges at the time (see 55 FR 47990). Municipalities are required to submit comprehensive applications providing information that: 1) identifies major sources of pollution to the system, 2) characterizes pollutants in system discharges, 3) describes existing and proposed municipal stormwater management programs, and 4) describes the administrative and legal aspects of the municipal stormwater management program.

Perhaps the most important aspect of the permit application requirements is that they lay out the framework for municipalities to propose comprehensive municipal stormwater management programs. When developing permit conditions, permit writers will consider the management programs that are proposed as part of the permit applications. The municipal stormwater management programs envisioned by the November 16, 1990, regulations address the four following areas:

- *Measures to reduce pollutants in runoff from residential and commercial areas:* A major focus of this program component is controlling pollutants in stormwater from new development where stormwater controls are generally more cost effective and municipalities do not have to incur costs directly. Retrofitting controls for existing development can also be considered where practicable. Another focus is vegetation maintenance and snow removal activities for roads. Other source control measures, such as transportation plans, can be required where practicable.
- *Measures to reduce pollutants in runoff from industrial facilities:* EPA anticipates that a large percentage of stormwater discharges associated with industrial activity discharge through municipal separate storm sewer systems. The Agency intends to coordinate requirements in permits for stormwater discharges associated with industrial activity with efforts to develop municipal stormwater management programs in permits for discharges from municipal separate storm sewer systems serving a population of 100,000 or more. Under this coordinated effort, municipal permittees will have a major role in implementing programs to control pollutants from stormwater associated with industrial activity that discharges through their municipal separate storm sewers. For example, municipal operators can assist EPA and authorized NPDES states in identifying priority stormwater discharges associated with industrial activity; reviewing and evaluating stormwater pollution prevention plans developed by industrial facilities pursuant to NPDES permit requirements; and complying with requirements. (See 56 FR 40972 for a more complete description of the relationship EPA intends to develop between federal, state, and local governments for controlling pollutants in stormwater from industrial sources.)
- *Measures to reduce pollutants in runoff from construction sites:* Many municipalities currently have sediment and erosion requirements for construction activities. These programs, however, often are not adequately implemented or enforced. NPDES permit conditions for municipalities are expected to focus on ensuring adequate municipal implementation and enforcement of their controls. (See 57 FR 41206 and Metropolitan Washington Council of Governments [17].)
- *Measures to detect and control nonstormwater discharges to the storm sewer system:* Nonstormwater discharges to separate storm sewer systems are a major pollutant source in many municipalities. EPA anticipates that permits will require municipalities to continue field screening efforts started during the permit application phase of the program and to undertake other efforts to detect and control nonstormwater discharges.

For a more complete description of the components of a municipal stormwater management program, see *Guidance Manual for the Preparation of Part 2 of the*

NPDES Permit Applications for Discharges From Municipal Separate Storm Sewer Systems (16).

The November 16, 1990, regulations take two very different approaches to defining the roles of different levels of government. With respect to permits for large and medium municipal systems, the efforts of the NPDES permit authority (EPA or an authorized NPDES state) are directed toward ensuring that municipalities develop and implement stormwater management programs to control pollutants to the maximum extent practicable. Under these requirements, the NPDES program can define the role of municipalities in a flexible manner that allows local governments to assist in identifying priority pollutant sources within the municipality and to develop and implement appropriate controls for such discharges. With respect to permits for stormwater discharges associated with industrial activity, the NPDES permit authority has a direct role in regulating individual industrial sites.

Moratorium Sources: Why Municipalities?

Section 402(p)(6) of the CWA requires EPA to issue regulations that designate additional stormwater discharges to be regulated to protect water quality and that establish a comprehensive program to regulate such designated sources. EPA can generally take two different approaches to identifying classes of discharges to be regulated by NPDES permits: 1) to require municipalities to develop systemwide stormwater management programs, or 2) to require NPDES permit coverage for targeted commercial and residential facilities. When evaluating whether to address selected municipalities in the regulatory program required under Section 402(p)(6), the following factors should be considered:

- There are institutional considerations.
- Some existing municipal functions can be modified to address stormwater concerns in a cost-effective manner.
- Municipal participation is necessary for regional or systemwide stormwater management programs.
- There are pollutant load considerations.
- Issuing permits to municipalities allows for municipal programs that incorporate innovative controls, such as market-based incentives and pollutant trading.
- Municipalities are in the best position to address high risk sources, including new development, and to protect priority resources and watersheds.
- Some municipal activities are significant pollutant sources.
- Municipalities can ensure maintenance of structural controls and implementation of nonstructural measures.

Institutional Considerations

Municipalities contain the institutions that are critical for surface water resource protection programs. Urban stormwater management has been, is, and will continue to be primarily the responsibility of local governments (18). Municipalities install or oversee the installation of storm sewer systems to provide drainage for lands used for residential, commercial, and industrial activities as well as roads and highways. Municipalities can provide the institutional framework necessary to implement many components of an effective stormwater management program.

Components of a comprehensive stormwater management program that only municipalities can effectively address include land use planning, detailed oversight of new development, maintenance of roads, retrofitting controls in areas of existing development, and operation and maintenance of municipal storm drains. Municipalities can provide the detailed planning necessary to implement watershed and other risk-based approaches.

The role of municipalities under the NPDES program is to make stormwater management programs work. This involves overseeing day-to-day program operations, identifying local priorities and pollutant sources, developing detailed program requirements, conducting site inspections and evaluations, monitoring activities, assessing impacts to surface water resources, initiating compliance efforts, and ensuring effective outreach. Municipal activities can be funded by a variety of mechanisms, including general revenues, developer fees, flood control assessments, and stormwater utilities. Raising funds at the municipal level can provide a municipalitywide source of funds that can then be directed at priority projects. Thus, comprehensive programs can be implemented in a phased manner over a long period. In addition, such an approach takes advantage of pollutant trading concepts by directing resources from many sources to priority sources.

The role of the federal government and authorized NPDES states under the NPDES municipal stormwater program is to ensure that regulated entities implement pollution control measures. In the municipal stormwater area, this means providing oversight to guide the direction of municipal programs and providing technical assistance. Oversight activities include issuing permits that establish the framework for municipal stormwater control programs and taking targeted enforcement actions, for example, when municipalities fail to develop and implement a program. In addition, the NPDES authority must work in partnership with municipalities to ensure that, where appropriate, priority pollutant sources that municipalities may have difficulty controlling, such as certain federal or state facilities, are directly issued NPDES permits for their stormwater discharges. As Thomas Mumley, Associate Water Resource Control

Engineer at the San Francisco Regional Water Quality Control Board (19) states:

> Successful control of urban runoff will require a carrot, a stick, and . . . the implementation of common-sense, cost-effective, environmentally beneficial measures. . . . We need incentives to change our ways . . . we now have a big stick to drive these needed efforts, in the form of the NPDES stormwater regulations [for municipalities] which require the implementation of these measures. Fortunately, the current regulations promote flexibility[6] and don't impose a lot of bureaucratic red tape, and therein lies the carrot.

Expanding the Mission of Existing Municipal Programs

Municipalities typically operate programs whose primary mission is to address a set of concerns other than stormwater or water quality. Expansion of the mission of these existing municipal programs to address stormwater concerns can be much more cost effective than initiating entirely new programs. Municipal functions that can be adapted to assist in providing stormwater management benefits include oversight of new development, pretreatment program implementation, fire safety inspections, flood control, trash collection, management of municipal lands, and road maintenance. Municipal lands, for example, can provide retrofit opportunities for a number of reasons. The use of municipal lands for retrofits typically does not require additional property purchases. In addition, the use of municipal lands ensures opportunities to provide future maintenance and security in preservation of the retrofit control. (See Washington State Department of Ecology [20] for special stormwater management practices for public buildings and streets; vehicle and equipment maintenance shops; maintenance of open space areas; maintenance of public stormwater facilities; maintenance of roadside vegetation and ditches; maintenance of public utility corridors; water and sewer districts and departments; and port districts.)

In addition, many municipal activities and programs can be significant sources of pollutants, such as road maintenance, road construction, siting and operating flood control devices, maintenance of municipal vehicles, municipal landfills, and airports.[7] Expanding the mission of these programs can assist in the development of a pervasive municipal ethic regarding stormwater management that ensures effective use of municipal resources and mitigates the effects of municipal activities that can affect water resources.

Regional or Systemwide Programs

Urban stormwater is a diffuse source of pollution. The impacts of stormwater on receiving waters generally cannot be attributed to individual sources or discharge points; rather, the cumulative effects of many discharges from widespread areas of urban development in a watershed are of major concern. Often, approaches that consider watershed characteristics are necessary for success.

Control of urban stormwater is critical from a regional perspective, which addresses the entire UA. The lack of regional or systemwide planning is often cited as a major reason for incomplete and unsuccessful stormwater control efforts and for the inability to protect downstream areas from stormwater from upstream development. A comprehensive stormwater management program cannot rely solely on addressing individual sources within large UAs.

A regional approach can also bring together financial resources, planning, and scientific expertise not otherwise available for individual municipalities, thereby increasing the likelihood for success. Regional entities that can play an important role in planning, implementing, and evaluating stormwater programs include flood control districts, stormwater or drainage districts, counties, and Councils of Governments.

Pollutant Load Considerations

UAs comprise a mixture of different land uses. For general planning purposes, most UAs are distributed as follows: residential, 50 to 70 percent; commercial, 10 to 20 percent; industrial, 10 to 15 percent; open area, 10 to 15 percent (13). Concentrations of pollutants in stormwater from nonindustrial areas can be assumed to be roughly the same for different land use types, but the degree of imperviousness plays an important role in determining pollutant loads (8). This is because many diffuse sources of pollutants to urban stormwater operate in different land use areas, and areawide sources are important. While commercial and industrial land uses generally have a higher level of imperviousness than some types of residential development, a large amount of residential area will result in residential land use being a major pollutant source to stormwater. For example, a study of the Santa Clara Valley found that the volume of stormwater flows from residential and

[6]Concerns have been raised regarding the requirements under the current Clean Water Act that NPDES permits for municipal separate storm sewers, in addition to mandating the reduction of pollutants to the maximum extent practicable, must ensure compliance with water quality standards. The water quality standards issue is not discussed in this paper.

[7]Some municipal activities are considered to be industrial activities under the NPDES program. Section 1068 of the Intermodal Surface Transportation Efficiency Act of 1991 placed stormwater discharges associated with industrial activity owned or operated by a municipality with a population of less than 100,000 in the moratorium from NPDES permit requirements.

commercial land uses in the Valley was 10 times greater than the volume of flow from industrial uses. The loading of metals in stormwater flows from residential and commercial lands was estimated to be 5 to 30 times greater than from industrial lands (11).

A program that only addresses industrial stormwater flows is limited because it only addresses a fraction of the total urban stormwater flows. Similarly, programs to address illicit connections to storm sewers should address municipal sources. Municipalities have responsibilities associated with several important classes of illicit connections, including sanitary collection systems (ownership of collection system), improper connections between sanitary and storm sewer systems, and improper connections from residential or commercial areas. For example, investigations in Houston, Texas, indicated that most of the city's problems associated with nonstormwater discharges to the separate storm sewer system were associated with broken wastewater collection system lines discharging to its stormwater collection system (21).

In general, municipal programs should include legal authority to address the majority of stormwater sources into their municipal system. However, this does not mean that a municipality should have to ensure that every existing residential, commercial, or industrial site within its jurisdiction actively controls its stormwater. Rather, municipalities should develop programs that result in the implementation of practicable controls for high-priority sources that maximize cost-effectiveness by considering possible sources and conditions within the jurisdiction. In addition, EPA must be a partner in efforts to control selected priority sources, such as industrial, federal, and state facilities. For example, some municipalities have indicated that practical problems are associated with controlling stormwater from federal and state facilities. In such cases, a partnership between the municipality and the NPDES authority may be appropriate where the municipality identifies high-risk state and federal facilities for the NPDES authority to consider issuing an NPDES permit directly.

In addition, the Agency should lead national efforts to directly reduce some pollutant sources or find product substitutes. For example, federal requirements under the Clean Air Act have resulted in significant decreases in the use of lead in gasoline, which in turn have resulted in decreases in lead concentrations in urban runoff. Other areas of national regulation and/or pollution prevention efforts that have been suggested are reduction in the amount of zinc in tires, reductions in the amount of copper in brake pads, and lower emission standards for particulate emissions for diesel engines (11).

Flexibility in Selecting Measures

Municipal stormwater management programs should be comprehensive efforts that address a wide range of innovative measures in addition to traditional command-and-control requirements. Federal or state permitting programs generally have limited flexibility to directly implement many types of innovative control strategies in a widespread manner. Requiring municipalities to obtain NPDES permits for their municipal systems could create a regulatory framework that could support municipalities' use of innovative controls, such as market-based incentives.

For example, municipalities can fund stormwater programs with a utility rate system that accounts for the impervious area at a site, which is roughly proportional to the amount of stormwater generated at the site. A survey of 54 stormwater agencies with stormwater utilities located in 19 states indicated that 70 percent of the agencies surveyed based their utility on the amount of impervious area at a site, while an additional 17 percent based their utility on the product of area times an intensity of development, which can approximate impervious area (22). Such a rate system can also consider whether stormwater controls are provided at a site. These approaches create market-based incentives for reducing site imperviousness (thereby reducing stormwater volumes and pollutant loads) and for installing and operating stormwater measures. (See U.S. EPA for a list of 21 municipal stormwater utilities that provide credits for onsite stormwater management [23].)

Municipalities have a wide range of tools for ensuring stormwater control measures occur with new development. For example, municipalities can have zoning provisions that establish setbacks for buffer zones, limit the amount of impervious area, require maintaining minimum amounts of open space, and encourage cluster development. Municipalities can also develop watershed management plans that provide for preservation of floodplains, wetlands, shoreline, and other critical areas. In addition, during the building plan approval process, municipalities can designate, through deed modification or other means, an entity or individual who is responsible for maintaining the stormwater management systems of a new development. Controls on siting, installing, and maintaining septic systems and for ensuring proper sanitary sewer connections can reduce pollutant discharges from municipal separate storm sewer systems.

Other innovative approaches to stormwater management include used oil and/or household hazardous waste municipal collection programs. Municipalities can conduct portions of public outreach programs in a more cost-effective way than other levels of government. For example, municipalities can stencil catchbasins to minimize improper dumping of materials and send informational flyers with water or sewer bills.

Another approach is for a municipality to use pollutant trading concepts to select cost-effective controls. One example of pollutant trading is for a municipality to allow a developer to contribute to an offsite regional stormwater measure where onsite measures are not feasible. Other pollutant trading concepts are discussed in Santa Clara Valley Nonpoint Source Pollution Control Program (11) and U.S. EPA (24). It should be noted that some concerns have been raised regarding trading structural controls for nonstructural controls where opportunities to install structural controls can be lost and the continued implementation of nonstructural controls cannot be assured.

Municipalities can also incorporate voluntary components into their municipal stormwater management programs, such as adopt-a-highway litter programs or adopt-a-stream programs. In addition, the development of stormwater programs at the municipal level can encourage high levels of public input from local groups.

Flexibility To Address High-Risk Sources and To Protect Priority Resources and Watersheds

Controlling pollutants in stormwater involves addressing many and diffuse pollutant sources. The nature of the problem calls for focusing on priority sources and emphasizing controls in priority watersheds. Municipalities are in the best position to evaluate local conditions and to determine local priorities for implementing and overseeing control strategies and measures that ensure the water quality impacts of land use activities in its jurisdiction are mitigated. This is particularly true when evaluating the risks of new development.

Urbanization is a gradual process that spans decades and occurs over a wide region. It is composed of hundreds of individual developments that take place over much shorter time frames. The true scope of water resource degradation associated with urbanization may not fully manifest at the watershed scale for many years. This presents the challenge of evaluating the impact of individual development proposals over the long term at the watershed scale (25) and planning appropriately. Such detailed planning can only occur on the municipal level.[8] Detailed efforts to plan and oversee new development could not (and should not) be undertaken at the federal level.

Municipalities typically have planning processes and administrative systems in place to address some aspects of new development. When municipalities plan for new development, the total development of the area can be considered. This can provide a much more comprehensive basis for planning than when developers plan at the site level. Municipalities can accomplish these tasks with a much greater sensitivity to local conditions and in a more equitable and reasonable manner. In addition, municipalities can develop watershed plans that consider the tradeoffs associated with the placement of onsite controls and regional stormwater management approaches. Some municipalities advocate stormwater control strategies that use a mix of regional controls and onsite controls that reflects watershed hydrology. Advantages of this approach are said to include better control of peak flows; reduced impacts to streams and riparian wetlands; improved pollutant removal efficiencies; lower costs; a significantly higher likelihood of adequate maintenance; and recreational amenity values (26).

The ability of EPA or NPDES states to conduct such detailed planning is limited. For example, EPA indicated that a consideration of possible water quality impacts associated with the timing of releases from onsite stormwater management measures involves a complex array of variables, including the nature and locations of other activities within a watershed, and is generally beyond the scope of the Agency's NPDES general permits for stormwater from construction activities (see 57 FR 41202). Municipal consideration of mitigation measures for numerous smaller projects in a watershed may better maintain the integrity of an aquatic ecosystem.

A goal of the stormwater program should be that municipalities have planning procedures to identify and address the potential impacts of development on water resources. NPDES permits for municipal separate storm sewer systems can assist in reaching this goal by ensuring that municipalities consider the impact of stormwater on surface waters. Traditionally, the major objective of installing separate storm sewers has been to remove as much stormwater runoff from developed lands as soon as possible. To achieve this goal, local governments have constructed thousands of miles of curb, gutter, road side ditches, and other storm sewers to convey stormwaters as quickly and as efficiently as possible to the nearest stream (18). Efforts often focus on channelization projects that attempt to make streams more "efficient" at conveying waters downstream. Extensive channelization projects and other stream "improvements," such as concrete-lined walls or heavy riprap, can destroy the habitat value of streams.

A few communities have developed programs where stormwater is managed for multiple purposes, including controlling water quantity (to avoid flooding and stream scour and to maintain stream flows during dry weather by recharging ground water during storms) and improving water quality. A range of alternative stormwater control measures and facilities can be implemented to serve multiple purposes effectively. The natural cycles and processes that occur before land development are used

[8] EPA has recognized that many local governments typically require sediment and erosion plans, grading plans and/or stormwater management plans that are significantly more detailed and are accompanied by a more rigorous review process than those required under EPA-issued general permits (57 FR 41196).

as a guide for managing stormwater after development has occurred, and natural flow patterns and rates of discharge are retained through special stormwater control facilities and measures. Natural processes are incorporated into the design of many "soft" engineered systems, including vegetated buffers, greenways, revegetation of stormwater systems, wetland creation or retention for stormwater management, and onsite retention, detention, or infiltration systems. Policies emerging from these programs include:

- Reducing peak flows and improving stormwater quality through onsite retention.
- Reducing the volume of stormwater leaving the site using natural infiltration.
- Releasing stormwater from onsite facilities at a rate similar to the predevelopment runoff rate.
- Managing for smaller storm events as well as those larger storm events that can cause major floods.
- Protecting wetlands and floodplains as natural stormwater storage areas.
- Making stormwater facilities amenities of the development (such as retaining natural drainage channels or providing attractive landscaping for stormwater management ponds) and encouraging open space and recreational uses.
- Developing programs that relate erosion and sediment controls during construction with stormwater management after construction is completed.

The implementation of this approach typically involves somewhat higher costs for development plan review by local governments but lower costs for stormwater facility construction, and results in lower social costs.

Maintenance of Controls

The installation of structural controls (e.g., wet ponds, infiltration devices) during the construction phase of new development is often cited as a key component to a successful stormwater program. To continue to operate, these devices need to be maintained every 5 to 15 years. Lack of maintenance is often cited as a leading cause of failure of stormwater management devices.

While NPDES permits for stormwater discharges from construction activities disturbing more than 5 acres can require the installation of stormwater measures during the construction phase of a project, permit coverage for residential and commercial sites ends when the site is stabilized. Therefore, NPDES permits for stormwater discharged from construction sites may not be able to ensure the continued maintenance of these sites. Municipalities are in a better position to require or conduct maintenance activities for these devices. For example, municipalities can require maintenance of stormwater management devices through deed modification prior to site development or through ordinances.

Moratorium Sources: Which Municipalities?

Public commentors on previous NPDES stormwater rulemakings have identified a number of principles that are critical to successful implementation of NPDES requirements for a stormwater regulatory program (55 FR 48039):

- Municipalities should be regulated as equitably as possible.
- Major sources of pollutants must be addressed through control, treatment, or prevention.
- The approach must be administratively realistic and achievable.
- New development should be addressed.
- Programs must be coordinated or developed on a regional basis to avoid fragmentation or balkanized programs and to support watershed approaches.
- Regional approaches are necessary to address interrelated discharges into the municipal separate storm sewer system.

Municipalities associated with Census-designated UAs or a subset thereof appear to meet most of the criteria in a way that makes them candidates for consideration for Phase II stormwater requirements. Additional municipal candidates for Phase II requirements are pockets of high growth levels outside of Census-designated UAs and areas with large seasonal activities (e.g., some tourist towns) that are not classified as part of a Census-designated UA because of small year-round populations.

Equitable Treatment/Major Pollutant Sources

Currently, NPDES requirements for discharges from municipal separate storm sewer systems focus on core cities, and generally do not address UAs surrounding core cities in a comprehensive manner. The regulations do address 47 counties that were selected because they had significant populations in unincorporated, urbanized portions of the county. In most UAs, however, areas surrounding core cities are broken into incorporated areas and/or minor civil divisions with populations of less than 100,000. These areas are not addressed by current NPDES requirements even though they may be in a heavily populated county. For example, 400 counties have a population of greater than 100,000 but are not addressed by the current NPDES regulations.

At least three factors are important to consider when determining whether municipalities are being regulated as equitable as possible: 1) demographic patterns associated with per capita income; 2) the pollutant sources that are being addressed; and 3) the ability to control major pollutant sources. Some states have also advocated national NPDES requirements to ensure national consistency and to prevent economic disincentives that make it difficult for states and municipalities to implement progressive stormwater management programs (57 FR 41205).

The per capita income of suburban fringe areas is typically significantly higher than the per capita income of core cities. A 1991 report by the National League of Cities indicates that the per capita incomes of residents in the largest cities is only on average 59 percent of the per capita incomes in the surrounding suburbs. The magnitude of these income disparities was cited as a clear indicator of the disparities in tax bases. The report also suggested that continued demographic shifts are expected to increase these differences (27). In addition, municipal governments associated with core cities often provide a greater range of services than surrounding areas, resulting in higher per capita municipal government costs.

As discussed above, the pollutant sources associated with urban stormwater are diffuse in nature and are associated with widespread areas of development. Census data from 1990 indicate that approximately 46 percent of the total area and 35 percent of the total population of UAs containing a city with a population of 100,000 or more are located outside of the core city in suburban fringe areas.[9] As a rough approximation, suburban fringe areas are generating as much stormwater pollution as core cities with a population of 100,000 or more. Failure to address suburban fringe areas outside of these cities would severely limit the ability of the core city to protect receiving waters.

The equity issue is also related to the types of controls that are available to municipalities. Older, densely developed core cities have limited opportunities to control pollutants in their stormwater (8). Areas with substantial new growth, however, including many suburban fringe areas, have greater opportunities to ensure appropriate stormwater management and mitigate impacts to receiving waters associated with new growth.

Between 1970 and 1980, the population of incorporated cities with a population of 100,000 or more (those with municipal separate storm sewer systems addressed by NPDES regulations before October 1, 1992) increased by only 0.6 million, with much of this increase associated with the addition of the populations of 17 cities that had populations of 100,000 or more for the first time. The land area of most of these cities remained the same, while the populations of many large cities decreased.

Most growth in UAs occurs in areas that were not required to obtain an NPDES permit for their stormwater discharge before October 1, 1992. Between 1970 and 1980, the population of UAs outside of cities with a population of 100,000 or more increased 30 times more (an increase of 18.9 million) than the population of these cities. This growth resulted from both increases in population densities of existing urban lands and by the urbanization of previously rural lands. Factors such as lower costs of land, commercial space, and residential housing continue to cause urban sprawl even in UAs that are not experiencing population growth.

Equity and pollutant source considerations would appear at least to require that NPDES requirements be extended to cover suburban fringe municipalities in Census-designated UAs in which one or more large or medium municipal separate storm sewer systems are already subject to NPDES requirements. Municipalities with a large or medium municipal system should not be held solely responsible for implementing NPDES stormwater requirements when stormwater from suburban municipalities limits the opportunities of the core cities to effectively protect water resources.

Perhaps a more equitable approach would be to expand NPDES requirements to cover municipalities associated with Census-designated UAs of a specified size (e.g., 100,000 or 50,000). This approach would ensure that urban centers of similar size and the largest sources of urban runoff would be subject to program requirements.

Administratively Achievable/New Development

In core cities, urban streams are typically already heavily degraded, with limited opportunities for full restoration. Significant opportunities exist in suburban fringe areas, however, to conduct new development in a way that mitigates impacts on water resources. A basic principle of stormwater controls is that developing controls for new development is much more cost effective (8) and institutionally feasible than retrofitting old development. EPA has also indicated that, where properly planned, stormwater controls can *increase* the property values and satisfy consumer aesthetic needs (56 FR 40989).

Municipalities often oversee the development process. They usually have some form of approval or permit program in place. Developers have incentives to comply, because enforcement can be stringent (e.g., stop-work orders), and the developer usually wants to have a workable relationship with the municipality to ensure that future projects proceed smoothly. In addition, the costs of the controls are not borne by the municipality directly but rather by the developer. Several states with

[9] In the United States, most people served by combined sewers are located in cities with a population of 100,000 or more (57 FR 41349). Thus, the percentage of urbanized population served by *separate* storm sewers in suburban fringe areas is higher than indicated above.

progressive stormwater management programs have initially focused on new development (e.g., Maryland, Florida, and Delaware). This is unlike the approach taken in the 1987 amendments to the CWA, which initially focused on core cities with little or no growth and temporarily excluded suburban municipalities. The November 16, 1990, EPA regulations addressed 47 counties and 173 cities. The counties that were addressed where in a handful of states, primarily Maryland, Virginia, Florida, and California. While the Agency was able to address suburban growth in these states, in most parts of the country the regulations only address core cities and exclude suburban development.

Perhaps the biggest challenge associated with Phase II NPDES stormwater requirements for municipalities is the potentially large number of small municipalities that should be addressed. Census-designated UAs offer advantages over broader classifications of metropolitan areas, such as Standard Metropolitan Statistical Areas (SMSAs),[10] in that UAs do not include significant amounts of rural areas or small urban municipalities that are isolated from larger urban centers. In many parts of the country, however, suburban urban fringe areas are broken into a significant number of small municipal entities (see Table 3). In developing Phase II requirements for municipalities, EPA could consider promoting regional approaches, developing tiered requirements for different sizes of municipalities, and limiting requirements or providing exemptions for very small municipalities. For example, the Agency could consider focusing requirements for small municipalities on a few key program components, such as new development, municipal activities that affect stormwater quality (e.g., road building and maintenance), illicit connections, and public education.

Regional Approaches

As discussed above, regional approaches to stormwater management offer a number of advantages, including providing municipalities with the opportunity to pool resources and to address stormwater management with a more holistic watershed approach. Successful programs must face the challenge that municipalities do not follow watershed boundaries. Currently, the NPDES municipal stormwater program principally focuses on core cities with a population of 100,000 or more.[11] If suburban municipalities fail to develop adequate stormwater programs, the ability of core cities adequately to protect the receiving waters of the core city will be limited. As Tucker (18) states,

> Dealing with drainage across jurisdictional lines is important. . . . The ability to look at urban stormwater management from a regional or metropolitan wide perspective is important. The larger drainageways typically flow from one jurisdiction to another and what happens in one entity can impact others. Planning should be approached on a basinwide basis and not stop at jurisdictional boundaries. . . . Once the Phase II regulations for NPDES permits for municipal separate storm sewers become a reality, more metropolitan areas will seriously consider regional approaches to stormwater management.

Conclusion

Urban stormwater discharges have been shown to be a major source of water quality impairment. Section 402(p)(6) of the CWA requires EPA to identify additional stormwater sources to be regulated to protect water quality. In UAs, pollutants associated with stormwater come from many sources distributed throughout the area of urban development. Commercial and residential areas appear to be significant sources of pollutants, along with certain municipal activities. Municipal governments in UAs must play a significant role in developing and implementing programs that effectively address priority pollutant sources within their jurisdictions. Municipal governments have the critical institutional framework for making the day-to-day decisions to address these problems, to minimize or prevent the risk associated with stormwater from areas undergoing urbanization, and to collect the majority of funds necessary to implement the comprehensive programs needed to address urban stormwater management. The condition of a waterbody is a reflection of watershed management and land use characteristics. To ensure that the waterbody is protected and maintained, citizens must be empowered to work together to that end.

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[10]Unlike Census-designated urbanized areas, SMSAs, which are identified by the Office of Management and Budget, are based on county boundaries and can contain significant rural areas. Urbanized areas are defined to describe population densities. An urbanized area consists of the contiguous builtup territory around each larger city and thus corresponds generally to the core of the SMSA. SMSAs are defined to describe a large population nucleus and adjacent communities that have a high degree of economic and social integration with that nucleus. This designation has been developed for use by federal agencies in the production, analysis, and publication of data on metropolitan areas (28).

[11]The NPDES storm water program also currently addresses unincorporated portions of 47 counties. However, most large counties, including those in many heavily urbanized areas of the country, are currently not subject to NPDES stormwater requirements. Those counties currently addressed by the NPDES storm water program have large populations in unincorporated areas and only represent a few states, notably California, Florida, Maryland, and Virginia.

Table 3. Municipalities Associated With Census-Designated UAs Based on 1990 Census Data[a]

Class of UA	No. of UAs	No. of Incorporated Places[b]	No. of MCDs[c]	No. of Counties[d]	Total Population (millions)
All UAs	396	3,624	1,655	703	158.3
250,000 or more	103	2,672	1,022	358	127.5
100,000-250,000	121	490	349	185	18.9
50,000-100,000	172	462	284	258	11.9
Phase I municipalities	Parts of 137	621	0	70	76.2
UA with large or medium MS4	137	2,147	665	280	118.8

[a] Examples of Census-designated UAs and associated 1990 populations:

Brunswick, GA	50,066	Ogden, UT	259,147
Ithaca, NY	50,132[e]	Albuquerque, NM	497,120
San Luis Obispo, CA	50,305	Albany-Schenectady-Troy	509,106
Lafayette-West Lafayette, IN	100,103	Akron, OH	527,863
Sioux Falls, SD	100,843	Oklahoma City, OK	784,425
Jacksonville, NC	101,297	Salt Lake City, UT	789,447
Pensacola, FL	253,558	New Orleans, LA	1,040,226
Sacramento, CA	1,097,005	Shreveport, LA	256,489
San Antonio, TX	1,129,154		

[b] Incorporated places include incorporated cities, towns, villages, and boroughs.

[c] Minor civil divisions (MCDs) include unincorporated towns and townships in 20 states.

[d] County equivalents include counties, parishes in Louisiana, and boroughs in Alaska. Some double counting of counties occurred as portions of several UAs may be in one county. (For example, portions of the Washington UA, Baltimore UA, and Annapolis UA are in Ann Arundel County, Maryland.)

[e] The Ithaca, New York, population does not include student population at Cornell University.

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Municipal Permitting: An Agency Perspective

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This paper presents the U.S. Environmental Protection Agency's (EPA's) perspective regarding the municipal side of the National Pollutant Discharge Elimination System (NPDES) stormwater program. It begins by briefly providing some background information on the stormwater program. It then highlights an EPA review of costs that municipal separate storm sewer systems (MS4s) have incurred or anticipate incurring during the next 5 years. After discussing the types of programs that MS4s proposed in their Part 2 applications, the paper concludes by presenting the current status of the permitting process.

Background

The Water Quality Act (WQA) of 1987 added Section 402(p) to the Clean Water Act (CWA). In Section 402(p), MS4s serving a population of 100,000 or more must obtain an NPDES permit for their stormwater discharges. Section 402(p)(3)(A) specifically provides that permits for these discharges:

- May be issued on a system- or jurisdictionwide basis.
- Shall include a requirement to effectively prohibit non-stormwater discharges into storm sewers.
- Shall require controls to reduce the discharge of pollutants to the maximum extent practicable; controls may include management practices, techniques, system design and engineering methods, and such other provisions as the Administrator or the state determines appropriate for control of such pollutants.

NPDES permits historically have imposed end-of-pipe controls on industrial and publicly owned treatment works discharges. The legislative history of the WQA, however, indicates that Congress does not consider end-of-pipe controls to be necessarily appropriate for stormwater discharges from MS4s. Consequently, in the November 16, 1990, *Federal Register*, EPA published a final rule intended to reflect the unique nature of discharges from MS4s. The final rule establishes permit application requirements and application deadlines for all MS4s covered under Phase I of the stormwater program. For MS4s required to obtain a stormwater permit, EPA established a two-part permit application process. The Part 1 application primarily focuses on a municipality's existing stormwater management activities and includes the following components:

- General information
- Discharge characterization
- Existing legal authority
- Existing stormwater management programs
- Source identification
- Existing fiscal resources

The Part 2 application requires additional information that builds on the information submitted with the Part 1 application. Rather than emphasizing current stormwater management activities, however, the Part 2 application focuses on what future stormwater management activities an MS4 will adopt. Major components of the Part 2 application are similar to those identified above; however, their level of detail is much greater.

Some of the major highlights of the stormwater program involve:

- Obtaining the adequate legal authority to implement an MS4's stormwater management program.
- Developing estimates of annual pollutant loadings and a schedule to submit seasonal pollutant loadings estimates.
- Developing a monitoring program to run throughout the permit term.
- Developing a site-specific and comprehensive stormwater management program.
- Conducting an assessment of the effectiveness of stormwater controls.

- Conducting a fiscal analysis of the costs to implement the applicant's proposed stormwater management program.

The cornerstone of the stormwater program is the requirement that MS4s must develop site-specific and comprehensive stormwater management programs. MS4s should employ all program requirements identified in the final rule. Given their geographical, climatological, and physical differences, however, MS4s can exercise discretion when establishing priorities for their site-specific stormwater management programs. For example, an MS4 in a densely populated urban corridor is not reasonably expected to have the same program priorities as an MS4 servicing an area experiencing rapid development. Later, the paper presents a few different approaches and types of programs that various MS4s are proposing. First, however, is a brief discussion of the present status of the MS4 permitting process.

Present Status of the MS4 Permitting Process

Effects of the 1990 Decennial Census

In the November 16, 1990, *Federal Register*, EPA identified 219 municipalities required to seek coverage under an NPDES stormwater permit. Appendices F and H of 40 CFR 122 identified 73 of these municipalities as large MS4s. Similarly, Appendices G and I of 40 CFR 122 identified 146 municipalities as medium MS4s. EPA based these 219 identifications on the definition of a municipal separate storm sewer system, which incorporates population data from the latest Decennial Census. In this case, the 1980 Census helped identify the 219 MS4s. Recently, however, the results of the 1990 Decennial Census have become available and, consequently, affect more municipalities. EPA is currently drafting a *Federal Register* notice (FRN) that identifies 42 additional municipalities (30 cities and 12 counties) that now meet the definition of a medium MS4 based on the results of the 1990 Census. Sixty percent of the new cities now required to seek NPDES permits are in the state of California, while 33 percent of the new counties are located in the state of Florida.

In contrast to the number of newly identified MS4s, the 1990 Census found that five cities and two counties dropped in population to below 100,000. Although these municipalities no longer satisfy the definition of a medium MS4, two counties and one city still participate in the stormwater program.

Next, the paper discusses municipalities that the appendices of 40 CFR 122 did not originally identify but that nevertheless have been designated as Phase I sources.

Designated MS4s

Section 402(p)(2)(E) and 40 CFR 122.21(b)(4)(iii) and (7)(iii) provide that permitting agencies may use their authority in designating municipalities that operate separate storm sewer systems and serve populations of less than 100,000 as regulated MS4s. EPA has compiled some preliminary information on the number of these municipalities, some of which are volunteering to participate in the program. Based on the best information available to date, it appears that states and EPA regions designated small municipalities as regulated MS4s primarily because they share common watersheds or are interconnected with a nearby regulated MS4. In at least two states, EPA observed that all incorporated cities below a population of 100,000 were designated if they are within the boundary of a regulated MS4 (county); therefore, these municipalities must submit a stormwater permit application. EPA is currently trying to determine what permit application deadlines have been established for these designated MS4s and whether they are participating as coapplicants with a regulated MS4 or are filing as single applicants.

Table 1 summarizes some preliminary data on the number of cities, counties, and special districts that have either been designated or who are voluntarily participating in the program as Phase I stormwater sources.

EPA considers the figures presented in Table 1 preliminary because additional information is still pending from three Regional Water Quality Control Boards (RWQCBs). Some general observations, however, are noteworthy. First, 65 percent of the designated cities in Region 4 are located in the state of Florida. In the case of the 47 designated special districts, 26 are state departments of transportation, 11 are flood control districts,

Table 1. Summary of MS4 Designations by EPA Region

EPA Region	Designated Cities	Designated Counties	Special Districts
1	0	0	0
2	0	0	0
3	13	5	2
4	236	9	6
5	1	0	8
6	0	0	6
7	1	0	2
8	1	0	2
9[a]	127	7	14
10	1	1	7
Total	380	22	47

[a]Additional information pending three RWQCBs in the state of California.

four are state universities, three are port authorities, and three represent a group of water control districts.

Effects of Combined Sewer Overflow Exclusions

The NPDES stormwater regulations allow municipalities to deduct the population served by combined sewer systems from the total population served by the MS4. To date, this provision has exempted 29 municipalities as Phase I sources. An additional eight large MS4s have been reclassified as medium MS4s. Table 2 provides a breakdown of combined sewer overflow (CSO) exclusions by EPA region.

Current Permit Applications

As noted earlier, the NPDES stormwater regulations require MS4s to submit a two-part permit application. Table 3 provides the latest information available on the number of submissions of Part 1 and Part 2 applications. *This table specifically excludes permit application submissions for the states of California and Nevada.*

The next section of this paper summarizes the results of a recent EPA effort to document costs that MS4s have incurred or are expected to incur over a 5-year period. The information represents the most specific information EPA has received to date on stormwater costs associated with the stormwater program.

Review of MS4 Program Cost Data

EPA recently conducted an analysis of Part 2 applications in an effort to gain a better understanding of costs associated with implementing the municipal effort of the stormwater program. EPA is currently completing a review that documents the costs that 20 MS4s expect to incur or have incurred as a result of implementing their stormwater management programs. These costs are based on fiscal information provided in Part 2 permit applications. The primary purpose of this effort is to assist EPA's Office of Water in determining the cost burden that results from developing and implementing programs in response to the NPDES stormwater regulations. To that end, EPA has developed a preliminary draft estimate for the total annual per capita cost to develop and implement the stormwater management program over a 5-year period. Some background information on the analysis may provide a basis for better understanding the results.

Table 2. Summary of CSO Exclusions by EPA Region

EPA Region	Medium MS4s	Medium to Large MS4s	Large MS4s	Total
1	5	1	0	6
2	7	4	2	13
3	2	0	1	3
4	0	0	0	0
5	6	0	2	8
6	0	0	0	0
7	0	2	2	4
8	0	0	0	0
9	0	0	1	1
10	1	1	0	2
Total	21	8	8	37

Table 3. Summary of Part 1 and Part 2 Submissions by EPA Region

EPA Region	Medium MS4s, Part 1	Medium MS4s, Part 2	Large MS4s, Part 1	Large MS4s, Part 2
1	3	0	0	0
2	0	0	5	5
3	10	0	11	10
4	24	0	20	15
5	12	0	5	5
6	7	0	9	7
7	7	0	3	1
8	3	2	3	1
9[a]	2	0	4	3
10	6	0	4	2
Total	74	4	64	49

[a] California RWQCBs have issued permits for 130 applicants. Information is still pending from three RWQCBs. The state of Nevada has issued final permits for its regulated MS4s. Permit application submission figures for EPA Region 9 reflect those applications that are currently under review.

Applications Reviewed

EPA selected the Part 2 applications for this analysis from among those that had been submitted to permitting agencies by the November 16, 1992, deadline. EPA selected municipalities located throughout the country to obtain a more realistic representation of the cost data. Thus, eight MS4s are located in the eastern part of the United States, seven in the central part, and five in the west. Selected municipalities also fall within eight of the nine Rainfall Zones of the United States. The 20 municipalities reviewed are:

- Aurora, Colorado
- Baltimore, Maryland
- Charlotte, North Carolina
- Dallas, Texas
- Denver, Colorado

- Fairfax County, Virginia
- Harris County, Texas
- Honolulu, Hawaii
- Houston, Texas
- King County, Washington
- Lakewood, Colorado
- Norfolk, Virginia
- Philadelphia, Pennsylvania
- Phoenix, Arizona
- Prince Georges County, Maryland
- Seattle, Washington
- Tampa, Florida
- Tucson, Arizona
- Tulsa, Oklahoma
- Virginia Beach, Virginia

Based on the 1990 Decennial Census, the combined populations of these MS4s totaled over 11.3 million. Fifteen percent of these MS4s have populations exceeding 1 million, 75 percent have populations between 250,000 and 1 million, and 10 percent have populations of less than 250,000. With the exception of Aurora and Lakewood, Colorado, all of these MS4s were previously identified as large MS4s in the November 16, 1991, *Federal Register*.

Grouping of Cost Data

This analysis broke down the actual and estimated costs that MS4s reported in their applications into the following eight major program components:

- Public education
- Monitoring
- Commercial and residential
- Construction
- Industrial facilities
- Maintenance of controls
- Improper discharges
- Miscellaneous

EPA selected these categories because they generally reflect the variety of costs reported in the applications and are largely consistent with the categories outlined in the permit application regulations. Each of these eight major categories were further subdivided into specific program components. An underlying objective of this effort was to determine the additional financial burden the stormwater program imposed on municipalities. Whenever possible, therefore, a breakout between new and existing program costs was made for each reviewed application.

Limitations

At this point, it is crucial to note some of the limitations associated with this analysis. First and foremost are limitations with the sample. Applications selected represented mostly large MS4s; therefore, EPA cannot be certain that these results are fully representative of costs that medium MS4s would report. Nearly 68 percent of the regulated MS4s were not required to have submitted their Part 2 applications at the time EPA conducted this analysis. Consequently, this limits the availability of Part 2 applications that the analysis could have included. One other important consideration with regard to the sample selection is that the results may be overstated in instances where MS4s are subject to more stringent local and regional controls or other environmental initiatives for stormwater management.

The second limitation is that, in many instances, MS4s did not include the cost of projects normally included in a capital improvement program (CIP). Although these projects often pertain to flood control, future CIP projects typically will have features that also address stormwater quality. Therefore, although providing the additional benefit of improved stormwater quality may be in response to the stormwater program, the analysis results do not typically reflect these associated costs. In contrast, EPA did not attempt to exclude significant costs that MS4s reported for programs unreasonably attributed to the stormwater program, even though they probably would have existed regardless of the stormwater program.

The third limitation reflects the difficulty in making direct comparisons between applicants. The regulations provide flexibility to the MS4s with regard to proposing stormwater management programs that reduce or eliminate the contribution of pollutants in stormwater discharges to the maximum extent practicable. The diverse approaches to stormwater management that MS4s have proposed reflect this flexibility. MS4s also used a variety of methods to report annual cost data.

Inconsistencies that existed within individual applications account for the fourth limitation. In many instances, the text describing a proposed stormwater management program component often did not correlate with the cost information provided. For example, the application may have indicated that an existing program would cover an activity, but the fiscal analysis section of the application did not provide the costs associated with the existing program. Often, MS4s reported that an existing stormwater management program was "absorbing" a new proposed program. The MS4s, however, provided no separate fiscal data in the application.

Finally, the results of this analysis suggest that in a number of instances MS4s both overreported and underreported costs. EPA did not attempt to exclude any reported costs from this analysis. Consequently, EPA is attempting only to document average costs.

Results

Of the 20 MS4 applications reviewed, the average annual reported cost for both new and existing programs ranged from $211,000 or $0.76 per capita (Tampa Bay, Florida) to $98 million or $190.85 per capita (Seattle, Washington). Table 4 highlights the ranges of average annual costs that municipalities reported.

Using population data from the 1990 Census, EPA calculated a preliminary average annual per capita cost for both new and existing programs of $23.91. Based on information reported by MS4s, it appears that costs for new programs or initiatives typically ranged from 10 to 15 percent of the average annual cost. As noted earlier, EPA reviewed Part 2 applications mostly from large MS4s. As medium MS4 applications become available, EPA anticipates examining cost data from some of these applications as well.

Programs the Part 2 Applications Proposed

Having reviewed some of the cost data, this paper will now present more specific details and examples of the types of stormwater management programs proposed in a number of Part 2 permit applications. The discussions's structure follows the organization of the Part 2 application (e.g., adequate legal authority, source identification, characterization data, and management programs). The discussion's scope is confined to some observations on a sample of eight Part 2 applications.

Legal Authority

According to the stormwater regulations, municipalities must demonstrate that they possess the adequate legal authority to implement their stormwater management activities when they submit their Part 2 applications. In the Part 2 guidance manual, EPA acknowledges that this is not always possible if an MS4 lacks the enabling legislative authority to develop the necessary ordinances. In these cases, applicants need to provide a schedule as to when adequate legal authority will be obtained.

Table 4. Ranges of Average Annual Costs Reported by Municipalities

Average Annual Costs	Number of Municipalities
Less than $1,000,000	4
$1,000,000 to $5,000,000	6
$5,000,000 to $10,000,000	5
Greater than $10,000,000	5

Six municipalities stated that they had obtained the adequate legal authority to carry out the requirements of the stormwater regulations. One municipality anticipated having necessary legal authority by the spring of 1993, and one anticipated having the authority within 2 years. As a general note, municipalities reported existing ordinances that addressed most of the legal authority requirements of the regulations, especially with regard to controlling improper discharges, illegal dumping, and erosion and sediment control provisions. The comprehensive nature of the stormwater regulations, however, required most municipalities to establish new ordinances or update existing ones, particularly for obtaining the necessary authority to conduct monitoring and surveillance of stormwater discharges from private sources.

Several municipalities provided detailed excerpts or, in some cases, the complete text of their comprehensive stormwater ordinances. For example, Seattle, Washington, and Prince Georges County, Maryland, provided the text of their grading, erosion, and control ordinances, while King County, Washington, provided the text of both its water quality ordinance and its pesticide regulation. Ordinances of both Seattle, Washington, and Prince Georges County, Maryland, addressed the requirements of the stormwater regulations in addition to other local or regional initiatives, such as the Puget Sound Water Quality Management Plan and the Chesapeake Bay Preservation Act, respectively.

Source Identification

The principle requirement of the source identification component of the Part 2 application is to identify any previously unknown major outfalls and to compile an industrial inventory. The industrial inventory must then be organized on a watershed basis. Perhaps one of the biggest challenges of the permit application is identifying all major outfalls that comprise the storm sewer system. Several MS4s reported using the analytical capabilities of their geographic information systems (GISs) to identify potential locations of outfalls not previously identified in the Part 1 application. A few applicants specifically noted that this was a particularly effective approach. Although a GIS is not a requirement of the stormwater regulations, EPA recognizes that GISs are well suited for many of the activities associated with stormwater management. Out of the eight applications reviewed, at least six reported having GIS capability, while one applicant anticipated having GIS capability in the near future.

Characterization Data

The characterization data portion of the Part 2 application requires an MS4 to submit the results of wet weather sampling with the application. More specifically, applicants must submit sampling data for five to 10 outfalls from at least three representative storm events. EPA has not had an opportunity to conduct a detailed analysis of this information. Some general observations, however, follow.

First, although many of the applicants reported completing their wet weather sampling requirements, they typically expressed similar difficulties in doing so. MS4s often noted that they had to sample several more than the requisite minimum of three storm events to obtain the number of requisite samples. In one instance, an applicant reported that it took a total of 18 storm events to obtain the requisite number of samples. Applicants also frequently cited that they had to discard samples because a particular storm's duration and rainfall accumulation did not meet the requirements of a representative storm event. Other problems commonly cited included sampling during storm events with frequent starts/stops and the logistics of mobilizing sampling crews at the onset of a storm event. The unpredictability of storm events and the logistics associated with wet weather sampling prompted at least four of the eight MS4s to use automatic samplers.

In at least one instance, an MS4 obtained approval to use available historical data to satisfy the majority of their sampling requirements. In this case, the applicant needed to sample one additional storm event at two sampling sites. Applicants often cited that concentration data compared well with the results of the NURP study. In general, the eight MS4s reported that the results of the analysis of composite samples exhibited characteristic concentrations for metals such as copper, cadmium, zinc, and lead. The sampling data also suggest that the concentration of organic contaminants often fell below detection levels for composite samples. Individual grab samples, however, detected many organic contaminants.

The second major component of this portion of the application requires the municipalities to estimate annual pollutant loadings. EPA allows MS4s the flexibility of selecting an appropriate method to estimate pollutant loadings. A majority of the eight applicants elected to use computer models such as SWMM, P8, and the CDM Nonpoint Source model to estimate annual loadings. A few applicants elected to use the simple method developed by the Metropolitan Washington Council of Governments.

EPA expected that computing pollutant loadings would satisfy at least two objectives. First, loading estimates would raise the level of awareness within municipalities of the relative magnitude of pollutant loadings associated with stormwater discharges. Second, the estimates could be used as part of a screening process when establishing priorities for stormwater management activities. One applicant specifically noted using loading estimates in this manner. Some applicants noted that these estimates had limited value and that other means of representing sampling data would be more appropriate.

The Part 2 application requires applicants to maintain an ongoing monitoring program for the duration of the term of the permit. An approach proposed by the city of Baltimore, Maryland, warrants special mention. Baltimore proposed a comprehensive and phased approach to monitoring which consists of four major components:

- Dry weather stormwater outfall monitoring
- Pollutant source tracking
- Long-term trend monitoring
- Stormwater runoff monitoring

The city identified the following six major goals to its monitoring program:

- *Dry weather screening:* This entails developing a "water quality dry weather flow" database to assist in isolating watersheds that may require further investigation as potential sites of illicit connections.
- *Dry weather source tracking:* This entails conducting investigations to detect and eliminate sources of dry weather flows.
- *Toxicity testing:* A pilot toxicity testing program would evaluate the impact of pollutants on a receiving water ecosystem due to unknown contaminants and synergistic effects.
- *Stream ecosystem database:* A database that describes the biological integrity of the receiving streams could assist in analyzing long-term trends, prioritizing management practices, and assessing the effectiveness of management programs.
- *Stormwater runoff and best management practice (BMP) assessments:* This effort could characterize stormwater runoff quality and assess the effectiveness of BMPs that may be used in the future.
- *Receiving stream water quality database:* This entails establishing dry and wet weather flow water quality databases for major stream systems that can be used for conducting long-term assessments and determining the effectiveness of watershed management programs.

The city's proposal to establish a stream ecosystem database is particularly noteworthy because it would provide the city with a baseline of its existing biological community (e.g., benthic macroinvertebrate population and diversity). It would also provide a basis from which to conduct a long-term assessment of the effectiveness of watershed management activities. More importantly, it would allow the opportunity to gain a greater understanding of the effects of stormwater discharges on a specific aquatic habitat. Finally, the city is closely coordinating its monitoring program with several subwatershed studies to determine the effectiveness of certain BMPs in protecting receiving water quality, including aquatic habitat.

Management Programs

Of course, the cornerstone of the two-part permit application is the requirement that MS4s develop site-specific and comprehensive stormwater management programs. Each applicant must address four major areas in its application:

- A description of structural and source control measures to reduce pollutants in runoff from residential and commercial areas.
- A description of procedures to detect and remove illicit connections and a program to control improper disposal.
- A description of structural and source control measures to reduce pollutants in runoff from industrial areas.
- A description of programs to maintain structural and nonstructural BMPs to reduce pollutants from construction sites.

In most instances, applicants elect to follow the application format established in the November 16, 1990, *Federal Register* to describe their management programs. From an initial review of eight applications, it appears that many MS4s are proposing approaches that entail phasing in components of their programs over the permit term. Applicants not only cited economic reasons for this approach but also the desire to ensure that a particular BMP is effective before it is implemented on a systemwide basis. For example, several applicants reported initiating studies to determine what factors significantly influence the performance of a specific structural control before its use on a systemwide basis. Pending the results of these studies, applicants proposed modifying their watershed management programs accordingly. While a phased approach may be reasonable in some instances, there are cases where the permitting authority may not consider it appropriate.

In one of the reviewed cases, an applicant proposed a phased approached to its illicit connections program. Although EPA acknowledges the effort necessary to detect and isolate the source of an illicit connection, a phased approach appears to overlook the immediate benefits of a fully implemented illicit connections program. This is especially true for municipalities in densely populated urban corridors that have both separate and combined sewer systems.

Implementing a comprehensive stormwater management program is a complex effort that requires the participation of numerous inter- and intragovernmental agencies. Before implementing a program, a municipality needs to establish program priorities. It may be helpful at this point to briefly illustrate one applicant's approach to establishing criteria for prioritizing basins for watershed management activities.

In 1987, King County, Washington, completed a "Basin Reconnaissance Program" that provided the information necessary to establish an initial basin planning prioritization scheme. The county provided a complete set of the results of this effort with its Part 1 application. King County established four major prioritization categories with commensurate criteria for each category. The major categories and criteria are as follows:

- Existing problems
  - Landslides
  - Erosion/Sediment
  - Flooding
- Future problems
  - Unincorporated land in King County
  - Subdivision/Plat activities
  - Population growth
  - Permitted residential units
- Existing resources
  - Stream habitat
  - In-stream resources
  - Wetland value
  - Wetland storage potential
  - Water quality potential
- Urgency/Timeliness
  - Other Agency interest
  - Opportunity to integrate with other programs

For all 37 basins identified, King County assigns a numerical rating to each criterion and a composite score for each major category, then establishes a total basin numerical rating. After completing basin prioritization ranking, the county proceeds with a six-step basin planning process. The first step is the formation of a basin plan team consisting of a project manager, biologists, geologists, water quality specialists, engineers, resource planners, mapping and GIS technicians, and graphics support. In the next step, the team collects data that include information on rainfall, flow levels, geological makeup, geomorphology, habitat complexity and diversity, fish utilization, and water quality. The basin plan team may spend up to 2 years compiling data.

The third and fourth steps entail computer modeling of a basin's hydrology and predicting the effects of alternative land-use activities. The results of the modeling efforts assist in developing a current and future conditions report that documents existing conditions and provides an analysis of future trends.

The fifth step entails drafting a basin plan and conducting public meetings and hearings. After necessary modification, the team finalizes the draft plan and submits it to the King County Council for approval. Following approval, the King County Surface Water Management (SWM) Division is responsible for implementing the basin plan. King County SWM anticipated completing 12 of its 37 basin plans by the end of 1992.

The King County basin planning program reflects a resource-intensive effort and a commitment to reducing the deleterious effects of stormwater discharges. Municipalities that are essentially new to stormwater management may find elements of King County's program not only innovative and informative but also adaptable to their needs.

MS4s proposed some general observations about particular program components. First, a majority of the applications placed a heavy emphasis on minimizing future problems associated with stormwater management, specifically in the area of long-term planning for future development. In several instances, MS4s reported that they had either completed or initiated the development of stormwater management master plans for major watersheds.

Also, MS4s are increasingly requiring approval of erosion and sediment control plans before approving a site plan or allowing construction to begin. Similarly, many MS4s require permanent BMPs (privately financed), such as installation of retention/detention basins for all new developments over a certain size area. MS4s also frequently reported that inspections programs had been or are being established to ensure maintenance of publicly and privately owned BMPs over their useful life. In at least one instance, an MS4 provides an economic incentive to install BMPs by establishing a BMP credit-ing system for non-single-family residences.

A couple of applicants also reported a substantial commitment to preserving open space. In one case, a municipality reported that it is pursuing a "Greenways" program that could potentially preserve 16,000 acres as open space. To date, 400 acres have been preserved. Similarly, one county has established a stream valley park system. All major streams in the county are to become part of the park system. In this instance, the county has imposed an additional requirement: new development must provide for buffer zones or easements.

Over the long term, approaches like these may minimize the need to construct costly structural controls to remove pollutants from stormwater discharges. Moreover, this preventative approach to stormwater management can potentially reduce the significant costs that some municipalities are incurring to restore degraded stream corridors and wetlands. EPA recognizes that this is a contentious issue. It is encouraging to note, however, the emphasis municipal applicants are placing on community involvement and public outreach programs. The "adopt-a-stream" program and other similar community-based environmental programs, such as household hazardous waste collection, routinely appeared in Part 2 applications.

Paraphrasing one applicant's comment, the goals of a stormwater management program cannot be fully achieved unless there is participation and consensus among those who are affected. Otherwise, past practices will continue to have a detrimental influence on valuable water resources within our communities.

Current EPA Activities in the Area of MS4 Permitting

Several EPA regions and state permitting authorities have supported the formation of an MS4 steering committee to look at specific issues pertinent to MS4 permits. The steering committee is looking at program components and permits that may be suitable as model programs or model permits. It also will assist in determining how to incorporate core elements of a stormwater program into an MS4 permit. Lastly, the steering committee will be exploring alternative mechanisms of exchanging information on stormwater management. The committee will coordinate this particular effort with ongoing outreach activities at EPA.

EPA also is conducting a municipal assessment project (MAP) that continues to examine the progress of the municipal permitting process. This entails compiling information on the status of both permit applications and permit development. Whenever possible, EPA will suggest future improvements or enhancements to the MS4 permitting process. EPA is continuing to compile information on MS4s designated by state permitting agencies and EPA regions. Other objectives of the MAP include examining the Part 2 applications in more detail to identify programs as potential model candidates.

As the permitting process moves from the development of permit applications to permit development, EPA anticipates distributing information on the progress of permit development to permitting authorities. Hopefully, this approach will benefit all those participating in the permitting process.

Municipal Stormwater Permitting: A California Perspective

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Abstract

The California Regional Water Quality Control Board, San Francisco Bay Region (Regional Board), began a program for control of stormwater discharges from urban areas in 1987. The initial focus of the program has been on the municipalities in Santa Clara and Alameda counties. An areawide approach was promoted in which all the cities in each county, the county, and the county flood control agency worked collectively. The Santa Clara and Alameda programs were issued municipal stormwater National Pollutant Discharge Elimination System (NPDES) permits in June 1990 and August 1991, respectively. These efforts have focused on implementation of stormwater management programs rather than on the NPDES permit itself. Essentially, the permit serves as an enforceable mechanism requiring implementation of the programs developed by the municipalities and approved by the Regional Board.

The municipal stormwater management programs all involve similar elements, including public information/participation, elimination of illegal discharges, public agency activities, control of industrial/commercial stormwater discharges, new development management, stormwater treatment, program evaluation, and monitoring. The process of developing these programs has uncovered several issues and problems, mostly nontechnical, which could potentially impede successful implementation. On the other hand, workable solutions to most of these problems have also been identified. The essential ingredient of the process that has enabled progress has been a cooperative, proactive relationship between the Regional Board and municipalities. Continuation of this process is expected to result in a realistic and meaningful municipal stormwater NPDES permit program.

Background

The California Regional Water Quality Control Board, San Francisco Bay Region (Regional Board), is the state water pollution control agency responsible for protection of San Francisco Bay and its tributaries. San Francisco Bay is a highly urbanized estuary and as such receives significant loads of pollutants through discharges of urban runoff. The responsibilities of the Regional Board include water quality control planning, control of nonpoint sources of pollution, and issuance and enforcement of NPDES permits. Using its authorities, the Regional Board began a program for control of stormwater discharges from urban areas in 1987. The initial focus of the program was on the most highly urbanized areas, which include the municipalities in Santa Clara and Alameda counties. An areawide approach was promoted in which all the cities in each county, the county, and the county flood control agency worked collectively.

Santa Clara and Alameda counties developed their programs through a strategic planning process (1). The process followed a series of steps that involved establishing program goals and framework; compiling existing information; assessing water quality problems through collection and analysis of data and modeling of pollutant loads; identifying, screening, and selecting appropriate control measures; and establishing a plan for implementation. This planning process lead to development of a comprehensive stormwater management plan by each program (2, 3). In addition, institutional arrangements, legal authorities, and fiscal resources for implementation were addressed.

The efforts of the Regional Board and the Santa Clara and Alameda municipalities were well under way when the stormwater National Pollutant Discharge Elimination System (NPDES) permit regulations were promulgated in November 1990. The Regional Board found the information that the planning process followed by the two areawide programs provided was equivalent to federal permit application requirements. Consequently, the Regional Board issued municipal stormwater NPDES permits to the Santa Clara and Alameda programs in June 1990 and August 1991, respectively, which required implementation of their stormwater management plans. Issuance of these "early" permits served to recognize the accomplishments of the two programs and to provide a focus on implementation actions while avoiding the time delays and costs associated with the promulgated application requirements. We also have focused attention on the adequacy and effectiveness of the stormwater management plans rather than the permits. Essentially, the permit serves as an enforceable mechanism requiring implementation of the programs developed by the municipalities and approved by the Regional Board.

The efforts of the Santa Clara and Alameda municipalities have provided a meaningful framework for and the essential elements of an effective stormwater management program. A similar approach is being followed by municipalities in the other urban areas of the San Francisco Bay region. The process of developing these programs has uncovered several issues and problems, mostly nontechnical, which could potentially impede successful implementation. On the other hand, workable solutions to most of these problems have also been identified. The following discussion provides a status report of the San Francisco Bay programs, a description of the elements of the stormwater management programs, and insight into the problems encountered and their solutions.

San Francisco Bay Region Municipal Stormwater Programs

In the San Francisco Bay region, nearly all municipalities in urban areas have stormwater management programs and NPDES permits under way or under development. The Regional Board has encouraged, recognized, or required areawide programs in which all municipalities within a watershed or municipal systems that interconnect are managed under one program. In addition, municipal flood management agencies are included as co-permittees. The California Transportation Department (Caltrans) is required to implement a stormwater management program for all storm drain systems within the region. The municipal stormwater programs in the San Francisco Bay region are listed below.

- Santa Clara Valley Nonpoint Source Pollution Control Program, including the county and all cities:
  - Population approximately 1,500,000
  - NPDES permit issued June 1990
- Alameda County Urban Runoff Clean Water Program including the county and all cities:
  - Population approximately 1,250,000
  - NPDES permit issued October 1991
- Contra Costa Cities, County, District Stormwater Pollution Control Program including the county and all cities:
  - Population approximately 800,000
  - Part 1 Application submitted May 1992
  - Part 2 Application due May 1993
- San Mateo County Urban Runoff Clean Water Program, including the county and all cities:
  - Population approximately 650,000 (no city nor the county has population more than 100,000)
  - Combined Parts 1 and 2 Application due May 1993
- Caltrans, including all operation, maintenance, and construction activities:
  - Incomplete application submitted July 1992
  - Complete application due May 1993
- City of Vallejo:
  - Population more than 100,000 (as of 1990 Census)
  - Part 1 Application due March 1993
  - Part 2 Application due March 1994
- Cities of Fairfield and Suisun City Joint Program:
  - Population more than 100,000
  - Part 1 Application due March 1993
  - Part 2 Application due March 1994

Municipal Stormwater Program Elements

The municipal stormwater management programs all involve similar elements except for Caltrans, which will not be discussed here. These include public information/participation, elimination of illegal discharges, public agency activities, control of industrial/commercial stormwater discharges, new development management, stormwater treatment, program evaluation, and monitoring. The activities associated with each of these essential program components are presented below.

Public Information/Participation

This element is considered the most important early action and is the cornerstone of effective pollution prevention. Its objectives are to inform the public, commercial entities, and industries about the proper use and disposal of materials and waste and to correct practices of stormwater runoff pollution control. Activities include development of general and focused information materials and public service announcements. Participation

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activities include citizen monitoring programs, stenciling of storm drain inlets with no dumping signs, and organized creek cleanups.

Elimination of Illegal Discharges

Elimination of illicit connections to the storm drain system and the prevention of illegal dumping are other essential early action elements. The objective is to ensure that only stormwater or otherwise authorized discharges enter storm drains. Activities include inspection of storm drain outfalls, surveillance of storm drain systems, and enforcement actions.

Public Agency Activities

Many public agency activities affect stormwater pollution. Some activities prevent or remove stormwater pollution, while other activities are sources of pollution. The objective of this element is to ensure that routine municipal operations and maintenance activities are initiated or improved to reduce the likelihood that pollutants are discharged to the storm drain system. Activities include street sweeping; maintenance of storm drain inlets, lines and channels, and catch basins; corporation yard management; and recycling programs. Coordination of road maintenance and flood control activities with the stormwater management program is also included.

Control of Industrial/Commercial Stormwater Discharges

Industrial and commercial sources may contribute a substantial pollutant loading to a municipal storm drain system. The objective of this element is to identify and effectively control industrial and commercial sources of concern. Activities include compiling a list of industrial and commercial sources, identifying appropriate pollution prevention and control measures, and inspecting facilities. The focus is not only on facilities associated with industrial activity as defined in the stormwater regulations but on any facility that conducts industrial activities, as well as commercial facilities such as automotive operations and restaurants. This effort is expected to complement federal and state industrial stormwater permitting efforts.

New Development Management

Areas of new development and redevelopment offer the greatest potential for implementation of the most effective pollution prevention and control measures. The objective of this element is to reduce the likelihood of pollutants entering the storm drain system from areas of new development and significant redevelopment, both during and after construction. Activities include review of existing local permitting procedures and modification of the procedures to identify and assign appropriate site design, erosion control, and permanent stormwater control measures.

Stormwater Treatment

The initial focus of the stormwater management programs is on pollution prevention and source control. Treatment of stormwater is expected to be a costly alternative. There may be opportunities, however, for installation or retrofitting of structural controls. The objectives of this element are to study the various treatment alternatives available, to test the feasibility of conducting the activities, and to determine the effectiveness of the treatment through pilot-scale projects. Initial focus has been on existing wetland systems, flood control detention basins, and treatment of parking lot runoff.

Program Evaluation

Stormwater management programs are expected to change as they mature. Consequently, they should have built-in flexibility to allow for changes in priorities, needs, or levels of awareness. The objective of this element is to provide a comprehensive annual evaluation and report of program effectiveness. Measures of effectiveness include quantitative monitoring to assess the effectiveness of specific control measures and detailed accounting of program accomplishments and funds and staff hours expended. The annual report provides an overall evaluation of the program and sets forth plans and schedules for the upcoming year. The annual report is considered a program's self audit and provides a mechanism to propose modifications to the stormwater management plan in response to program accomplishments or failures. The annual report also serves as the key regulatory tool for providing accountability and public review in accordance with the NPDES permit.

Monitoring

Monitoring is an essential component of any pollution control program. The objectives are to obtain quantitative information to measure program progress and effectiveness, to identify sources of pollutants, and to document reduction in pollutant loads. The success of a monitoring program can be measured by the ability to make more informed decisions on a program's direction and effectiveness. Monitoring activities include baseline monitoring of storm drain discharges and receiving waters and focused special studies to identify sources of pollutants and to evaluate the effectiveness of specific control measures. Types of monitoring include water column measurements, sediment measurements, and nonsampling and analysis measurements, such as number of outfalls inspected or amount of material removed by maintenance. Toxicity identification evalu-

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ations are an integral component of monitoring programs in the San Francisco Bay area.

Municipal Stormwater Program Problems

The process of developing these programs has uncovered several issues and problems, mostly nontechnical in nature, that could potentially impede successful implementation. The first step towards avoiding or solving these problems is understanding what they are and how they may affect a program. The following discussion provides insight into the more common problems.

Internal Agency Coordination

Municipalities are public agencies, often with multiple departments serving different functions, that are an integral part of stormwater management. The missions and actions of separate departments are often carried out without coordination with other departments. Commitments or actions by planning department personnel that are not coordinated with public works result in problems. All affected departments must participate in development of a stormwater management program. The stormwater program plan also must clearly identify the roles and levels of participation of all involved departments.

External Agency Coordination

In addition to coordination within a municipality, communication and coordination is necessary between adjacent cities, the county, and regional organizations such as flood control and wastewater treatment agencies. Historically, there may have been little need for coordination, or problems encountered by other programs may have created barriers. As with the internal agency issue noted above, all affected agencies must participate in the program development process and clearly understand their implementation responsibilities.

Resistance by Key Individuals

Individuals play a strong role in local government. Consequently, one or more key individuals can make or break a program. Often one individual causes the internal and external coordination problems noted above. Also, in the early development stages of a program, until dedicated personnel are identified, individuals may resist the additional work load required of them to make the program work.

Financial Resources

Without dedicated financial resources, a stormwater management program is destined to fail. Programs that do not start the process to secure dedicated funds early in program development find themselves unable to commit to a meaningful program. The process of establishing a stormwater utility, assessment district, or other funding mechanisms is cumbersome and requires strategic planning.

Legal Issues

Initial review of existing local ordinances may result in the conclusion that sufficient legal authorities already exist. Later on in the development process, however, when specific implementation activities are identified, the existing authority may be found to be too vague or unsuitable. Review of legal issues should be part of the annual evaluation process.

Competing Mandates

Mandates by other programs within a municipality or by external agencies may directly conflict with stormwater program mandates. Examples include fire departments prohibiting inside or covered storage of certain materials or the obvious conflict between eradication of vegetation with herbicides in flood control channels and water quality concerns.

Problem Awareness/Understanding

To solve or manage a problem, one must first understand the problem. Effective pollution prevention requires a new way of thinking that may be foreign to those accustomed to more conventional engineering solutions. A subset of this issue involves those who deny that a problem exists.

Resistance to Maintenance Responsibility

Municipal programs are expected to result in installation of some structural controls, particularly in areas of new development or significant redevelopment. A frequently encountered barrier is that municipalities are not willing to take on the additional maintenance responsibility associated with new structural controls.

Problem Sources Beyond Municipal Authority

Many sources of stormwater pollution involve atmospheric emissions, automobile wear (e.g., brakes, tires), and household products over which a municipality has no control. Transportation related issues are beyond the control of a single municipality. State and federal coordination with local programs is essential.

Lack of Tools To Evaluate Effectiveness

The effectiveness of pollution prevention measures is difficult to quantify. Natural variability in stormwater quality may mask improvements associated with certain control measures. Surrogate measures and analytical tools to evaluate stormwater management program effectiveness should be better defined.

Municipal Stormwater Program Solutions

The efforts of the Regional Board and the municipalities in the San Francisco Bay area have overcome many of the problems noted above. The essential ingredient of the process that has enabled progress has been a cooperative, proactive relationship between the Regional Board and municipalities. A discussion of some of the solutions that have evolved follows.

Carrot and Stick Approach

At the onset of each new municipal program, the Regional Board has made it clear that stormwater pollution is a serious problem that must be dealt with and that the best solutions will only happen at the local level. The carrot has been an offer to the municipalities to control their own destinies rather than waiting for the powers that be in Sacramento or Washington to determine what they can or cannot do. This approach allows the municipalities to identify and select the measures that are workable for them and, most importantly, that are most cost-effective. On the other hand, the Regional Board has also made it clear that participation is not voluntary and that failure to commit to meaningful actions will result in enforcement actions.

Round Table Forum

Contrary to the conventional regulatory approach, in which the regulator demands and the regulatee reacts, the Regional Board has promoted a round table forum in which all involved parties work collectively and cooperatively to identify solutions that address the concerns and means of all involved. This approach has also provided a mechanism for participation by all affected internal and external public agencies.

Regular Meetings

The Regional Board has met in the round table format with municipalities throughout the program development process. Meetings have been held at least monthly. This has allowed for timely and effective decision-making. Focused work groups to address specific problems or program elements have also been formed.

Minimization of Bureaucracy

The stormwater pollution problem is not a conventional problem that can be solved by conventional means. Any program is doomed to fail if it is mired in red tape. To promote innovative solutions, the regulators must be willing to promote innovative regulatory mechanisms.

Flexibility

To truly present a carrot to entice municipalities and promote innovative solutions, the regulator must be willing to be flexible. No one solution exists for stormwater pollution problems. What works in one municipality may not work in another. Also, flexibility provides a reward mechanism for those municipalities who are committed and proactive.

Phased Approach

The phased approach promotes a strategy based on goal setting, identification of actions, planning and preparation for planned actions, small-scale implementation, and finally full-scale implementation. Evaluation is essential to each step. It must be recognized that some actions may be implemented immediately or in the short term, while others may take many years to fully implement.

Pilot Studies

Although many control measures have been demonstrated to be effective, such measures often need testing within the conditions of a specific municipality. Pilot studies also provide an opportunity to identify factors such as operation and maintenance parameters or non-technical factors such as legal issues that may not be apparent. They also provide a mechanism for demonstrating acceptability to concerned parties and should be considered a first step leading to successful wide-scale implementation.

Annual Program Audit

Recurring evaluation is essential. At a minimum, program participants and the regulator should annually evaluate program progress. This comprehensive annual audit should identify program successes as well as failures and should provide a mechanism to steer the program in the most effective direction.

Conclusions

Focusing on the described municipal stormwater program elements and taking a cooperative approach to solving problems have led to the development of successful stormwater management programs by municipalities in the San Francisco Bay area. Although program implementation is in the early stages and total success cannot be claimed, the programs are successful in that they present a workable framework for implementation of meaningful actions. Essential to the process is strategic planning, accountability, and recurring evaluation of program direction, success, and failure.

The NPDES permit issued to a municipality is not going to solve the stormwater pollution problem—it can only serve as a tool to facilitate action. The success of the municipal stormwater permit program will be recognized when municipalities are committed to action, and NPDES permits merely require municipalities to do what they have committed to do.

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Stormwater Management Ordinance Approaches in Northeastern Illinois

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Abstract

Stormwater drainage and detention is widely regulated by local ordinances in northeastern Illinois. Early ordinances, going back to about 1970, focused exclusively on the prevention of increased flooding and nuisance drainage problems. Recent ordinances address the objectives of preventing flooding and channel erosion, preserving predevelopment hydrology, protecting water quality and aquatic habitat, providing recreational opportunities, and enhancing aesthetic conditions.

The basis for many of the newer ordinances is a model ordinance developed by the Northeastern Illinois Planning Commission. The "Model Stormwater Drainage and Detention Ordinance" calls for "natural" drainage practices to minimize increases in runoff volumes and rates and for detention basins that control the full range of flood events and effectively remove stormwater pollutants.

The model ordinance requires detention designs that limit the 100-year release to 0.15 ft^3/sec/acre and the 2-year release to 0.04 ft^3/sec/acre. These rates are actually lower than the local predevelopment runoff rates and are based on observed capacities of the downstream channel system. Detention design also must incorporate water quality mitigation features, including permanent pools or created wetlands, stilling basins, and the ability to avoid short-circuiting. Further, the model ordinance strongly discourages detention in onstream locations or in existing wetlands.

As multipurpose ordinances are implemented, several issues remain. Some municipal officials are concerned about the aesthetics and maintenance needs of wetland-type detention basins and natural drainage practices, such as vegetated swales. Technical debate continues over the effectiveness of on-line and onstream detention, both from a water quality and flood prevention perspective. Also, the appropriateness of using existing wetlands for stormwater detention remains to be determined.

History

Stormwater drainage and detention has been widely regulated by local ordinances in northeastern Illinois since the early 1970s. Early ordinances were implemented because of a recognition that rapid suburban development was causing more frequent and more damaging flooding and drainage problems. Flooding and drainage problems in the region are exacerbated by the very flat landscape; typical ground slopes range from 0.5 to 4 percent. As a result, even a slight increase in flood volumes and rates can expose large additional areas to flooding.

Most early ordinances required storage of the 100-year rainfall event. These ordinances were based on requirements developed by the Metropolitan Water Reclamation District of Greater Chicago (MWRDGC). MWRDGC requires sewer permits for new development within Cook County, the largest and most populous in the six-county northeastern Illinois region. Many communities in the outer "collar" counties followed MWRDGC's lead and developed similar ordinances.

At the same time that municipalities began to implement stormwater detention controls for new development, most also required via subdivision ordinances that new development be drained by curb and gutter and storm sewer systems. This drainage philosophy was intended to reduce local drainage problems but resulted in increased rates and volumes of runoff.

The quality of urban runoff began to receive some attention in the late 1970s with the completion of the Areawide Water Quality Management Plan by the Northeastern Illinois Planning Commission (NIPC) (1). This plan reported much higher pollutant loads for urban land-use categories compared with rural land uses. As a consequence, the plan recommended that stormwater loadings of suspended solids and biological oxygen demand (BOD) be reduced by 50 percent by appropriate best management practices (BMPs) for all new development. Despite the recommendations of the plan, few changes occurred in the stormwater management strategy of local governments, which addressed exclusively the *quantity* of runoff but not the *quality*.

Assessment of Ordinance Effectiveness

In 1986 and 1987, large areas of northeastern Illinois were besieged by major floods, with total damage estimates exceeding $100 million. In some locales, flood flows exceeded the reported 100-year frequency event. Of particular concern was the observation that large flood damages had occurred in watersheds that had developed extensively since the implementation of detention ordinances in the early 1970s. This lead to the suspicion that detention was not preventing increases in flood flows.

To address these concerns, NIPC was funded by the Illinois Department of Transportation, Division of Water Resources, to investigate the effectiveness of existing stormwater detention ordinances. First, a literature review was performed to assess the effectiveness of detention in various locales around the country. Next, a comprehensive watershed modeling study was performed to evaluate both the effects of urbanization and a range of existing and proposed stormwater detention controls. The study concluded that the detention standards that most communities required were not adequate to prevent increases in flooding due to new development (2). Other local studies initiated by the Soil Conservation Service reached similar conclusions (3). Several specific weaknesses were identified:

- Detention volumes were inadequate to store the intended 100-year design event due to outdated rainfall statistics and/or simplistic hydrologic design techniques.
- Required 100-year release rates were typically based on site predevelopment runoff rates rather than observed instream flood flow rates.
- Because detention outlets were designed to explicitly control only the 100-year event, smaller flood events (e.g., the 2-year event) typically passed through detention facilities with inadequate control.

The study also noted two problems in addition to flooding impacts. The first was increased stream channel erosion, caused in part by the increased magnitude and frequency of small floods. The second was water quality impairment due to inadequately controlled urban runoff.

New Model Ordinance Approach

With the preceding problems in mind, NIPC was contracted to develop an updated model stormwater ordinance. This "Model Stormwater Drainage and Detention Ordinance" (4) was developed with the assistance of a regionwide, multiagency technical advisory committee.

The primary purposes of the ordinance are to minimize the stormwater-related effects of development on downstream and local flooding, stream channel erosion, water quality, and aquatic habitat.

The model ordinance is intended to apply to all development, including redevelopment. It requires the submittal of a basic drainage plan consisting of a topographic map, a detailed description of the existing and proposed drainage system, and a description of sensitive environmental features such as wetlands. An advanced drainage plan is required for sites larger than 10 acres. The advanced plan should include flow rates, velocities, and elevations at representative points in the drainage system for events up to the 100-year. The following are some important ordinance standards and criteria:

- *Runoff reduction hierarchy:* The ordinance requires the evaluation of site design practices that minimize the increase in runoff volumes and rates. A preference is stated for, in order, minimization of hydraulically connected impervious surfaces, use of open vegetated swales and channels and natural depressions, and infiltration practices. Traditional storm sewer approaches are discouraged unless other measures are not practical.
- *100-year release rate:* The peak 100-year discharge should not exceed 0.15 ft^3/sec/acre. This release rate is related to the capacity of the downstream channel/floodplain system for extreme flood events. The referenced detention effectiveness evaluation indicated that this release rate should prevent development-related increases in flooding for watersheds up to at least 30 square miles in size (and probably much larger).
- *2-year release rate:* The peak discharge for events up to the 2-year event should not exceed 0.04 ft^3/sec/acre. This release rate is designed to minimize increases in the magnitude and frequency of the instream 2-year event, which is sometimes associated with bankfull flow conditions. This requirement is intended to minimize increases in stream channel erosion. This release rate also will provide extended ponding for small storm events, which will enhance pollutant removal.
- *Detention storage requirements:* The design maximum storage should be based on the runoff from the 100-year, 24-hour event. Storage should be computed based on hydrograph methods, such as TR-55 or TR-20. Design rainfall should be based on the Illinois State Water Survey's Bulletin 70 (5), which supersedes the U.S. Weather Bureau's Technical Paper No. 40 (6). Bulletin 70, which is based on a precipitation database that is more extensive and more current, reports a 100-year, 24-hour rainfall of 7.6 in., while Technical Paper 40 recommends 5.8 in.

- *Water quality design features for detention:* The ordinance indicates a preference for wet detention basins over dry extended detention facilities to maximize pollutant removal potential. For wet basins, the ordinance includes design criteria for depths, shoreline slopes, permanent pool volume, and inlet/outlet orientation. For dry extended detention basins, the ordinance includes design criteria for velocity dissipation at inlets and inlet/outlet orientation.

- *Detention in floodways and stream channels:* The ordinance discourages detention in designated floodways, particularly in onstream locations with upstream drainage areas larger than about 1 to 2 square miles. The principal concerns with onstream detention are that it may be less effective in mitigating stormwater pollutants and it allows stormwater pollutants to be discharged into stream channels without adequate pretreatment.

- *Detention in wetlands:* Use of existing wetlands to accommodate stormwater detention requirements is strongly discouraged. The ordinance requires that all stormwater be stored and routed through a 2-year water quality detention facility (consistent with the previous design criteria) before being discharged to a wetland. The ordinance allows *additional* storage, up to the 100-year event, to be provided in a wetland if it can be shown that the wetland is low in quality and that proposed detention modifications will maintain or improve its habitat and other beneficial functions.

Overall, the new model ordinance is one of the most stringent in the country in its storage and release rate requirements for minimizing the effects of development on downstream flooding. The new ordinance also includes, for the first time, some basic requirements for BMPs to mitigate stormwater quality effects.

Recent Improvements in Local Stormwater Regulations

As an advisory agency, NIPC has no authority to require compliance with its model ordinances. Similarly, there is no comprehensive state requirement for local stormwater regulations. Because of recent experience with devastating floods, however, many communities were eager to consider alternatives to stormwater standards that were a decade or more old.

The process of evaluating new ordinances was facilitated by state legislation, passed after the floods of 1986 and 1987, that authorized northeastern Illinois counties to establish stormwater management committees (SMCs). These committees, with equal representation from county government and municipalities, were authorized to develop comprehensive, binding stormwater management plans. These plans included both watershed-based flood remediation measures as well as uniform, countywide stormwater regulations.

So far, comprehensive countywide ordinances have been implemented in two counties, DuPage (7) and Lake (8). These ordinances address traditional stormwater drainage and detention concerns as well as floodplain management, soil erosion and sediment control, and stream and wetland protection. The ordinances incorporate many standards from the NIPC models and address multipurpose objectives of preventing flooding and channel erosion, preserving predevelopment hydrology, protecting water quality and aquatic habitat, providing recreational opportunities, and enhancing aesthetic conditions. Probably the most remarkable element of these new ordinances is their inclusion of some basic stormwater BMPs that are intended to address both stormwater quantity and quality concerns.

Countywide stormwater planning efforts also have begun in Cook, Kane, and McHenry Counties. Many communities in these counties have individually begun to update their ordinances. Some of the impetus for ordinance updates has come from watershed-based groups, such as the Butterfield Creek Steering Committee. This group developed a comprehensive ordinance for seven watershed communities all faced with similar problems of overbank flooding, stream channel erosion, and water quality degradation (9).

Other communities are updating ordinances based on requirements of the Illinois Environmental Protection Agency (IEPA) as a condition for facility planning area amendments for expanded wastewater service. These requirements are based on provisions of the Illinois Water Quality Management Plan and essentially require that development within new FPA expansions not adversely affect water quality, either due to point or nonpoint sources.

The IEPA also is delegated to implement the new NPDES requirements for stormwater discharges. In particular, as part of its new general permit for construction site activities, IEPA requires the development of a pollution prevention plan that must include provisions for soil erosion and sediment control as well as stormwater BMPs such as detention facilities, vegetated swales and natural depressions, infiltration practices, and velocity dissipation measures (10). While the construction site general permit does not mandate the adoption of ordinances, it does provide further incentive to local governments to begin to add stormwater quality control measures to their existing ordinances.

Regionwide enthusiasm for inclusion of water quality BMPs in stormwater ordinances is still somewhat limited because of a lack of awareness among many stormwater engineers, local officials, and the public of the adverse effects of stormwater runoff on water quality and aquatic life. This perception appears to be at least partly related to the long-term degradation of urban water bodies in the region and the lack of a prominent focal point, such as a Chesapeake Bay or Puget Sound, for viewing stormwater quality impacts.

Some Current Issues

As multipurpose stormwater ordinances are adopted throughout the region, several issues remain. Some municipal officials are concerned about the aesthetics and maintenance needs of wetland-type detention basins and natural drainage practices, such as vegetated swales. Technical debate continues over the effectiveness of on-line and onstream detention, both from a water quality and flood prevention perspective. Also, the appropriateness of using existing wetlands for stormwater detention remains to be resolved.

Perhaps the most important consideration of local government officials regarding stormwater drainage is public acceptance, which generally translates as the avoidance of "nuisance" drainage conditions. Some commonly cited nuisance concerns include extended saturation or ponding on lawns or swales, "weedy" vegetation, mosquito breeding potential, and wet detention areas. These concerns have driven many communities to require highly engineered drainage systems, including curbs and gutters, storm sewers, and concrete channels, which rapidly convey runoff from the site. Some public works officials also argue that engineered drainage systems are less expensive to maintain.

There is growing support, however, in other parts of the country and in a few northeastern Illinois communities for "natural" drainage practices using vegetated swales, channels, and filter strips and created wetlands. In addition to providing significant pollutant removal and runoff reduction benefits, natural practices may be much less expensive to install and, at least to some, are preferred aesthetically over engineered systems. Progress in gaining acceptance of natural drainage systems has been slow in northeastern Illinois. Successful ongoing demonstration projects, innovative new corporate campus developments, and improved public education should be helpful in advancing natural drainage approaches.

Onstream stormwater detention is a desirable alternative to many site design engineers in the region. In a typical situation, such facilities generally do not provide regional detention for the entire upstream watershed; rather, they serve the storage requirements of a development adjacent to the floodplain. As previously mentioned, however, there are significant concerns about the effects and effectiveness of onstream facilities. These facilities alter the free-flowing nature of streams, creating impoundments susceptible to sedimentation and eutrophication. Impoundments can impede the upstream migration of fish and the downstream drift of benthic organisms. Onstream detention essentially uses the stream as a treatment device. Because of typically shorter residence times relative to offline facilities, however, onstream facilities may not be very effective in trapping stormwater runoff pollutants and protecting downstream water bodies. While the appropriateness of onstream detention in northeastern Illinois merits additional debate, currently this debate is not fully considering the potential adverse water quality and habitat impacts of onstream facilities.

Another unresolved issue is the appropriateness of using existing wetlands for stormwater detention. Section 404 permits have been issued for the incorporation of detention into existing wetlands and mitigation wetlands. If a wetland is impounded without the introduction of fill material, a Section 404 permit may not even be required. Limited water quality protection is provided by several new stormwater ordinances and the NIPC model ordinance, which require pretreatment of stormwater before it is discharged into a wetland. Even if stormwater quality effects are reasonably mitigated, however, detention in a wetland can radically affect its hydrology. In particular, detention is likely to pond water more frequently and at greater depths than in a natural wetland. Such alterations can adversely affect sensitive plant communities and wildlife.

Conclusions

Stormwater management ordinances have evolved dramatically in northeastern Illinois since their introduction over 20 years ago. Always a leader in flood prevention, northeastern Illinois now has some of the most stringent standards in the nation for detention volumes and release rates.

Evolving from an early emphasis on local drainage and flood prevention, many ordinances now recognize the importance of water quality mitigation and habitat protection. Some newer ordinances reflect a revised philosophy of stormwater management that takes advantage of natural drainage and storage functions, with the objective of limiting stormwater runoff rates, volume, and quality to predevelopment conditions. Much remains to be learned, however, about effective designs for BMPs such as wetland detention, filter strips, and infiltration practices.

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The Lower Colorado River Authority Nonpoint Source Pollution Control Ordinance

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Abstract

Urban development can be managed to control nonpoint source pollution using a variety of methods. The method selected is typically a function of the jurisdictional agency's authority (or lack thereof), the use and desired quality of the receiving waters, and the impact on and acceptance by the public.

The Lower Colorado River Authority (LCRA) is a conservation and reclamation district created by Texas legislation. LCRA is responsible for the conservation, control, and preservation of the waters of the Colorado River and its tributaries within a 10-county area. Given this responsibility but not land-use control authority, LCRA has developed a nonpoint source pollution control ordinance with a technology-based approach.

The ordinance requires a large percentage of the pollutants generated from new development to be removed before stormwater discharge from the property. A technical manual accompanies the ordinance and explains how to calculate the expected increase in pollution and the various management practices a developer may employ to achieve the required pollutant removal standards. The developer and engineer determine what combination of management practices are most compatible with their site and development plan.

This paper provides the methodology and primary features of the ordinance and technical manual. The reasoning behind this approach is explained, with discussion regarding the strengths and weaknesses of a technology-based ordinance.

Introduction

The Lower Colorado River Authority (LCRA) is a conservation and reclamation district created by the Texas legislature in 1934. LCRA is also a self-sufficient public utility company. The authority's responsibilities are many and include energy generation, water supply, flood control, management of certain public lands, and preservation and conservation of the waters of the lower Colorado River.

While given these responsibilities, LCRA has limited authority and can only exercise powers expressly given by the legislature. As such, LCRA cannot regulate land use, impose zoning or site development restrictions, or assess taxes. LCRA can, however, promulgate ordinances to control water pollution within its 10-county statutory area.

With these powers and limitations, LCRA has developed an ordinance to control nonpoint source (NPS) pollution from urban development. The ordinance does not impose any land-use regulations other than to establish a technology-based pollutant reduction standard for new development.

Background

In 1988, the LCRA board of directors approved a water quality leadership policy stating LCRA's goals regarding water quality protection. This policy directed staff to develop a program to control NPS pollution within the 10-county area, commencing with the area of the Highland Lakes.

The Highland Lakes are a chain of seven lakes located west of Austin, Texas. The lakes were created in the 1930s and 1940s for flood control, water supply, and hydroelectric generation. In the early 1980s, the area around the lakes experienced tremendous growth in development activity. This growth prompted concern about the long-term health of the lakes.

A Pollution Control Approach

From the outset, LCRA was limited in the number of options available to manage development for control of NPS pollution. We realized, however, that it must be attacked in several ways. The initial effort was a public education program, the highlight of which was a 30-minute video entitled, "Pointless Pollution: America's Water Crisis," narrated by Walter Cronkite.

Realizing that public education alone would not protect water quality, LCRA staff began addressing the control of NPS pollution through a regulatory program. Lacking land-use control or zoning power, LCRA selected a strategy to reduce the quantity of pollution generated by new development that would otherwise be received by the lakes.

In December 1989, the LCRA board of directors adopted the Lake Travis NPS Pollution Control Ordinance, the first of its kind ever promulgated by a river authority in the state of Texas. In March 1991, a similar ordinance was passed to cover the upper Highland Lakes, which includes Lakes Buchanan, Inks, LBJ, and Marble Falls.

A Nonpoint Source Control Ordinance

The main strategy of the Lake Travis NPS Pollution Control Ordinance is to establish a set of pollution reduction performance standards. Pollution reduction would be through three methods: 1) removal of a specified percentage of the projected increase in annual NPS pollution load; 2) streambank erosion protection via stormwater detention requirements; and 3) employment of erosion controls during construction.

Pollution Reduction Standards

LCRA's primary goal was to develop a pollution prevention strategy to protect the lakes. At the same time, consideration was given to producing feasible standards that would not prevent development activity.

The basic requirement of the ordinance is the removal of 70 percent or more of the increased pollution generated over background or undeveloped conditions. Higher removal rates are required for steeply sloped property or land located adjacent to the lakes. The required removal rates were chosen first from a water quality standpoint, but also were considered feasible. Analysis of existing developments and the anticipated performance of best management practices (BMPs) showed possibilities of significant land-use restriction if higher removal standards were employed. Additionally, members of LCRA's board of directors represent their respective counties or service areas, a majority of which are predominantly rural. While the board adopted an environmental leadership policy, its concern about imposing regulations that could adversely affect local economic development was clear.

Streambank Erosion Control

Urbanization of a site or area can have a great impact on the downstream conveyance system. As pavement and rooftops replace the natural soil and vegetative cover, the magnitude and frequency of runoff increases dramatically.

Just as runoff from an undeveloped watershed has carved out a stream channel over time to convey typical runoff events, the increased volume and frequency of runoff from an urbanized area will reconfigure the streambank to create a larger conveyance system. The result is erosion of streambanks transporting sediment to receiving water bodies, degrading of undercut streams, removal of aquatic habitat, and loss of public and private property.

The approach LCRA has taken to control streambank erosion is to require detainment of postdeveloped runoff to predeveloped runoff conditions for the 1-year design storm. Stream morphology is generally dictated by the 2-year storm event.

To simplify the permitting process, the technical manual provides the required detention volume in inches of runoff as a function of impervious cover. These detention volume requirements can be incorporated into the use of BMPs to meet the pollutant removal performance standards.

Temporary Erosion Control

The ordinance requires erosion and sedimentation to be controlled throughout the development process. For permitted activities, an erosion control plan is required for review and approval. Activities not requiring a permit, such as the construction of a single-family home, also require erosion controls to be in place until revegetation occurs.

The technical manual provides guidance for appropriate erosion controls. These strategies include minimization of area cleared; physical controls such as silt fences, brush berms, and rock berms; downstream vegetative buffers; diversion of upstream flow; flow spreading; contour furrowing; loose straw or jute netting for soil protection; and use of structural BMPs as sedimentation basins during construction.

Technical Manual

The ordinance is accompanied by a technical manual that provides explanation and guidance for the applicant or engineer. Included in the technical manual are permitting procedures, pollutant loading calculations, and design standards and efficiencies of management practices.

Types of Pollution

Urbanization causes numerous forms of pollution. Analysis of all pollutant elements through a permitting program would encumber both the applicant and review body. LCRA has classified these forms of pollution into three distinct groups important to the protection of the lakes: sedimentation, eutrophication, and toxins. LCRA

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then selected an indicator pollutant to represent these categories. Indicator pollutants are total suspended solids (TSS) for sedimentation, total phosphorus (TP) for eutrophication, and oil and grease (O&G) for toxins.

- TSS consist of colloidal and settleable particulate matter. In alkaline waters such as those of the Highland Lakes, metals tend to precipitate and become particulate matter. In addition, some organic compounds such as chlordane and polychlorinated biphenyls tend to be adsorbed onto sediment particles.
- TP can be indicative of other nutrients. While the nitrogen cycle is different, plant and microbial uptake occurs for both elements.
- O&G, while encompassing both nontoxic and toxic organic compounds, represents petroleum hydrocarbon pollutants, including carcinogens such as benzene and toluene and chlorinated compounds such as pesticides and herbicides.

These indicator pollutants are used to represent the array of pollutants generated. It is reasonable to assume that removal of these indicator pollutants will result in removal of other pollutants not specifically analyzed.

Pollutant Loads

A mass loading equation is used to calculate the pollutant load under existing and developed conditions. This determines the increase in pollution generated over background conditions. The equation is a product of annual runoff volume and the average stormwater pollutant concentration.

The pollutant load is calculated in pounds per year and is represented as follows:

$$L = A \cdot RF \cdot Rv \cdot C \cdot K,$$

where L = annual pollutant load (pounds)
A = area of development (acres)
RF = average annual rainfall (inches)
Rv = average runoff-to-rainfall ratio
C = average pollutant concentration (mg/L)
K = unit conversion factor (0.2266)

The runoff-to-rainfall ratio equation used is as presented in the Metropolitan Washington Council of Governments document *Controlling Urban Runoff: A Practical Manual for Planning and Designing Urban BMPs*. This regression equation simplifies the runoff-to-rainfall relationship to a function of impervious cover as follows:

$$Rv = 0.05 + (0.009 \cdot IC),$$

where IC is impervious cover in percent

Background and developed pollutant concentrations for the indicator pollutants are provided. These values were acquired primarily from screening local and national reports. The average pollutant concentrations used for indicator pollutants under background and developed conditions are shown in Table 1.

Table 1. Average Pollutant Concentrations for Indicator Pollutants

	Background (mg/L)	Developed (mg/L)
TSS	48	130
TP	0.08	0.26
O&G	0	15

The manner in which this information is supplied within the technical manual results in reasonable estimates of a development's potential pollution impact while making calculations simple and consistent.

Selection of Management Practices

The technical manual provides design criteria and estimated removal efficiencies for BMPs. The manual is intended to provide guidance to the applicant in selecting BMPs. The applicant must select the BMPs that will enable the development to meet the criteria of the ordinance. The basic strategy for selecting BMPs is to match the pollutant removal requirements with site and development characteristics. Consideration must be given to drainage area, soil type, and topography to select BMPs effectively.

The technical manual provides the expected removal efficiencies for BMPs with a performance history. Most of this data is based on criteria presented in nationally published documents. For structural BMPs, a percent removal efficiency is provided for each indicator pollutant. This is then multiplied by the percent of the total average annual runoff volume to be captured by the proposed BMP. The product is the expected removal efficiency of that BMP. This is done for each indicator pollutant. The analysis and performance standard for O&G is applied only to developments other than single-family residential use. The focus on O&G is on commercial land and parking lots instead of single-family residential neighborhoods. Efficiencies used for each BMP are shown in Table 2.

Other BMPs for which removal efficiencies are provided include vegetated filter strips, street sweeping, and pollution source removal credit for using an integrated pest management plan.

The manual promotes the use of innovative practices as long as the applicant can document the potential effectiveness of the practice. LCRA may also require, by ordinance,

Table 2. Expected Removal Efficiencies of Selected BMPs

Best Management Practice	Pollutant TSS	TP	O&G
Sedimentation basin	60	20	10
Sand filtration	70	33	30
Extended detention	70	60	30
Retention basin	80	80	80
Infiltration practices	80	80	80

that innovative BMPs be monitored at a cost borne by the applicant. Some innovative practices include water quality catch basins (oil/grit separators), peat/sand filters, zeolite filters, and wet ponds. While wet ponds have a proven track record in portions of the United States, their performance, and more particularly their maintenance requirements, in semiarid regions warrants further scrutiny.

BMPs In Series

Based on the removal efficiencies of known BMPs and the removal requirements of the ordinance, development with moderate or high impervious cover may need to provide BMPs in series to meet the ordinance performance standards. One of the unknowns at this juncture is how BMPs operate in series. LCRA currently assumes that the total removal is the sum of the individual BMP removal performances. This is an assumption that warrants further analysis from monitoring BMPs in series.

Example of Ordinance Application

A commercial establishment desires to develop 200,000 ft^2 of retail space and is looking at a 23-acre undeveloped site in the Austin, Texas, area. What would be required for the development to meet LCRA's NPS ordinance?

The site plan layout shows parking for 1,200 vehicles. With access drives and loading areas, the impervious cover provided for vehicular traffic is about 400,000 ft^2. The proposed total impervious cover is 600,000 ft^2, or 60 percent of the site area.

The average annual rainfall in Austin is 32.5 in. Applying the pollutant load calculations shown in the technical manual,

$$L = A \cdot RF \cdot Rv \cdot 0.2266 \cdot C,$$

yields the average pollutant concentrations shown in Table 3.

With a pollutant removal standard for the site of 70 percent:

Table 3. Pollutant Concentrations for Austin Example Site

	Background (mg/L)	Developed (mg/L)
TSS	407	12,992
TP	0.68	26.0
O&G (calculated for paved area only, at 100% IC)	0	963

- TSS removal = (12,992 - 407) • 0.70 = 8,810 lb
- TP removal = (26.0 - 0.68) • 0.70 = 17.7 lb
- O&G removal = (963 - 0) • 0.70 = 674 lb

The applicant proposes a weekly street sweeping program for general maintenance of the area. The pollutant removal efficiencies assumed for this practice with a vacuum-type sweeper are 20 percent for TSS, 10 percent for TP, and 15 percent for O&G.

The site is gently sloping and does have adequate soil for percolation. Infiltration is desirable; however, it must be preceded by a sediment removal practice according to the technical manual.

To meet the streambank erosion control criteria, a site with 60 percent IC must provide detention for 1 in. of runoff. Therefore, structural BMPs should be sized to also meet this criteria.

The designer decides to try a sedimentation basin followed by an infiltration basin. With 60 percent IC, a 1-in. capture volume will collect 89.7 percent of the average annual runoff based on historical rainfall data and runoff/rainfall relationships. The removal efficiencies of these ponds are the product of the BMP efficiency and percent of average annual runoff captured, as shown in Table 4.

Table 4. Remove Efficiencies of Sedimentation Basin and Infiltration Basin BMPs

Sedimentation Basin	Infiltration Basin
TSS - 0.60 • 0.897 = 53.7 %	TSS - 0.80 • 0.897 = 71.6 %
TP - 0.20 • 0.897 = 17.9 %	TP - 0.80 • 0.897 = 71.6 %
O&G - 0.10 • 0.897 = 9.0 %	O&G - 0.80 • 0.897 = 71.6 %

To test whether the above controls would meet the ordinance's performance standard requirements, the following equation is used:

$$\text{Total BMP Series Eff.} = [1-((1-E_1)\cdot(1-E_2)\cdot(1-E_3))]\cdot 100$$

where

E_1 = removal efficiency of first BMP
E_2 = removal efficiency of second BMP
E_3 = removal efficiency of third BMP

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$\text{TSS Eff. (total)} = [1-((1-0.2)\cdot(1-0.537)\cdot(1-0.716))]\cdot 100 = 89.5$ percent

$\text{TP Eff. (total)} = [1-((1-0.1)\cdot(1-0.179)\cdot(1-0.716))]\cdot 100 = 79.0$ percent

$\text{O\&G Eff. (total)} = [1-((1-0.15)\cdot(1-0.09)\cdot(1-0.716))]\cdot 100 = 78.0$ percent

Therefore, the above controls would meet the performance standard requirements of the ordinance. Had infiltration not been a viable option, other potential solutions include 1) a street sweeping program with a 1-in. volume extended detention basin followed by 8.4 acres of vegetative filter strip (fair condition, 2- to -7 percent slope) or 2) a street sweeping program with three extended detention ponds, each of 2-in. capture volume.

Administration

Maintenance Agreements

Maintenance of BMPs is critical to their long-term performance. Without maintenance, the effective life of a BMP may be limited to a couple of years. Relying on good faith or volunteer efforts has not shown to be an effective way to maintain these pollution controls.

The ordinance requires that a NPS Best Management Practice Maintenance Permit be issued upon acceptable completion of construction. Whether through a homeowner's association or through the land owner as an individual, a maintenance association must be formed. The maintenance association is to post financial security or create a fund for the purpose of maintaining all BMPs implemented to meet the ordinance.

Enforcement

A necessary portion of any regulatory program is the ability to impose penalties for not complying with the regulations. The ordinance contains a violations section that allows financial penalties to be imposed for violations of a provision of the ordinance.

Case Application

The ordinance is relatively new, and there have been few opportunities to evaluate its effectiveness. Two projects of note have shown the impact that the ordinance has had on development.

LCRA Office Complex

The first project of note is construction of LCRA's general office buildings. While not located in an area under the purview of the ordinance, LCRA chose to make a leadership statement by applying ordinance standards to the office complex.

The offices are located on 11.7 acres of land and consist of 250,000 ft^2 of office space with close to 600 parking spaces. Site IC is approximately 55 percent. Due to site constraints, innovation had to be applied to achieve the performance standards of the ordinance.

A series of BMPs are employed on the site, including a full integrated pest management and xeriscape plan, a street sweeping program, five surface ponds composed of extended detention ponds, a peat/sand filter, and an enhanced (partial wet pond) extended detention pond. There are also subsurface treatment devices that include off-line water quality catch basins conveying to a sand filtration system beneath a parking lot and peat/sand filtering system under an open-space front yard area. Infiltration practices could not be used due to soil conditions. LCRA has acquired grants from the U.S. Environmental Protection Agency to monitor the effectiveness of some of the innovative practices being applied on this project.

The total construction cost associated with the NPS controls on this project was $250,000. This represents about 1.5 percent of the total project cost.

Sun City Development

The Del Webb Corporation is in the planning stages of developing a 2,400-acre active adult community west of Austin, Texas. The project is within the jurisdiction of the Lake Travis NPS Pollution Control Ordinance. Del Webb is presently going through a master plan approval phase with LCRA.

The development is predominantly single-family residential and entails 4,200 single-family homes with recreational amenities. The overall proposed IC for the site is slightly less than 30 percent. The project has incorporated in the preliminary design 60 to 70 structural BMPs to meet the performance requirements of the ordinance. Over 90 percent of the runoff from the development will convey to a structural BMP of some form. The structural practices proposed include extended detention ponds, wet ponds, retention ponds, sedimentation ponds, and infiltration practices. These structural facilities take up 5 percent of the total land area.

In addition, the development includes a roadway system that has vegetated filter strips throughout and grass-lined swales for stormwater conveyance. Commercial areas include a street sweeping program, and areas left as native open space receive credit for pollution reduction as low-maintenance landscapes.

The cost of meeting the performance standards of the ordinance has been estimated by the applicant to be about $1,300 per single-family home. It is quite possible that

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an economy of scale is realized, as studies before ordinance implementation estimated a per-unit cost of almost twice this amount for developments of similar net density.

Pros and Cons

The quality of any development management strategy has to be measured on the basis of what it achieves versus the impacts it may create.

Strengths of a Technology-Based Approach

A technology-based approach to control NPS pollution from urbanization has several strengths. The first is the transferability of this approach to other jurisdictions. Creating pollution reduction strategies of this kind can be applied on a city, county, watershed, or statewide basis. The only variables may be in the selection of BMPs that are compatible with a region and the percentage of annual runoff captured based on rainfall patterns.

Implementing land-use restrictions from a density or IC standpoint can be difficult due to public opposition. The technology-based approach gives the landowner the freedom to determine the highest use of the land with consideration given to the increasing costs of providing and maintaining additional BMPs to compensate for dense development. It is theoretically possible for a landowner to use every square inch of land for development purposes if the developer is willing to incur the increased cost of subsurface stormwater treatment or even mechanical treatment.

The standards for achieving compliance with a technology-based ordinance are clear. The approach is simple, with straightforward calculations. This cookbook approach minimizes staffing requirements for review of applications.

Density or IC limitations are a best management practice. More pollution could be discharged, however, from a less dense development with no other BMPs than from a more intense development with BMPs. There is also concern that density controls contribute to urban sprawl, which may result in poorer water quality on a regional basis and may adversely affect air quality through increased vehicular operating time.

Finally, there is no question that implementation of this technology-based practice mitigates some of the water quality impacts associated with urbanization.

Weaknesses of a Technology-Based Approach

The sole use of a technology-based pollution reduction strategy has weaknesses as well. First and foremost is the full reliance on this new technology to maintain a high level of pollution removal over the long term. Recognition of the requirements for maintaining these facilities at their expected performance standards over the long term has yet to occur.

Notwithstanding the urban sprawl issue, there is no question that on a site-specific basis the reduction of IC and maintenance of land in a natural vegetative state are more foolproof means of reducing pollution from that site.

The technology-based approach only considers water quality issues. Land use is at the disposal of the landowner. There are locations where aesthetics, views, and protection of existing vegetation and habitat are equally as important as the quality of water. This ordinance does not directly address these other considerations.

Conclusion

LCRA considers the NPS ordinance to be an excellent beginning in protecting the quality of the waters of the Highland Lakes and Colorado River. Close to a million people rely on the Highland Lakes for drinking water supply and countless thousands for recreational and aesthetic purposes.

LCRA is committed to evaluating the effectiveness of this ordinance. Depending on the actual development that takes place around the Highland Lakes, the actual pollution removal achieved, and the change in water quality evidenced, more or less restrictive standards or alternate practices may be required. The effectiveness of the ordinance must be analyzed as development takes place to ensure good water quality.

There are limitations in our knowledge of BMPs and of pollution generation from various land uses. The current version of the technical manual is already in need of revision to account for research performed over the last few years. The calculations do not adequately address certain land uses, such as golf courses, nurseries, or parks, due to the low IC yet high maintenance associated with these land uses, particularly as they pertain to pesticides and nutrients.

Finally, it is LCRA's desire to ultimately connect the pollution removal standards of the ordinance to established water quality standards of the receiving waters. There is much work to be performed before a full understanding of the dynamics of the lakes and Colorado River permit us to achieve this goal.

New Development Standards in the Puget Sound Basin

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Abstract

The Puget Sound Water Quality Management Plan (PSWQMP) calls for all counties and cities in the Puget Sound drainage basin to adopt ordinances that require stormwater control for new development and redevelopment. Ordinances were to be adopted by July 1, 1994. The PSWQMP also directed the Washington Department of Ecology to prepare technical guidance and a model ordinance to assist local governments in implementing these standards.

In response, the Department of Ecology has prepared several sets of minimum requirements that are applied based on the type and size of proposed development. These include:

- Simplified erosion and sediment controls and a small parcel erosion and sediment control plan for small developments (under 5,000 ft^2 impervious surface), single-family homes, and land-disturbing activities under 1 acre.
- A set of 11 minimum requirements for proposed new development of large parcels (5,000 ft^2 impervious surface and greater) and/or land-disturbing activities over 1 acre. The requirements include erosion and sediment control, and source control and treatment best management practices designed to prevent or minimize impacts to receiving waters. A stormwater site plan is also required for this level of development.
- The same 11 requirements apply to large parcels with less than 1 acre of land-disturbing activities except that the small parcel erosion and sediment requirements are substituted for the large parcel erosion and sediment controls.

If redevelopment is proposed, the same minimum requirements apply, subject to a set of thresholds and criteria for applying the minimum requirements to all or part of the site.

Introduction

Puget Sound, which is located in western Washington State, has been the focus of a comprehensive water quality improvement effort in recent years—especially since documentation of liver tumors in English sole and toxics in sediments and with increasing closures of shellfish beds (1). Initial efforts culminated in 1986, with the publication of the *Puget Sound Water Quality Management Plan* (PSWQMP) and subsequent amendments in 1989 and 1991 (2). In 1991, Puget Sound was listed as an Estuary of National Significance under Section 320 of the federal Clean Water Act.

The section of the PSWQMP that covers stormwater management calls for all counties and cities in the Puget Sound drainage basin to adopt ordinances that require stormwater control for new development and redevelopment by July 1, 1994. The plan also requires all local governments in the basin to adopt operation and maintenance programs for new and existing public and private stormwater systems. Local governments located within census-defined urbanized areas have additional requirements that include:

- Identification and ranking of significant pollutant sources.
- Corrective actions for problem drains.
- A water quality response program.
- Assurance of funding.
- Local coordination.
- Public education.
- Compliance measures.
- An implementation schedule.
- As a last resort in problem areas, retrofitting of control measures.

The PSWQMP also directed the Washington State Department of Ecology (Ecology) to prepare a best management practices (BMPs) technical manual (3) and a program guidance manual containing model ordinances and other supplemental guidance (4) to assist local governments in implementing plan requirements. The guidance prepared for new development and redevelopment consists of several sets of minimum requirements that are applied depending on the type and size of proposed development. In summary, these include:

- Simplified erosion and sediment controls (ESCs) and a small parcel ESC plan for small developments (under 5,000 ft^2 impervious surface), detached single-family homes and duplexes, and land-disturbing activities under 1 acre.
- A set of 11 minimum requirements for proposed new development of large parcels (5,000 ft^2 impervious surface and greater) and/or land-disturbing activities over 1 acre. The requirements include ESC and source control and treatment BMPs designed to prevent or minimize impacts to receiving waters. A stormwater site plan is also required for this level of development.
- The same 11 requirements apply to large parcels with less than 1 acre of land-disturbing activities except that the small parcel ESC are substituted for the large parcel ESCs.

If redevelopment is proposed, the same minimum requirements apply, subject to a set of thresholds and criteria for applying the minimum requirements to all or part of the site.

The BMP manual that Ecology prepared contains a full description of the minimum requirements and technical guidance on how to meet them. In essence, development sites are to demonstrate compliance with the requirements by preparing and implementing a stormwater site plan that includes an appropriate selection of BMPs from the manual.

Two major components of a stormwater site plan are an ESC plan and a permanent stormwater quality control (PSQC) plan. The ESC plan is intended to be temporary in nature to control pollution generated during the construction and landscaping phase only, primarily erosion and sediment. The PSQC plan is intended to provide permanent BMPs for the control of pollution and other impacts from stormwater runoff after construction is completed. For small sites, this is met by implementing a small parcel erosion and sediment control (SPESC) plan.

Further details of these plans are contained in the *Stormwater Management Manual for the Puget Sound Basin* (3).

The following sections describe the minimum requirements as they apply to local governments in the Puget Sound basin and have been adapted directly from the technical manual (3). The description also includes several associated requirements specific to Washington laws; therefore, some modifications would be needed for application of the minimum requirements to areas outside of Washington. The model ordinance that was prepared as guidance for enacting the minimum requirements is contained in the program guidance manual (4). The full guidance package may be ordered from Ecology by calling (206) 438-7116. The current cost of the technical manual is $24.85 plus postage, and of the program guidance manual is $28.00 plus postage.

Definitions

The following definitions are useful to the understanding of the minimum requirements:

- *Approved manual:* A technical manual that is substantially equivalent to the *Stormwater Management Manual for the Puget Sound Basin* (3). (The PSWQMP requires all counties and cities located in the Puget Sound basin to adopt a manual that is the same or substantially equivalent to this manual by July 1, 1994.)
- *New development:* Development consisting of land-disturbing activities; structural development, including construction, installation or expansion of a building or other structure; creation of impervious surfaces; Class IV general forest practices that are conversions from timber land to other uses; and subdivision and short subdivision of land as defined in RCW 58.17.020. All other forest practices and commercial agriculture are not considered new development.
- *Redevelopment:* On an already developed site, the creation or addition of impervious surfaces; structural development including construction, installation, or expansion of a building or other structure, and/or replacement of an impervious surface that is not part of a routine maintenance activity; and land-disturbing activities associated with structural or impervious redevelopment.
- *Impervious surface:* A hard surface that either prevents or retards the entry of water into the soil mantle as under natural conditions prior to development, and/or a hard surface area that causes water to run off the surface in greater quantities or at an increased rate of flow from the flow present under natural conditions prior to development.
- *Land-disturbing activity:* Any activity that results in a change in the existing soil cover (both vegetative and nonvegetative) and/or the existing soil topography. Land-disturbing activities include, but are not limited to, demolition, construction, clearing, grading, filling, and excavation.
- *Source control BMP:* A BMP that is intended to prevent pollutants from entering stormwater. Examples include covering an activity, controlling erosion,

directing wash water to a sanitary sewer, and altering a practice that results in pollution prevention.

Exemptions

Commercial agriculture and forest practices regulated under Title 222 WAC, except for Class IV general forest practices that are conversions from timber land to other uses, are exempt from the provisions of the minimum requirements. All other new development is subject to the minimum requirements.

Small Parcel Minimum Requirements

The following new development shall be required to control erosion and sediment during construction, to permanently stabilize soil exposed during construction, to comply with Small Parcel Requirements 1 through 5, and to prepare a SPESC plan:

- Individual, detached single-family residences and duplexes.
- Creation or addition of less than 5,000 ft² of impervious surface area.
- Land-disturbing activities of less than 1 acre.

Supplemental Guidelines

The objective of these requirements is to address the cumulative effect of sediment coming from a large number of small sites. The SPESC plan is meant to be temporary in nature to deal with erosion and sediment generated during the construction phase only. Local governments may choose to apply additional permanent, site-specific stormwater controls to small parcels.

Small Parcel Requirement 1: Construction Access Route

Construction vehicle access shall be limited to one route whenever possible. Access points shall be stabilized with quarry spall or crushed rock to minimize the tracking of sediment onto public roads.

Small Parcel Requirement 2: Stabilization of Denuded Areas

All exposed soils shall be stabilized by suitable application of BMPs, including but not limited to sod or other vegetation, plastic covering, mulching, or application of ground base on areas to be paved. All BMPs shall be selected, designed, and maintained in accordance with an approved manual. From October 1 through April 30, no unworked soils shall remain exposed for more than 2 days. From May 1 through September 30, no unworked soils shall remain exposed for more than 7 days.

Small Parcel Requirement 3: Protection of Adjacent Properties

Adjacent properties shall be protected from sediment deposition by appropriate use of vegetative buffer strips, sediment barriers or filters, dikes or mulching, or by a combination of these measures and other appropriate BMPs.

Small Parcel Requirement 4: Maintenance

All ESC BMPs shall be regularly inspected and maintained to ensure continued performance of their intended function.

Small Parcel Requirement 5: Other BMPs

As required by the local plan-approval authority, other appropriate BMPs to mitigate the effects of increased runoff shall be applied.

Application of Minimum Requirements for New Development and Redevelopment

New Development

All new development that includes the creation or addition of 5,000 ft² or greater of new impervious surface area and/or land-disturbing activities of 1 acre or greater shall comply with Minimum Requirements 1 through 11 below and be in agreement with a stormwater site plan.

All new development that includes the creation or addition of 5,000 ft² or more of new impervious surface area and land-disturbing activities of less than 1 acre shall comply with Minimum Requirements 2 through 11 below and the Small Parcel Minimum Requirements listed above. This category of development requires preparation of a stormwater site plan that includes a SPESC plan.

Redevelopment

Where redevelopment of 1 acre or greater occurs, new development Minimum Requirements 1 through 11 apply to that portion of the site that is being redeveloped, and source control BMPs shall be applied to the entire site, including adjoining parcels if they are part of the project.

Where one or more of the following conditions apply, a stormwater site plan shall be prepared that includes a schedule for implementing Minimum Requirements 1 through 11 below to the maximum extent practicable for the entire site, including adjoining parcels if they are part of the project:

- Existing sites greater than 1 acre in size with 50 percent or more impervious surface.
- Sites that discharge to a receiving water that has a documented water quality problem.

- Sites where the need for additional stormwater control measures has been identified through a basin plan or other local planning activities.

Note: An adopted and implemented basin plan (Minimum Requirement 9) may be used to develop requirements that are tailored to a specific basin.)

Minimum Requirement 1: Erosion and Sediment Control

All new development and redevelopment that includes land-disturbing activities of 1 acre or more shall comply with Large Parcel ESC Requirements 1 through 15 below. Compliance shall be demonstrated through implementation of a Large Parcel ESC plan.

All proposed developments where land-disturbing activities 5,000 ft^2 and greater but less than 1 acre are planned shall implement the Small Parcel Minimum Requirements above, as well as Minimum Requirements 2 through 11 below.

Large Parcel ESC Requirement 1: Stabilization and Sediment Trapping

All exposed soils shall be stabilized by suitable application of BMPs. From October 1 to April 30, no unworked soils shall remain exposed for more than 2 days. From May 1 to September 30, no unworked soils shall remain exposed for more than 7 days. Prior to leaving the site, stormwater runoff shall pass through a sediment pond or sediment trap, or other appropriate BMPs shall be employed.

Supplemental Guidelines. This criterion applies both to soils not yet at final grade and soils at final grade. The type of stabilization BMP used may differ depending on the length of time that the soil is to remain unworked.

Soil stabilization refers to BMPs that protect soil from the erosive forces of raindrop impact, flowing water, and wind. Applicable practices include vegetative establishment, mulching, plastic covering, and the early application of gravel base on areas to be paved. Soil stabilization measures should be appropriate for the time of year, site conditions, and estimated duration of use. Soil stockpiles must be stabilized or protected with sediment trapping measures to prevent soil loss, including loss to wind.

These requirements are especially important in areas adjacent to streams, wetlands, or other sensitive or critical areas.

Large Parcel ESC Requirement 2: Delineated Clearing and Easement Limits

In the field, clearing limits and/or any easements, setbacks, sensitive/critical areas and their buffers, trees, and drainage courses shall be marked.

Large Parcel ESC Requirement 3: Protection of Adjacent Properties

Properties adjacent to the project site shall be protected from sediment deposition.

Supplemental Guidelines. This may be accomplished by preserving a well-vegetated buffer strip around the lower perimeter of the land disturbance; by installing perimeter controls such as sediment barriers, filters or dikes, or sediment basins; or by using a combination of such measures.

Vegetated buffer strips may be used alone only where runoff in sheet flow is expected. Buffer strips should be at least 25 ft wide. If at any time the vegetated buffer strip alone is found to be ineffective in stopping sediment movement onto adjacent property, additional perimeter controls must be provided.

Large Parcel ESC Requirement 4: Timing and Stabilization of Sediment Trapping Measures

Sediment ponds and traps, perimeter dikes, sediment barriers, and other BMPs intended to trap sediment on site shall be constructed as a first step in grading. These BMPs shall be functional before land-disturbing activities take place. Earthen structures such as dams, dikes, and diversions shall be seeded and mulched according to the timing indicated in Large Parcel ESC Requirement 1.

Large Parcel ESC Requirement 5: Cut and Fill Slopes

Cut and fill slopes shall be designed and constructed in a manner that minimizes erosion. In addition, slopes shall be stabilized in accordance with Large Parcel ESC Requirement 1.

Supplemental Guidelines. Consideration should be given to the length and steepness of the slope, the soil type, upslope drainage area, ground-water conditions, and other applicable factors. Slopes that are found to be eroding excessively within 2 years of construction must be provided with additional slope stabilizing measures until the problem is corrected.

Large Parcel ESC Requirement 6: Controlling Offsite Erosion

Properties and waterways downstream from development sites shall be protected from erosion due to increases in the volume, velocity, and peak flow rate of stormwater runoff from the project site.

Large Parcel ESC Requirement 7: Stabilization of Temporary Conveyance Channels and Outlets

All temporary onsite conveyance channels shall be designed, constructed, and stabilized to prevent erosion from the expected velocity of flow from a 2-year, 24-hour

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frequency storm for the developed condition. Stabilization adequate to prevent erosion of outlets, adjacent streambanks, slopes, and downstream reaches shall be provided at the outlets of all conveyance systems.

Large Parcel ESC Requirement 8: Storm Drain Inlet Protection

All storm drain inlets made operable during construction shall be protected so that stormwater runoff shall not enter the conveyance system without first being filtered or otherwise treated to remove sediment.

Large Parcel ESC Requirement 9: Underground Utility Construction

The construction of underground utility lines is subject to the following criteria:

- Where feasible, no more than 500 ft of trench shall be opened at one time.
- Where consistent with safety and space considerations, excavated material shall be placed on the uphill side of trenches.
- Trench dewatering devices shall discharge into a sediment trap or sediment pond.

Large Parcel ESC Requirement 10: Construction Access Routes

Wherever construction vehicle access routes intersect paved roads, provisions must be made to minimize the transport of sediment (mud) onto the paved road. If sediment is transported onto a road surface, the roads shall be cleaned thoroughly at the end of each day. Sediment shall be removed from roads by shoveling or sweeping and shall be transported to a controlled sediment disposal area. Street washing shall be allowed only after sediment is removed in this manner.

Large Parcel ESC Requirement 11: Removal of Temporary BMPs

All temporary erosion and sediment control BMPs shall be removed within 30 days after final site stabilization is achieved or after the temporary BMPs are no longer needed. Trapped sediment shall be removed or stabilized on site. Disturbed soil areas resulting from removal shall be permanently stabilized.

Large Parcel ESC Requirement 12: Dewatering Construction Sites

Dewatering devices shall discharge into a sediment trap or sediment pond.

Large Parcel ESC Requirement 13: Control of Pollutants Other Than Sediment on Construction Sites

All pollutants other than sediment that occur on site during construction shall be handled and disposed of in a manner that does not cause contamination of stormwater.

Large Parcel ESC Requirement 14: Maintenance

All temporary and permanent erosion and sediment control BMPs shall be maintained and repaired as needed to ensure continued performance of their intended function. All maintenance and repair shall be conducted in accordance with an approved manual.

Large Parcel ESC Requirement 15: Financial Liability

Performance bonding or other appropriate financial instruments shall be required for all projects to ensure compliance with the approved ESC plan.

Minimum Requirement 2: Preservation of Natural Drainage Systems

Natural drainage patterns shall be maintained and discharges from the site shall occur at the natural location to the maximum extent practicable.

Supplemental Guidelines

Natural drainage systems provide many water quality benefits and should be preserved to the fullest extent possible. In addition to conveying and attenuating stormwater runoff, these systems are less erosive, provide ground-water recharge, and support important plant and wildlife resources. Effective use of the natural system can maintain environmental and aesthetic attributes of a site as well as be a cost-effective measure to convey stormwater runoff.

Creating new drainage patterns requires more site disturbance and can upset the stream dynamics of the drainage system, thus tending to increase erosion and sedimentation. Creating new discharge points can create significant streambank erosion problems because the receiving water body typically must adjust to the new flows. Newly created drainage patterns seldom, if ever, provide the multiple benefits of natural drainage systems. Where no conveyance system exists at the adjacent downstream property line and the discharge was previously unconcentrated flow or significantly lower concentrated flow, then measures must be taken to prevent downstream impacts. Necessary drainage easements may need to be obtained from downstream property owners.

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Minimum Requirement 3: Source Control of Pollution

Source control BMPs shall be applied to all projects to the maximum extent practicable. Source control BMPs shall be selected, designed, and maintained according to an approved manual.

An adopted and implemented basin plan (Minimum Requirement 9) may be used to develop source control requirements that are tailored to a specific basin; however, in all circumstances, source control BMPs shall be required for all sites.

Objective

The intention of source control BMPs is to prevent stormwater from coming in contact with pollutants. A cost-effective means of reducing pollutants in stormwater, source control BMPs should be a first consideration in all projects.

Minimum Requirement 4: Runoff Treatment BMPs

All projects shall provide treatment of stormwater. Treatment BMPs shall be sized to capture and treat the water quality design storm, defined as the 6-month, 24-hour return period storm. The first priority for treatment shall be to infiltrate as much as possible of the water quality design storm, if site conditions are appropriate and ground water quality will not be impaired. Direct discharge of untreated stormwater to ground water can cause serious pollution problems. All treatment BMPs shall be selected, designed, and maintained according to an approved manual.

Stormwater treatment BMPs shall not be built within a natural vegetated buffer, except for necessary conveyance as approved by the local government.

An adopted and implemented basin plan (Minimum Requirement 9) may be used to develop runoff treatment requirements that are tailored to a specific basin.

Supplemental Guidelines

The water quality design storm (the 6-month, 24-hour design storm, in this instance) is intended to capture more than 90 percent of annual runoff.

Infiltration can provide both treatment of stormwater, through the ability of certain soils to remove pollutants, and volume control of stormwater, by decreasing the amount of water that runs off, to surface water. Infiltration can be very effective at treating stormwater runoff, but soil conditions must be appropriate to achieve effective treatment while not affecting ground-water resources. Methods currently in use, such as direct discharge into dry wells, do not achieve adequate water quality treatment.

Minimum Requirement 5: Streambank Erosion Control

The requirement below applies only to situations where stormwater runoff is discharged directly or indirectly to a stream, and must be met in addition to the requirements in Minimum Requirement 4, Runoff Treatment BMPs.

Stormwater discharges to streams shall control streambank erosion by limiting the peak rate of runoff from individual development sites to 50 percent of the existing condition, 2-year, 24-hour design storm while maintaining the existing condition peak runoff rate for the 10-year, 24-hour and 100-year, 24-hour design storms. As the first priority, streambank erosion control BMPs shall utilize infiltration to the fullest extent practicable, only if site conditions are appropriate and ground-water quality is protected. Streambank erosion control BMPs shall be selected, designed, and maintained according to an approved manual.

Stormwater treatment BMPs shall not be built within a natural vegetated buffer, except for necessary conveyance as approved by the local government.

An adopted and implemented basin plan (Minimum Requirement 9) may be used to develop streambank erosion control requirements that are tailored to a specific basin.

Supplemental Guidelines

This requirement is intended to reduce the frequency and magnitude of bankfull flow conditions, which are highly erosive and increase dramatically as a result of development. Conventional flood detention practices do not adequately control streambank erosion because only the peak rate of flow is decreased, not the frequency nor duration of bankfull conditions.

Reduction of flows through infiltration decreases streambank erosion and helps to maintain base flow throughout the summer months. Infiltration should only be used, however, where ground-water quality is not threatened by such discharges. The use of an artificial treatment system, such as an aquatard, should be considered in areas with highly permeable soils. Treatment of the water quality design storm must be accomplished before discharge to these soils. If highly permeable soils are present, they should be utilized for streambank erosion control by infiltrating flows greater than the water quality design storm.

Minimum Requirement 6: Wetlands

The requirements below apply only to situations where stormwater discharges directly or indirectly through a conveyance system into a wetland, and must be met in addition to the requirements in Minimum Requirement 4, Runoff Treatment BMPs:

- Stormwater discharges to wetlands must be controlled and treated to the extent necessary to meet state water quality standards.
- Discharges to wetlands shall maintain the hydroperiod and flows of existing site conditions to the extent necessary to protect the characteristic uses of the wetland. Prior to discharging to a wetland, alternative discharge locations shall be evaluated, and natural water storage and infiltration opportunities outside the wetland shall be maximized.
- Created wetlands that are intended to mitigate the loss of wetland acreage, function, and value shall not be designed to also treat stormwater.
- For constructed wetlands to be considered treatment systems, they must be constructed on sites that are not wetlands managed for stormwater treatment. If these systems are not managed and maintained in accordance with an approved manual for a period exceeding 3 years, these systems may no longer be considered constructed wetlands.
- Stormwater treatment BMPs shall not be built within a natural vegetated buffer, except for necessary conveyance as approved by the local government.

An adopted and implemented basin plan (Minimum Requirement 9) may be used to develop requirements for wetlands that are tailored to a specific basin.

Objective

This requirement seeks to ensure that wetlands receive the same level of protection as any other state waters. Wetlands are extremely important natural resources that provide multiple stormwater benefits, including ground-water recharge, flood control, and streambank erosion protection. Development can readily affect wetlands unless careful planning and management are conducted. Stormwater discharges from urban development due to pollutants in the runoff and also due to disruption of natural hydrologic functioning of the wetland system severely degrade wetlands. Changes in water levels and the duration of inundations are of particular concern.

Minimum Requirement 7: Water Quality Sensitive Areas

Where local governments determine that the minimum requirements do not provide adequate protection of water quality sensitive areas, either on site or within the basin, more stringent controls shall be required to protect water quality.

Stormwater treatment BMPs shall not be built within a natural vegetated buffer, except for necessary conveyance as approved by the local government.

An adopted and implemented basin plan (Minimum Requirement 9) may be used to develop requirements for water quality sensitive areas that are tailored to a specific basin.

Supplemental Guidelines

Water quality sensitive areas are areas that are sensitive to a change in water quality, including but not limited to lakes, ground-water management areas, ground-water special protection areas, sole source aquifers, critical aquifer recharge areas, well head protection areas, closed depressions, fish spawning and rearing habitat, wildlife habitat, and shellfish protection areas. Areas that can cause water quality problems, such as steep or unstable slopes or erosive stream banks, should also be included. Water quality sensitive areas may be identified through jurisdiction-wide inventories, watershed planning processes, local drainage basin planning, and/or on a site-by-site basis.

Minimum Requirement 8: Offsite Analysis and Mitigation

All development projects shall conduct an analysis of offsite water quality impacts resulting from the project and shall mitigate these impacts. The analysis shall extend a minimum of one-fourth of a mile downstream from the project. The existing or potential impacts to be evaluated and mitigated shall include, but not be limited to:

- Excessive sedimentation.
- Streambank erosion.
- Discharges to ground-water contributing or recharge zones.
- Violations of water quality standards.
- Spills and discharges of priority pollutants.

Minimum Requirement 9: Basin Planning

Adopted and implemented watershed-based basin plans may be used to modify any or all of the Minimum Requirements provided that the level of protection for surface or ground water achieved by the basin plan will equal or exceed that which would be achieved by the Minimum Requirements in the absence of a basin plan. Basin plans shall evaluate and include, as necessary, retrofitting of BMPs for existing development and/or redevelopment in order to achieve watershed-wide pollutant reduction goals. Standards developed from basin plans shall not modify any of the above requirements until the basin plan is formally adopted and fully implemented by local government. Basin plans shall be developed according to an approved manual.

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Supplemental Guidelines

While Minimum Requirements 3 through 7 establish protection standards for individual sites, they do not evaluate the overall pollution impacts and protection opportunities that could exist at the watershed level. For a basin plan to serve as a means of modifying the Minimum Requirements, it must be formally adopted by all jurisdictions that have responsibilities under the basin plan, and construction and regulations called for by the plan must be complete; this is what is meant by an "adopted and implemented" basin plan.

Basin planning provides a mechanism by which the onsite standards can be evaluated and refined based on an analysis of an entire watershed. Basin plans are especially well suited to develop control strategies to address impacts from future development and to correct specific problems whose sources are known or suspected. Basin plans can be effective at addressing both long-term cumulative impacts of pollutant loads and short-term acute impacts of pollutant concentrations, as well as hydrologic impacts to streams and wetlands.

In general, the standards established by basin plans will be site-specific but may be augmented with regional solutions for source control (Minimum Requirement 2) and streambank erosion control (Minimum Requirement 4).

Minimum Requirement 10: Operation and Maintenance

An operation and maintenance schedule shall be provided for all proposed stormwater facilities and BMPs, and the party (or parties) responsible for maintenance and operation shall be identified.

Minimum Requirement 11: Financial Liability

Performance bonding or other appropriate financial instruments shall be required for all projects to ensure compliance with these requirements.

Exceptions

Exceptions to Minimum Requirements 1 through 11 may be granted prior to permit approval and construction. An exception may be granted following a public hearing, provided that a written finding of fact is prepared that addresses the following:

- The exception provides equivalent environmental protection and is in the public interest, and the objectives of safety, function, environmental protection and facility maintenance, based upon sound engineering, are fully met.
- Special physical circumstances or conditions affecting the property are such that strict application of these provisions would deprive the applicant of all reasonable use of the parcel of land in question, and every effort to find creative ways to meet the intent of the minimum standards has been made.
- The granting of the exception will not be detrimental to the public health and welfare, nor injurious to other properties in the vicinity and/or downstream nor to the quality of state waters.
- The exception is the least possible exception that could be granted to comply with the intent of the Minimum Requirements.

Supplemental Guidelines

The Plan Approval Authority is encouraged to impose additional or more stringent criteria as appropriate for its area. Additionally, criteria that may be inappropriate or too restrictive for an area may be modified through basin planning (Minimum Requirement 9). Modification of any of the Minimum Requirements that are deemed inappropriate for the site may be done by granting an exception.

The exception procedure is an important element of the plan review and enforcement programs. It is intended to maintain a flexible working relationship between local officials and applicants. Plan Approval Authorities should consider these requests judiciously, keeping in mind both the need of the applicant to maximize cost-effectiveness and the need to protect offsite properties and resources from damage.

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Ordinances for the Protection of Surface Water Bodies: Septic Systems, Docks and Other Structures, Wildlife Corridors, Sensitive Aquatic Habitats, Vegetative Buffer Zones, and Bank/Shoreline Stabilization

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Introduction

Local government can substantially protect surface water bodies by enacting and enforcing appropriate ordinances. As part of its Surface Water Improvement and Management (SWIM) Program, the Southwest Florida Water Management District (SWFWMD) in consultation with advisory committees developed a list of seven issues that needed ordinance models. As a result, the SWFWMD outlined and funded a project for model ordinance development. The scope of the project included preparing model ordinance language to address seven specific issues, drafting individual papers addressing the ecological and legal significance of each issue, and developing a decision model for local government planners to use in determining the applicability or need for ordinance adoption. The private consulting firm Henigar and Ray, Inc., of Crystal River, Florida, developed under contract the model ordinances, issue papers, and decision model.

This paper highlights the results of and recommendations for ordinances addressing six of the seven project issues:

- Placement and maintenance of individual septic systems
- Regulation of docks and other appurtenance structures
- Establishment of wildlife corridors
- Protection of environmentally sensitive habitats
- Vegetative buffer zones
- Erosion control and bank stabilization

The seventh issue, "Stormwater Management and Treatment," is covered in other papers in this publication.

Because any ordinance is likely to face challenges, often from a number of opposing camps, issue papers were drafted to support an ecologically and legally defensible argument. While legal information contained in the detailed issue papers focuses on the Florida experience, the ecological arguments are valid over a much larger geographic area.

It is not possible to consider in detail the products of this project; however, this paper attempts to transfer the flavor and scope of information available on each of the issues. The paper provides an overview on the need/justification for a particular ordinance, mentions some of the technical issues that should be considered, and recommends necessary components of a viable ordinance. (The U.S. Environmental Protection Agency [EPA] is currently condensing the body of this work [1].)

Project History

The State of Florida passed the SWIM Act in 1987 establishing a program similar to the Clean Lakes Program but encompassing all surface waters (i.e., estuaries, rivers, springs, lakes, and swamps [2]). The Act mandated that each of the state's five water management districts develop a list of priority water bodies and begin developing management plans for each of them. Once a management plan received approval, monies from the SWIM Trust Fund could help implement projects outlined in the specific management plan for each water body.

During plan development for a number of water bodies, several advisory committees suggested that drafting and enacting ordinances at the local government level (municipality or county), particularly with regard to land development issues, could do much to protect water bodies from degradation. Such ordinances would be proactive in that they would avoid or minimize anticipated deleterious impacts. SWIM staff at the SWFWMD in consultation with various members of advisory committees identified the seven issues that required model ordinances.

Although passage of the SWIM Act gave the state's water management districts no new regulatory authority, the SWFWMD felt it was appropriate to develop model ordinances for consideration by local governments. Because enactment of ordinances that affect development are likely to invoke challenges, SWFWMD deemed it necessary not only to develop model ordinance language but also to develop "issue papers" detailing the ecological justifications for a given ordinance. Issue papers would also review similar ordinances already enacted in Florida and elsewhere (i.e., establish precedence) and consider the legality of enacting a particular ordinance. Henigar and Ray, Inc., employed the appropriate technical and legal authorities to draft the issue papers and ordinance language. The project resulted in a series of seven issue papers, five model ordinances, a decision model (planning document), and a report summarizing "The Law of Surface Water Management in Florida."

Placement and Maintenance of Individual Septic Systems (3)

Almost invariably when potential sources of pollutants to a water body are discussed, the topic of septic tanks arises. Many people assume that their septic systems are operating effectively simply because failure is not obvious (i.e., blocked plumbing, standing water over the drain field). As Brown (4) has pointed out, a system's technical failure (the inability to effectively process the waste) goes unnoticed; as long as the homeowner is not inconvenienced, the system usually remains unrepaired.

Septic systems can fail for two basic reasons: poor design or poor maintenance. Design includes not only the tank and drain field layout, but also the soils and hydrologic character of the site. Maintenance implies a periodic check and cleaning of the tank and possibly the drain field, and a consideration of the substances discharged to the system.

Effective treatment in the drain field requires soils of the proper permeability. For example, soils that are too permeable permit the tank effluent to travel too rapidly away from the drain field and do not allow for proper biologic treatment in the biomat. Alternately, impermeable soils become clogged with effluent, causing lateral or upward seepage. In the latter case, the homeowner may be inconvenienced, but in the former the owner may assume everything is working fine.

Soil absorption fields must lie above the surficial water table. If not, the system will cease to function effectively. An unsaturated zone ensures a desirable effluent velocity away from the drain field and good aeration in the zone where aerobic decomposition should occur. A typical onsite sewage disposal system (OSDS) ordinance might require, for example, a minimum of at least 24 in. between the bottom of the absorption (drain) field and the seasonal high water table. Virtually every Health and Rehabilitative Services (HRS) worker in Florida who is familiar with OSDS permitting can cite at least one example of a drain field totally submersed underwater during Florida's summer wet season.

Design, siting, and construction of a proper OSDS do not ensure proper long-term operation. Maintenance is absolutely necessary. The typical OSDS owner is often unknowledgeable regarding proper OSDS maintenance. In fact, many owners are unaware that septic tanks should be pumped out periodically to remove accumulated septage. Ayers and Associates (5) reported that it is "relatively common for homeowners to have never serviced the septic tank during their occupancy in the home."

Water conservation within the home can reduce waste flow and attendant pollutant load. This extends the life of the drain field, reduces system failures, and saves money by increasing the time between needed pumpouts. Low-flow toilets and shower heads and "graywater" reuse are examples of water conservation measures that can reduce potable water consumption. Siegrist (6) reported that eliminating the use of garbage disposals in connection with OSDSs could decrease the total suspended solids load by as much as 37 percent.

A host of findings in the literature support the development of ordinances to regulate septic systems. Interestingly, Cooper and Rezek (7) found that most of the heavy metals in the typical OSDS effluent stream originated from pigments used in cosmetics. In addition, EPA (8) found that compounds from septic tank cleaning solvents (i.e., methylene chloride and trichloroethane) actually hinder septic tank operation by killing bacteria that promote decomposition. Bicki et al. (9) concluded that nitrate-nitrogen contamination of ground water by OSDSs is a national problem and that high concentrations in many areas pose a health risk to infants. Yates and Yates (10) documented the extreme distances that certain microorganisms can move and remain viable. Certain viruses, because of their small size and long survival times, were found as far as a mile from their source in karst areas, an especially significant subsurface geologic feature in Florida.

Certain authors have also correlated septic tank density (allowable units per acre) with ground-water contamination (10, 11). Recommended acceptable densities vary greatly, with densities being a function of soils, depth to water table, and distance from surface water bodies.

Any entity considering a local ordinance to regulate septic tanks can, based on the literature, consider several options that might be more restrictive (protective) than existing regulations. These can relate to soils, depth to ground water, densities, and distance to surface water. These options may take the form of pumpout and inspection requirements, alternative septic systems, prohibitions (e.g., no garbage disposals), and even "moratoriums" in already contaminated or totally unsuitable areas.

Regulation of Docks and Appurtenance Structures (12)

Czerwinski and McPherson (12) thoroughly defined the various classes of docks and marinas (e.g., private single family, multislip residential, and commercial marinas). The intended use and size of a facility are important from both an impact and a regulatory standpoint, but space does not allow us to consider these in detail; the interested reader should consult the original document or the condensation being prepared by Simpson (1). To be effective, an ordinance must clearly define what is to be regulated. It is advantageous to include definitions within the body of the ordinance to avoid ambiguity that could seriously limit ordinance effectiveness.

The potential need to adopt an ordinance on a local level may be determined by considering projected increases in the number of registered boats in an area. As an example, in Florida there are approximately 48 boats per thousand residents. This reflects a 300-percent increase in the number of registered boats since 1964. Florida ranks fourth nationally in the number of registered boats, and the Florida Department of Natural Resources has projected a 48-percent increase to 712,349 boats by the year 2005 (13).

Environmental impacts associated with docks and appurtenance structures (e.g., boathouses, gazebos, and diving platforms) can be direct or indirect. Direct impacts relate to areas adjacent to and covered by these structures, and would typically include the transitional zone between the upland, wetland, and open water. The "littoral zones provide many valuable ecological functions, including flood storage, erosion and sedimentation control, filtration of surface water runoff, and essential habitat for flora and fauna" (12). Indirect effects, which are due to the attendant use of these structures, include effects attributable to outboard exhausts, fuel spills, sanitation facilities, and prop scour.

When regulating these structures, the actual construction materials should be considered. The list is long and varied. Wood is probably the most widely used material, particularly for single-family facilities. Whereas untreated wood is no match for the aquatic environment, chemically treated wood may last for 15 to 20 years without replacement. Chemicals used in treatment processes include ammoniacal copper arsenate (ACA), chromated copper arsenate (CCA), creosote-coal tar (CCT), acid copper chromate (ACC), chromated zinc chloride (CZC), fluorochrome arsenate phenol (FCAP), pentachlorophenol (which provides a clean, paintable surface), and creosote-petroleum solutions (14). "Although the pertinent regulatory agencies . . . test and register these substances as generally safe for use," Czerwinski and McPherson (12) concluded that "research conducted in preparation of this paper revealed little data or information on the biologic effects of wood preservatives on (nontarget) aquatic and marine organisms."

Other construction materials include steel, aluminum, reinforced concrete, fiberglass, and polyvinyl chloride (PVC). Styrofoam (expanded bead foam polystyrene) is still common in floating docks, although it may not be the most suitable floatation material available today. Unfortunately, bead foam polystyrene tends to break up easily, has a long life, and may be ingested by and be harmful to wildlife. In addition, chlorofluorocarbons are used in the manufacturing process. Safer but more expensive alternatives such as petroleum-resistant polystyrene and sealed solid (as opposed to extruded) foam are available.

Docks and appurtenance structures should not interfere with navigation. In Florida, for example, a dock is not considered a navigation hazard if it does not exceed 20 to 25 percent of the distance across the water body, is limited to the minimum distance necessary to provide reasonable access to navigable waters (which is generally defined to be approximately 4 ft below mean or ordinary low water), and does not infringe upon the main navigational channel or upon the riparian rights of adjacent property owners. For safety reasons, docks may be required to be fitted with navigational aids (e.g., lights or reflectors).

Turbidity and sedimentation problems can result from construction activities. Such impacts, however, are likely to be small compared with other activities unless the construction requires a large area and considerable time, as might be the case with commercial marinas. Florida water quality regulations, however, do not allow turbidity in excess of 29 nephelometric turbidity units above background in any case, and regulatory agencies may require the installation of turbidity screens or other protective barriers. Turbidity problems more likely arise indirectly from effects such as prop scour as boats make use of docking facilities.

Shading of the water column and the littoral shelf can also affect the environment. Shading may not be a problem in areas where a tree canopy already exists, but obviously it can affect areas previously unshaded. Czerwinski and McPherson (12), however, cite no scientific studies on the direct effects of shading by docks or appurtenance structures. Employing some simple siting and design criteria can avoid or at least lessen any potential detrimental effects. Suggestions include:

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- Siting in areas already shaded or in areas low in light-dependent resources requiring protection.
- Elevating structures in areas high in light-dependent resources (e.g., grass beds).
- Substantially elevating accessways, boardwalks, or other appurtenance structures that are not as water dependent.
- Spacing of planking to allow sunlight to penetrate (e.g., leaving 1-in. gaps between boards).

Another obvious effect is that installation of docks and attendant structures directly alters the shoreline. In Florida, for example, a lakefront resident desiring access may remove a 25-ft wide band of vegetation to open water without a permit and without revegetating the area. These areas frequently suffer clearing in association with docks and similar structures. Depending on lot size, then, it is conceivable that residents may remove as much as half of the shoreline vegetation for access without needing a permit.

Fortunately regulatory agencies may have the ability to consider the cumulative impacts of projects in deciding whether to issue a permit. Florida's Department of Environmental Regulation, by virtue of its "dredge and fill" responsibilities, requires a permit to construct a dock or other structures that affect wetlands. "Therefore, these agencies have the authority to review, suggest alternatives ... or deny projects based upon the 'foreseeable,' future cumulative impacts. However, the ability to deny a project based upon future, anticipated cumulative impacts can be subjective and is cautiously exercised due to the potential for legal challenge. This is most likely to be a supportable factor in project review when specific endangered species concerns are at issue" (12).

Of course, not all shoreline changes are detrimental. For example, a dock could expose previously densely vegetated areas, thus creating open sandy areas that can provide valuable fish bedding areas. Docks and related structures can also provide cover or serve as substrate for aquatic organisms.

Most indirect environmental effects ascribable to docks and appurtenance structures result from recreational boating activity. These include potential effects from outboard motor exhaust contaminants, prop dredging, sanitation devices, fuel and oil spills, and antifouling boat paints. Rather than consider most boating impacts in detail here, the reader can refer to the review by Wagner (15).

Antifouling paints, which prevent fouling of hulls by marine organisms (e.g., barnacles), pose an unusual problem. Traditional coatings contain lead, copper, and organotin compounds. For antifouling, the organotins are especially effective because they continuously release active ingredients into the water. One of the organotins, tributyltin (TBT), has gained recent notoriety. EPA, due to the results of documented acute and chronic effects, has proposed maximum concentrations of 26 and 10 parts per trillion in fresh and marine water, respectively, for the protection of fish and other aquatic organisms. They have further proposed restricting sales of TBT to certified commercial pesticide applicators for use only on vessels greater than 65 ft in length.

The concepts of cumulative impacts and carrying capacity are important considerations. They are, however, difficult to implement with respect to docks and other water-dependent structures. Czerwinski and McPherson (12) did not cite studies that defined how one might set scientifically defensible limits. This is clearly an area needing research. Although often discussed and debated, regulation is difficult on this premise due to the lack of quantifiable data.

Docks and water-dependent structures should be located so as to minimize adverse environmental impacts. Where possible, authorities should encourage multislip facilities over the use of many individual docks. Approval of docks should include criteria for preserving a portion of the remaining unaffected shoreline, such as conservation easements or shoreline buffers. Another helpful measure may be to consider construction of boat ramps in lieu of docks; a careful analysis, however, is necessary to ensure consideration of increases in boat traffic and of the need for appropriate provisions to limit ramp usage.

The Need for, Rationale for, and Implementation of Wildlife Dispersal Corridors (16)

The SWIM Act was careful to stress the state's desire to restore or preserve the natural systems associated with its surface water bodies as well as its water quality. There is a growing awareness among resource managers that preserving fauna and flora involves strategies that stretch beyond watershed and governmental boundaries. The need to implement a system of faunal corridors may be the hardest issue to grasp in this paper, and it is doubtful that the authors can do more than introduce the topic. In fact, to a resource manager with a background in water-related issues, the issue paper developed by Harris (16) may appear exhaustive and rhetorical and is almost certain to pose unfamiliar questions and problems.

Model ordinance language proposed with regard to this topic (i.e., faunal corridors) was unlike the others developed. Accordingly, we have referred to the work as an "article" rather than an ordinance. The proposed article

> serves only to provide a means by which the boundaries and natural amenities of a WCSD [Wildlife Corridor Special District], as well as nonnatural

characteristics and associated implications, can be identified. Once the WCSD has been identified, and a strategy for its protection and management developed, an ordinance is required to actually create the WCSD. Due to the many site-specific characteristics involved in defining the areal extent, physical characteristics and management implications of the WCSD, such an ordinance is impossible to develop in a "generic" form that would be applicable to all jurisdictions and geographic areas in which the ordinance potentially would be used. This Article does, however, provide general guidelines for the creation of a WCSD, while also providing a method by which virtually all information needed for a WCSD-creation ordinance can be collected.

Harris (16) suggested that it is not possible to appreciate the need for implementing a system for faunal movement corridors without first comprehending three major issues:

"1. Throughout most of North American history, humans and their developments have occurred as localized entities in an expansive and interconnected matrix of undeveloped natural ecosystems; now, it is the natural systems that occur as localized entities in a matrix of human development.

"2. The second issue is the current biological diversity crisis. Without a keen awareness of the breadth of the dimensions and rapidity at which biological diversity (biodiversity) is currently being eroded there can be no grasp of the gravity of the remedial actions that must be taken.

"3. The third critical issue concerns the need of plants and animals to move; without carefully weighing the value of plant and animal movement corridors against other alternative conservation actions it is not possible to achieve balance and perspective in approaching these concerns."

Harris (16) makes a semantical distinction between the terms "wildlife" and "faunal," with faunal relating specifically to native animal species. Although it is important to appreciate how others may apply these terms, this paper applies them more or less interchangeably.

The need for implementing a system of faunal corridors is recent. Depending on the degree of development in an area, the need becomes more pressing in some areas than others. The need appears great in Florida. Historically, human developments have occurred as islands in a matrix of natural ecological communities; now, however, the pattern has changed, with unaltered natural communities occurring as islands in a predominately human-altered environment.

As noted by Harris (16), "a confusing paradox to many is the fact that habitat fragmentation may enhance local wildlife diversity while simultaneously reducing native biotic diversity at a somewhat larger scale." Harris explains this paradox is due to the action of the following mechanisms:

- Populations lose genetic integrity due to being sequestered within patches (i.e., islands).
- "Forest-interior" and "area-sensitive" species that cannot exist within small habitat patches are lost.
- Weedy species that are characteristic of disturbed environments increase in abundance.
- Important ecological processes are disrupted.

Geographic separation of populations and gene pools can, over geologic time, lead to new species. Spatial separation, however, which creates small isolated populations preventing gene flow, can lead to elimination of populations and even extinction of species. As an example, Harris (16) cites the following statistics on the degree of inbreeding depression that has already occurred in isolated populations of the Florida panther:

- Of all the Florida panthers known to exist in the wild today, less than a dozen are reproductively unrelated.
- The percentage of infertile spermatozoa in all male Florida panthers examined in recent years exceeds 90 percent.
- Of all the male Florida panthers examined, only about 50 percent have two distended testicles, and "it remains a matter of speculation if or when the highly inbred males might exhibit bilateral cryptorchidism and be unable to reproduce at all."

Roads are a significant fragmenting force because, unlike the passive fragmentation caused by areas such as farm fields, roads possess an active mortality-causing force—the associated traffic. Lalo (17) has estimated that nationally trucks and automobiles kill as many as 100 million vertebrates annually. Over 146,000 deer were killed on U.S. highways in 1974 (18). Adams and Geis (19) and Voorhees and Cassel (20) present statistics showing that within the contiguous 48 states and within individual states, the amount of land set aside in the form of national parks, wildlife refuges, and game management areas is smaller than the land that roads and rail right-of-ways occupy. Vehicles, including boats, represent one of the most significant sources of mortality for all of Florida's large threatened, rare, and endangered vertebrates. These include the panther, key deer, black bear, eagle, crocodile, and manatee. Data cited by Harris (16) even suggest that the number of road kills increases in direct proportion to vehicle speed.

Roads create barriers in several ways:

- They alter light, wind, temperature, humidity, evaporation rates, and noise level as they create a different microclimate in and near the right-of-ways.
- Exhaust fumes cause avoidance by some species, and heavy metals accumulate in those that occur adjacent to roadways (21).
- Pesticides used to maintain right-of-ways affect non-target plants and animals as well.

Right-of-ways have led to the creation of a different type of ecological community. Harris (16) cites numerous examples of opportunistic predators that "run roadsides" in search of prey.

Over the last 20 years, there has been an increasing realization that habitat fragments, even relatively large fragments, are not adequate protection for many species; if these species are to be protected, corridors must connect these habitat fragments. Simple green belts are not sufficient because corridors of non-native habitat welcome "weedy" species. Interconnecting corridors must be consistent with the habitats they are connecting to avoid "edge effects"; the wrong types of corridors could conceivably hasten the spread of exotic or weedy species. Currently in Florida, considerable funds are being spent to "Save Our Rivers" and protect the water quality of streams. Careful consideration and planning could ensure that these programs accomplish a dual function by protecting our biological diversity as well. As Harris (16) states, "When sufficiently wide, streamside management zones serve as critically important habitat for many rare and endangered native species. But unless the streamside zones connect larger tracts of habitat or protected areas they may function simply as long narrow fragments of habitat."

Corridors are necessary to keep small fragmented populations from being expatriated, to preserve biodiversity, and ultimately to allow populations to adapt to major climatic and geologic changes. Because of the geographic scope involved, corridors are an issue that will require cooperation and coordination between local, regional, and state governments and agencies.

Protecting Environmentally Sensitive Aquatic Habitats (22)

Aquatic habitats include lakes, rivers, streams, estuaries and bays, springs, and wetlands. These habitat areas are typically subject to a variety of differing agency jurisdictions. Quite commonly, though, ordinances developed at the local level protect wetlands (including marshes, swamps, bogs, ponds, and wet prairies). Local wetland resource areas promote the local quality of life as well as the quality of the environment. The advantages include hydrologic functions (flood control, runoff velocity control, ground-water and surface-water recharge), water quality benefits (erosion and sedimentation control and removal of pollutants such as nutrients and heavy metals), and wildlife habitat benefits (food source, breeding, nesting, spawning, and wildlife protection) (23).

When wetlands are allowed to remain in their natural state, they maximize multiple benefits and achieve ecological stability. Anthropogenic changes, however, can affect the natural function and resultant benefits of the wetland, such as change the quality of the water entering the wetland, the hydrologic cycle of the wetland, and the physical structure of the wetland (24). Several sources can affect the quality of water entering the wetland, including point and nonpoint pollution, nutrient enrichment, and sedimentation (25). The hydrologic cycle of the wetland can be disrupted by well pumping, channelization, sedimentation, upstream diversions, increased surface flows, and decreased ground-water base flows. In addition, filling, dredging, and channelization can affect the physical structure of the wetland (26).

By identifying the sources of impacts to these valuable areas, one can begin to develop the necessary elements of a local ordinance that would help to restore and maintain ecological integrity. An ordinance should address the wetland system from a holistic perspective, not as isolated areas. Some recommendations for a wetlands protection ordinance include the following:

- Consider individual and cumulative impacts on aquatic habitats from anthropogenic alterations. Environmentally sensitive systems can degrade from the accumulation effect of many individual human activities (27).
- Develop specific performance standards. Performance standards will allow local governments to use environmentally sensitive lands in a manner that minimizes negative impacts (28).
- Develop financial incentives that encourage local property owners to protect aquatic habitats. If environmentally sensitive areas are to be protected through long-term management of private lands, land owners must be compensated accordingly (29).
- Develop mechanisms by which local government facilitates the property owner's efforts to protect aquatic habitats. If proper channels exist for conservation easements and reduced tax assessments, voluntary efforts to protect environmentally sensitive areas may increase (29).
- Coordinate state and federal permitting processes. Coordination at the local level will ensure compliance with all requirements that serve to protect, enhance, or restore environmentally sensitive areas.

- Identify state and federally exempted activities that contribute to the degradation of aquatic habitat, and regulate those activities locally.
- Develop an appropriate definition of aquatic habitat. An adopted definition will define the areas of jurisdiction for local, state, and federal regulations; few definitions, however, adequately describe all environmentally sensitive areas (29). Local definitions can provide greater protection for those areas not adequately protected by state or federal regulations.
- Develop a long-term plan for the protection of aquatic resource areas, and develop management objectives that will provide the desired level of protection.
- Provide for local enforcement. Taking responsibility for local environmentally sensitive areas ensures maximum protection.

Along with the above requirements, additional elements can be considered:

- Create a mechanism to develop site-specific upland buffer zones.
- Create a mechanism to implement fixed-distance upland buffer zones.
- Create a mechanism to implement no construction/no disturbance zones.
- Allow for restoration of disturbed areas at ratios greater than 1:1.
- Incorporate endangered, threatened, and special-concern species into upland buffer zone consideration.
- Encourage the use of creative site planning to preserve and protect sensitive aquatic habitats.

Vegetative Buffer Zones (30)

A transition zone is an area between a water body (e.g., wetland, lake, river) and upland areas. The area of land that a transition zone occupies varies and is greatly influenced by topography. In areas of major topographic changes, the transition zone tends to be small (1 to 2 ft). In areas where topographic changes are slight, the transition zone tends to increase in size substantially (30 to 50 ft).

Vegetative transition zones provide multiple benefits to the surrounding area. First, they are ecologically complex, as the assemblage of plants and animals can be characteristic of the nearby water body as well as the upland area. Within these areas, substantial ecological diversity can occur (31-33). Second, transition zones help maintain a balanced hydrologic cycle by retarding the flow of surface runoff volumes through absorption and by allowing for infiltration into the ground water. Vegetative transition zones also play a major role in the maintenance of the quality of the nearby water resource. Processes such as deposition, absorption, and transformation help remove pollutants such as sediment, phosphorus, nitrogen, and heavy metals from overland flows. Also, when vegetation is present, it tends to reduce the temperature of storm flows, thereby maintaining water body temperatures (34, 35).

When activities related to urbanization disturb vegetative transition zones, the benefits realized can be diminished or even lost. With the removal of the complex ecological area, habitat values decrease, resulting in a loss of species diversity and richness (36, 37). Urbanization activities can also disrupt the hydrologic balance of the nearby water bodies. Typically, surface water hydrology changes to reflect the increase in the volume and rate of surface flows. This causes increased streambank erosion adjacent to the disturbed area as well as downstream. Streambank erosion reduces water clarity, destroys benthic habitat, interferes with aquatic plant transpiration processes, and reduces stream storage capacity. Removal of vegetative transition zones affects ground-water flow by reducing the overall infiltration rate of surface water to ground water. The decrease in surface water recharge can affect the hydroperiod of nearby wetlands, which are heavily dependant on ground-water discharge, and nearby stream base flows. Removing transition zones also affects water quality by allowing pollutants to enter the watercourse untreated. One of the most obvious water quality impacts is the increase in sedimentation to the receiving waters (30).

Because vegetative transition areas provide such valuable ecological benefits, protection measures need to be implemented to ensure their preservation. The size of these areas, however, tends to be site specific and requires individualized management approaches. Therefore, local ordinances are the most effective and adaptive tool to facilitate preservation.

In developing an ordinance for vegetative transition zones, efforts should maximize the benefits to wildlife, habitat, hydrology, and water quality. Methodologies have been developed to "engineer" vegetative transition areas in a supportable, defensible manner. In general, the recommendations for vegetative transition areas are:

- Minimize disturbances of vegetative transition zone when possible through the use of site fingerprinting. Limiting the extent of disturbance will greatly reduce the potential of negative water quality impacts.
- Develop local requirements for "no-build" and "no-disturbance" zones. Protective buffer zones can be implemented in such a way to allow for construction while minimizing the impact of development.
- Encourage alternative land use planning that can protect vegetative transition areas. Planning techniques

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are valuable tools that can afford long-term protection and management of vegetative areas.

- Develop criteria for vegetative transition areas based on defensible procedures. This is an important step that will implement vegetation protection measures in a nonbiased manner. Based on identifiable and scientific procedures, arguments can be made for successful long-term implementation.

Examples of recommendations for vegetative transition follow:

- Area size of 30 to 550 ft may be necessary when ground-water drawdown is an issue (using surficial aquifer data and structure drawdown calculations).
- Area size of 75 ft for coarse sand, 200 ft for fine sand, and 450 ft for silty soils should be considered to protect water quality (utilizing Technical Release [TR] 55, local soils data, and soil deposition formula).
- Area size of 322 ft for fresh and saltwater marshes, 550 ft for hardwood swamps, and 732 ft for bordering sandhill communities to protect wildlife habitat (based on indicator species and 50 percent other present species).

Providing for Erosion Control and Bank/Shoreline Stabilization (38)

Banks and shorelines are those areas that occur along streams, lakes, ponds, rivers, wetlands, and estuaries where water meets land. The topography of banks and shorelines can range from very steep to very gradual. These areas can be considered a subset of the vegetative transition areas.

Banks and shorelines provide many benefits to the environment, including prevention of erosion, storage and attenuation of runoff, and provision of valuable habitat for fish and wildlife (39). Stabilization, which prevents erosion, occurs below the water line via root systems, as well as above the water line through absorption of raindrop energy and overland flow velocity. Both physical characteristics and stability of the bank and/or shoreline accomplish the storage and attenuation of runoff. The provision of habitat is also accomplished through physical stability and the unique physical characteristics of the bank and/or shoreline. Often, ecological zones will be apparent and consistent with the shoreline, and provide special habitat for various plant and animal species (29).

As water bodies continue to support human activities both on and near the water, impacts will occur to the bank and shoreline area. Flows of increased water movement from activities such as boating can cause erosion, damage to vegetation, and increased turbidity in aquatic habitat areas (40). Urbanization commonly results in a change in the surface water hydrology, increasing storm volumes and rates of discharge. This movement of storm flows through water channels tends to erode and undercut banks and shorelines over time. The resultant erosion reduces water quality through increased turbidity as well as destruction of existing bank and shoreline habitat and smothering of downstream habitat areas (29, 41).

Bank and shoreline stabilization is an important element necessary to protect multiple ecological benefits. Ordinances that recognize this can be developed to address local management needs. Bank and shoreline stabilization typically should include an array of approaches as outlined below:

- Promote nonstructural methods such as revegetation and preservation of vegetation because they are an inexpensive and beneficial approach. Studies have shown that nonstructural practices can provide multiple benefits to bank and shoreline areas where implemented. Also, construction costs are substantially lower than traditional structural methods (41, 42).
- Limit use of structural methods to when erosive forces are significant. Public perceptions and aesthetics have led to the construction of structural methods in areas where nonstructural methods could have worked. Structural methods should be the last option when addressing bank or shoreline erosion.
- Develop an appropriate definition for banks and shorelines. Good definitions provide jurisdictional boundaries to those attempting to implement protection measures.
- Develop a long-term comprehensive plan for the protection of banks and shorelines. Comprehensive planning will ensure that bank areas and shorelines remain in their natural state.

Additional recommendations for the protection and preservation of banks and shorelines can include:

- Meet environmental goals through shoreline stabilization regulations that are performance based (not numerical).
- Allow for flexibility to integrate structural and nonstructural methods.
- Address instability caused by water-based and land-based activities.
- Develop financial incentives that encourage the local property owner to employ nonstructural techniques.
- Prohibit the use of noxious plants while encouraging the use of native plant species.
- Provide design standards.

Conclusion

While much of the information considered in this paper was gathered with a focus on Florida, we feel it can be extrapolated to other states. Although ordinances can be enacted to address singular issues, it is better to develop a more comprehensive approach to development review. This kind of approach can eliminate potential duplicity while maximizing environmental benefit. The issues addressed above range widely, but environmental integrity and preservation are common themes. Enactment of an ordinance rarely occurs without challenge, but its chance of passage can only be increased by a scientifically justifiable and legally defensible argument.

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Urban Runoff Pollution Prevention and Control Planning: San Francisco Bay Experiences

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Abstract

The California Regional Water Quality Control Board, San Francisco Bay Region, began a program for control of urban runoff pollution in 1987. The initial focus of the program has been on the municipalities in Santa Clara and Alameda counties. Both county programs followed a similar methodology consisting of the following steps: establish program goals and framework; compile existing information; assess water quality problems through collection and analysis of data and modeling of pollutant loads; identify, screen, and select appropriate control measures; and establish a plan for implementation. The Alameda program had the benefit of lagging behind the Santa Clara program by about 1 year. This provided the Alameda program with the advantage of streamlining efforts based on the successes of the Santa Clara program.

The experiences of these programs provide even further insight into streamlining and optimizing the planning process. Understanding the benefits of each step of the planning process enables a municipality to focus limited resources on the more critical factors affecting development of an implementation plan. For example, a municipality may weigh the cost of obtaining new data to make more informed decisions with the risk associated with making assumptions in the selection and implementation of control measures in lieu of data acquisition. Lessons learned to date are now being utilized by other municipalities in the San Francisco Bay area, leading towards timely and cost-effective development of urban runoff management programs.

Introduction

The California Regional Water Quality Control Board, San Francisco Bay Region (Regional Board), is the state water pollution control agency responsible for protecting the beneficial uses of San Francisco Bay and its tributaries. San Francisco Bay is a highly urbanized estuary and, as such, receives significant loads of pollutants through discharges of urban runoff. The Regional Board began a program for control of urban runoff on a watershed basis in 1987. The goals of the Regional Board's program are to protect beneficial uses through attainment of water quality standards in waters of the region and to reduce pollutants in urban runoff to the maximum extent practicable. These two goals reflect a dual water quality and technology based approach and serve to integrate specific regulatory programs such as the stormwater National Pollutant Discharge Elimination System (NPDES) permit program. The Regional Board has promoted an areawide approach, with the initial focus of the program on the municipalities in Santa Clara and Alameda counties. This has led to the development of a pseudowatershed-based program in each county.

The Regional Board program goals also serve as the primary goals of the specific municipal urban runoff programs. We recognize, however, that attainment of such broadly defined goals can only be achieved through a carefully planned strategy. Both county programs followed a similar strategy consisting of the following steps: establish program goals and framework; compile existing information; assess water quality problems through collection and analysis of data and modeling of pollutant loads; identify, screen, and select appropriate control measures; and establish a plan for implementation. Normally, such steps would proceed in sequence. With an understanding of the purpose of each step and its relation to the others, however, one may consider a nonsequential or parallel process. The Alameda program commenced approximately 1 year after the Santa Clara program and had the advantage of being able to streamline efforts based on the successes of the Santa Clara program. The lessons learned by the Santa Clara and Alameda programs provide valuable insight for optimizing the planning process.

The Regional Board served as a facilitator in the development of both the programs, but it has been the cooperative, proactive approach of the municipalities that has resulted in the development of a technically sound and cost-effective urban runoff program. The following discussion reflects the experiences and accomplishments of the Regional Board and the Santa Clara and Alameda programs.

Planning Strategy Steps

Program Framework

Development of an effective urban runoff management program first requires an effective framework that involves participation by all pertinent municipal agencies. Initiation of both county programs began with creation of a task force with participants from city and county public works, city and county planning, sewage treatment works, and flood control. The task force served as a forum for communication among the involved agencies, as well as an oversight body to track all the steps of the planning process. Specific activities included establishment of program goals, development of a memorandum of agreement among the participating agencies, designation of a lead agency for anticipated contracts, and development of a work plan for the planning strategy. The work plan identified the specific tasks and timelines of the planning strategy, identified responsible parties and consultant needs, and identified the financial resources necessary for completion of the planning process.

Both programs relied on extensive consulting services for preparation of the planning process work plan and implementation of the planning tasks. Although the programs benefited from this approach, an overreliance on outside help may result in insufficient awareness and expertise within the ultimate implementation agencies of the urban runoff management program. An effective approach should use new or existing municipal personnel as much as possible throughout the planning process. Outside services may play a valuable role, but they will be most effective when specific technical or other needs have been identified and communication and cross training with municipal staff are provided.

Compilation of Existing Information

Identification and compilation of existing information are essential early steps in the process. The Alameda and Santa Clara programs benefited from these steps for several reasons, including that they provided a learning experience on the importance of the relationship of land-use information to water quality. Much pertinent information already existed, and many existing municipal activities were involved in the management of urban runoff and pollutant sources. This information was critical to the identification of monitoring, modeling, and mapping needs, and to the selection of appropriate control measures.

Neither of the programs chose to focus resources on detailed mapping efforts. Rather, available maps were used to compile information. Development of more detailed maps, specifically geographical information systems, was deferred to the implementation phase of the program when funding mechanisms would be in place and the cost could be better justified.

Monitoring and Modeling

Both the Santa Clara and Alameda programs conducted comprehensive monitoring and modeling programs (1, 2). The objectives of these programs were to characterize existing water quality conditions within storm drains and urban creeks and to estimate urban runoff pollutant loading. The programs included hydrologic monitoring, wet and dry weather water quality monitoring, sediment monitoring, and toxicity monitoring using acute and chronic bioassays. Data were compiled and used to calibrate and verify the Storm Water Management Model for estimating pollutant loads. The load estimates were also used to compare the relative contributions of treated wastewater and urban runoff discharges to the bay.

Results of both monitoring programs were similar. Heavy metal concentrations in receiving waters increased during wet weather. The metals primarily detected were cadmium, copper, lead, nickel, and zinc. Pesticides and petroleum hydrocarbons were prevalent in sediments. Metal concentrations were distinctly different for discharges from open space, commercial/residential, and industrial areas. It was also determined that annual urban runoff pollutant loads were equal to or greater than treated wastewater discharges, depending on the amount of precipitation.

Each of the monitoring and modeling programs cost from $1 to $2 million. Much valuable information was gained, and there were strong driving forces for obtaining the pollutant load information. Future programs may not have this level of available resources during the planning process, however. Municipalities must weigh the cost of obtaining new data to make more informed decisions with the risk associated with making assumptions in the selection and implementation of control measures in lieu of data acquisition. Newly developing programs in the San Francisco Bay Area are taking this latter approach, in part benefiting from the information developed by the Santa Clara and Alameda programs.

Selection of Control Measures

The process of selecting appropriate urban runoff pollution control measures involves three steps: 1) compilation of candidate control measures, 2) consideration of the candidate measures based on screening criteria, and 3) selection of control measures (3). The key to the success of the process was establishing meaningful selection criteria. The selection criteria addressed pollutant control effectiveness, reliability, and sustainability; capital, operation, and maintenance costs; public and agency acceptability; consistency with regulatory requirements; and legal and environmental liability.

An inventory of candidate control measures was developed through a review of technical literature and other urban runoff control programs. In addition, technical and managerial personnel from other state, county, and city agencies were interviewed. This initial screening produced a list of 92 separate candidate control measures. Upon application of the established screening criteria, the list was reduced to 59 control measures. The final step involved consideration of the overall costs of implementing all the control measures, with priority given to pollution prevention and source control measures over structural or treatment based controls. This final step ultimately lead to the selection of 41 separate control measures for implementation.

The Alameda program had the advantage of following the Santa Clara program. Consequently, the Alameda program streamlined the process by capitalizing on the efforts and progress of the Santa Clara program. The Alameda program also factored in the requirements of the storm water NPDES regulations. As more programs are developed, we expect the selection process to become even more streamlined, particularly in areas of similar land use and climatic conditions such as the San Francisco Bay area.

Implementation Plan

The final stage of the planning process is to develop a plan for implementation of control measures. The implementation plan should provide a clear framework of stated goals, tasks to achieve them, an evaluation process, and a mechanism for modification of the plan based on program successes and failures. The task forces of the Santa Clara and Alameda programs played a critical role in the development of their implementation plans. The multiagency involvement on the tasks forces allowed for a consensus-building process that resulted in establishing responsible agencies and institutional arrangements for implementation.

The Regional Board did not intend to require immediate implementation of all control measures. Through involvement with the respective task forces, high-priority, early-action measures were identified, and schedules for phased implementation of the remaining measures were established. For example, targeted early actions included a public information program and surveillance for illegal discharges. Improved operation and maintenance activities are being implemented under a phased schedule where the efficiency of various inlet cleaning procedures are being evaluated on a pilot scale first (4, 5).

Development of a comprehensive and effective implementation plan for an urban runoff control program is the most critical and difficult step in the planning process. The difficulties encountered are generally nontechnical in nature and involve legal, financial, and institutional limitations. The key to avoiding or overcoming such limitations is recognizing them early in the planning process and integrating their solution into the planning process. For example, the planning process work plan should include tasks to address legal authorities, funding mechanisms, and institutional arrangements, rather than waiting until a technical implementation plan is drafted. In essence, development of the implementation plan should commence with initiation of the planning process.

Conclusions

Development of an effective urban runoff control program requires a well-defined planning strategy. The experiences of the Regional Board and the Santa Clara and Alameda programs provide insight on how to efficiently proceed through the planning process. Understanding the benefits of each step of the planning process enables a municipality to focus limited resources on the more critical factors affecting development of an implementation plan. These factors include a multiagency task force; clear goals and a work plan for the planning process; compilation of all available information, with a strong emphasis on review of other programs; strategic focus of monitoring, modeling, and mapping resources; criteria for selection of control measures; and the foresight to commence development of the implementation plan at the beginning of the planning process. Lessons learned to date are now being used by other municipalities in the San Francisco Bay area, leading to timely and cost-effective development of urban runoff management programs.

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Whole Basin Planning: Practical Lessons Learned From North Carolina, Delaware, and Washington

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Abstract

Governments at all levels are broadening their view of water quality protection and are developing and implementing innovative strategies to achieve greater water resources protection. Many of these efforts center on "whole basin planning," which encourages active coordination across the full range of resource management programs to maximize the efficiency of program planning and administration, data collection and analysis, pollution prevention and control implementation, habitat protection and restoration, permitting, and enforcement.

Basin planning consists of two phases. The first develops the design of the state- or multistate-specific framework under which basin planning will be performed. The second phase implements the basin planning process. North Carolina, Delaware, and Washington have each employed a consensus-building, workshop-based process to develop planning frameworks. Delaware and Washington are currently in the framework design phase. North Carolina implemented basinwide planning in 1991. Preliminary results are encouraging, with improvements to the state's monitoring program, data management, analysis and assessment, and water quality program administrative functions being demonstrated.

Several aspects of the framework development process as employed in these three states stand out as practical suggestions for other states and federal and local agencies considering basin planning:

- Clearly define the state-specific objectives to be achieved.
- Encourage stakeholder involvement at the agency staff level.
- Allow time for discussion of ideas and iterations during framework development.
- Build in flexibility to the process development and basin planning processes.
- Define issues to address in order to translate objectives for basin planning into specific tasks.
- Implementing basin planning, the states found, does not necessarily lead to disruption of existing programs.

What Is Whole Basin Planning?

There is a growing awareness in the United States that point source water pollution control programs have been successful, but that nonpoint sources, groundwater contamination (1, 2), and habitat degradation (3) continue to diminish the quality of the nation's water supply. Point source chemical controls, while largely effective, have not led to the achievement, maintenance, nor protection of the three supporting components of clean water provided in Section 101(a) of the Clean Water Act (CWA): chemical, physical, and biological integrity. Nonchemical stressors resulting from nonpoint source pollution (e.g., "clean sediment," increased stream temperature, highly modified flow regimes) can lead to direct and indirect impacts on physical and biological integrity. A broad perspective on water resources management is required to reduce and eliminate such stresses. Government agencies at federal, state, and local levels are widening their views of water quality protection and are developing and implementing innovative strategies to achieve greater water resources protection. Many of these efforts center on the concept of a "whole basin planning" (WBP) approach, which realigns water pollution control programs to operate in a more comprehensive and coordinated fashion.

The underpinnings of basin planning can be found in federal legislation, notably numerous sections of the CWA (Table 1). Section 303(e) explicitly requires each

Table 1. Sections of the CWA That Support Basin Planning (Adapted From Creager et al. [4])

Section	Applicable Content
201(c)	To the extent practicable, waste treatment management shall be on an areawide basis.
208	Several clauses of this section call for areawide planning, reporting, and pollutant control.
303(d)	Subsection 1A. Each state shall identify waters within its boundaries which are water quality limited. The state shall establish a priority ranking for such waters.
303(d)	Subsection 1C. States shall establish TMDLs for the identified water quality limited waters.
303(e)	Establishes a continuing planning process that includes effluent limits and compliance schedules, applicable areawide waste management plans (§208) and basin plans (§209), TMDLs per §303(d), revision procedures, authority for intergovernmental cooperation, implementation including compliance schedules, residual waste disposal controls, and a prioritized inventory and ranking of waste treatment construction needs.
319(a)	Nonpoint source management program, state assessment reports.
319(b)	Nonpoint source management program, state management plans.
319(b)	Section 4. States shall develop and implement management programs on a watershed basis.
320	Comprehensive management plans to be developed over large geographic area for estuaries in National Estuary Program.

state to develop an areawide planning process for all navigable waters in the state to address a broad range of water quality issues. Sections 303(d) and 319 implicitly require or support basin planning. Section 303(d) requires states to define total maximum daily loads (TMDLs), as well as associated wasteload allocations for point sources and load allocations for nonpoint sources, to ensure the attainment of water quality standards within all surface waters. Section 319 requires watershed-based nonpoint source management programs. Section 320 establishes the National Estuary Program and requires the development of management plans for estuaries included in the program. The estuarine zone is broadly defined as extending to the upstream limit of historic anadromous fish migration or head of tide. Thus, the management plans must be prepared for broad geographic areas. In addition to the CWA, the Coastal Zone Act Reauthorization Amendments of 1990 (CZARA) included Section 6217, which requires coastal states with approved coastal management programs to develop Coastal Nonpoint Source Control Programs. During a review of state coastal zone boundaries required by Section 6217, National Oceanic and Atmospheric Administration will use U.S. Geological Survey (USGS) mapping units as the basis for examining state delineations of coastal watersheds (5). Section 6217 requirements provide implicit support for whole basin planning.

In a recent paper discussing integrated basin management, Downs et al. (6) identify five main facets that should be included when addressing the physical and biological attributes of river basins (Figure 1). Explicit incorporation of water, channels, land, ecology, and human activities management into the planning, design and implementation phases of aquatic resources management increases the likelihood that cumulative, incremental losses to resource quality and quantity will be identified and addressed. Whole basin planning encourages active coordination across the full range of resource management programs to maximize efficiency of program planning, data collection and analysis, pollution prevention and control implementation, habitat protection and restoration, permitting, and enforcement. Mitchell (7) recommends a two-stage strategy to achieve truly coordinated management of resources in river basins. The first, conceptual stage is an identification of the widest possible range of issues and variables. The second, operational stage involves an integrated, focused approach that concentrates on the issues identified as most significant.

The U.S. Environmental Protection Agency (EPA) has recognized the value of taking a wider view of water quality protection. Through the Office of Water, EPA encourages states to implement watershed protection and basin planning and has formulated three main principles to guide its support for state efforts in this area (8):

- Risk-based geographic targeting
- Stakeholder involvement
- Integrated solutions

Risk-Based Geographic Targeting

"Risk" in the context of whole basin planning refers to indication of impairment to human health, ecological

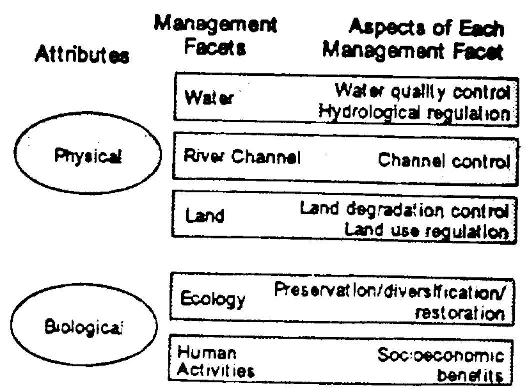

Figure 1. Facets of river basin management to include in basin planning (adapted from Downs et al. [6]).

resources, designated uses of the waterbodies, or a combination of these, resulting from manmade pollution and natural processes, based on a review of environmental data. A probabilistic approach, as is used in ecological risk assessment (9), has not been applied in basin planning. Phillips (10), however, argues for a probabilistic approach to targeting nonpoint source pollution control in a watershed context. Basin planning establishes a framework within which a more probabilistic risk assessment can be performed.

Problems that may pose risks in a watershed include:

- Industrial wastewater discharges.
- Municipal wastewater, stormwater, or combined sewer overflows.
- Waste dumping and injection.
- Nonpoint source runoff or seepage.
- Accidental toxics releases.
- Atmospheric deposition.
- Habitat alteration, including wetlands loss.
- Flow alterations.

Specific stressors within watersheds are targeted based on their potential to produce impairment to human health, ecological resources, or designated uses. Under a whole basin planning framework, the highest risk stressors within watersheds are identified using, for example, water quality and biological monitoring data, land use information, information on location of critical resources, and tools such as water quality models and geographic information systems (GIS). The stressors with the greatest potential to yield impairments are targeted for integrated assessment and corrective action involving cooperative efforts between multiple jurisdictions and interest groups. The targeting process may range from qualitative ranking to computerized techniques that incorporate various numeric criteria and weighting factors (11). Difficult management problems may not be completely addressed over the course of one basin planning cycle (5 years is being used in North Carolina). This can be used to advantage, however, by breaking the identified problems into components that can be solved, or for which measurable progress toward a solution can be made during a cycle.

The basin planning process itself can be broken into phases with near- and long-term goals. For example, near-term goals could include coordinating the permitting and monitoring schedules by basin, promoting public participation in basin planning, and expanding and improving wasteload allocation analyses and evaluation of nonpoint sources. Long-term goals could include optimizing the distribution of assimilative capacity within basins and developing and implementing basinwide management strategies.

Stakeholder Involvement

All parties with a stake in the specific local situation should participate in problem analysis and creation of solutions. The involvement of potentially affected parties ("stakeholders") during the development of basin plans is crucial to the success of those plans. The manner in which stakeholders are involved may vary from state to state, but a key activity for them, regardless of location, is to reach consensus on goals and approaches for correcting a watershed's problems, specific actions necessary to achieve those goals, and processes for coordinating implementation activities and evaluating the efficacy of problem solutions. The potential pool of stakeholders can be very broad and should be tailored to individual basins. Potential basin plan participants include members of:

- State environmental, public health, agricultural, and natural resources agencies.
- Local/regional boards, commissions, and agencies.
- EPA water and other programs.
- Other federal agencies (e.g., U.S. Department of Agriculture—Soil Conservation Service, U.S. Department of the Interior, U.S. Army Corps of Engineers).
- Indian tribes.
- The public.
- Private wildlife and conservation organizations.
- Industry.
- The academic community.
- The farming community.

Integrated Solutions

The basin approach provides a framework to design the optimal mix of water quality management strategies by integrating and coordinating across program and agency boundaries. Integrated solutions implemented by basin management teams use limited resources to address the most significant water quality problems without losing sight of and planning for other factors contributing to the degradation of the resource. Integration through the basin approach provides a means to achieve the short- and long-term goals for the basin by allowing the application of resources both in a timely and geographically targeted manner. Integrated solutions are possible because of a framework that encourages an interdisciplinary and interagency team to develop the most appropriate plan rather than impose predetermined solutions.

Whole Basin Planning in Three States

Before basin planning (the second, operational stage in Mitchell's construct [7]) per se is implemented, it must be preceded by a process to design the framework within which it will operate (Mitchell's first, conceptual stage [7]). This design process will be specific to each state that implements whole basin planning due to differences in target resources (e.g., a large number of rivers and streams versus lakes), the objectives of implementing basin plans (e.g., a water quality permitting focus versus an aquatic resources management focus), and differing organizational structure and implementation constraints. We draw on experiences in North Carolina, Delaware, and Washington during the framework design stage of basin planning and identify several practical lessons that can be applied by other states, EPA regions, or other government units.

North Carolina

The Framework

North Carolina Division of Environmental Management (NCDEM) Water Quality Section considered an National Pollutant Discharge Elimination System (NPDES) basin permitting strategy as early as 1989. However, due to resource limitations, NCDEM was unable to develop a framework document describing the strategy to submit to the North Carolina Environmental Management Commission for approval. NCDEM submitted a request for funding to the EPA Office of Policy, Planning and Evaluation, Water Policy Branch, for a facilitator to assist with the development of a basin approach for North Carolina. This consensus-building process was initiated in 1990.

The Process

The first step in the process involved a series of individual interviews with several members of the NCDEM Water Quality Section staff, including all branch chiefs. The benefits of expanding the focus from solely a NPDES permitting strategy to more comprehensive involvement of the water quality program soon became apparent. It was also clear that there was broad-based support for the basin approach but that individual views of that approach varied in several critical areas. The goal of the consensus process was to successfully synthesize those individual views.

The next step involved a series of small group meetings to begin outlining a framework for the basin approach. The results of these group meetings formed the basis for a "straw outline" compiled by the facilitator. The straw outline was used to provide structure for a "development" workshop attended by a large portion of the Water Quality Section staff. The purpose of the workshop was to finalize the outline and identify consensus positions.

Workshop results were used to produce a draft internal document describing the North Carolina Whole Basin Water Quality Management Framework.

The draft framework document was distributed within the Water Quality Section for review and comment. The revised document was circulated to a broader audience, including other state and federal agencies and selected academics. The draft framework document was presented at an implementation workshop, which included broader agency and public participation than previous meetings. The document was revised once again based on comments received at the implementation workshop and submitted to the North Carolina Environment Management Commission (EMC) for approval. The EMC approved the basin approach in 1991.

The framework document has been revised twice since its approval by the EMC. These changes reflect needed refinements recognized during the implementation and development of specific basin plans. These revisions have expanded the focus of basin plans and incorporate broader elements of the water resources program in North Carolina to ensure that the state's basin planning objectives are being appropriately addressed.

The final consensus basin approach established a rotating basin schedule for NPDES permitting, monitoring, and nonpoint source program implementation. These activities are performed for each basin on a 5-year cycle, with several basins moving through the planning cycle together. A general sequence of tasks over the 5-year planning cycle is illustrated in Figure 2. North Carolina basin plans are viewed as reports to the public, policymakers, and the regulated community. Revisions to the framework are addressing an insufficient public outreach program for the development of specific basin plans. Basin plans report on the current status of surface waters in the basin, identify major water quality concerns and issues, summarize projected trends in development and water quality, identify long-range management goals for the basin, present recommended management options, and discuss implementation plans (12). The plan also presents potential changes in

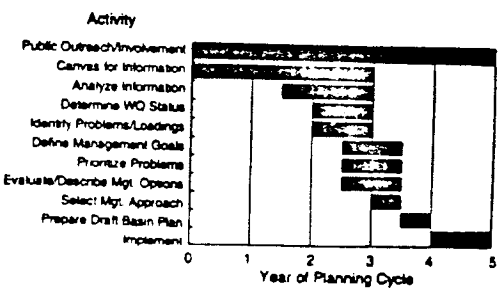

Figure 2. General sequence of planning tasks.

discharger waste limits and recommendations for reductions in nonpoint source loadings. North Carolina Basinwide Water Quality Management Plans do not, however, currently target specific physical habitat restoration issues or projects.

Barriers to Implementation

A major impediment to the development and implementation of the North Carolina basinwide approach has also been the greatest source of strength: the CWA. The strength comes from the merger of traditionally regulatory programs, having strong legal precedence for enforcement, with voluntary compliance programs, which have a strong public involvement component. Each approach has enhanced the application of the other.

The barriers result from the manner in which the CWA has been implemented, using a programmatic approach with specific grant and entitlement programs. This has led to a lack of coordination and integration in addressing water quality issues that require comprehensive strategies. The program funding requirements reduce the flexibility of the state to commit funds to targeted water quality issues.

Next Steps

A useful reform of the grants process would give states with defined basin frameworks authority to establish water quality priorities within basins. This approach would also reduce redundant application and reporting requirements that are fulfilled with the basin plans. Flexibility in this regard would enhance the North Carolina approach. EPA is currently using a trial block grant funding program with North Carolina.

Delaware

The Framework

The Delaware Department of Natural Resources and Environmental Control (DNREC) identified a need to focus existing water resources programs on priority watersheds. Basin planning will provide DNREC with the ability to assess pollution, living resources, and habitat problems, and manage Delaware's resources in a comprehensive manner (13). The department's perspective on basin planning, explicitly incorporating living resources and habitat degradation, from the outset of the process is significant from several standpoints. By including a wide range of basin management facets (Figure 1), DNREC will be more likely to proactively identify potential cost savings (e.g., combining aspects of current water quality and fisheries monitoring activities), watershed stressors with multiple impacts (e.g., loss of vegetated riparian buffer zones, which increases nonpoint source delivery to waterbodies and degrades aquatic and terrestrial habitat), and solutions with benefits to multiple resource categories (e.g., riparian zone revegetation, which reduces nonpoint source loadings and improves habitat). It is less likely that DNREC will need to "retrofit" the basin planning process at a later stage.

The Process

DNREC's framework design process began with a series of interviews of department staff by a facilitator to gain a better understanding of their goals for basin planning in Delaware. Following completion of these interviews in late summer 1992, a workshop was held for DNREC staff in September 1992 to provide detailed background information on whole basin planning and to begin to identify existing roles and responsibilities of the various functional units within the department. The workshop provided an opportunity for department staff to identify perceived needs for basin planning in Delaware and to begin an initial formulation of goals and objectives (14).

A second workshop was held in January 1993 with DNREC staff and representatives from other state, local, and federal agencies. The goal of this session was to establish commitment and direction for basin planning in the state. The 3 months between the first and second workshops proved to be a very fertile incubation period for agency staff to consider the design of a planning approach. Key outcomes of the discussions were:

- Identification of a strategy of sequential involvement of a larger group of participants as the framework planning effort proceeds.
- Firm commitment by agency staff to build the planning process from the bottom up, together with the stakeholders who will actually implement it, rather than imposing the plan without their input.
- A clear statement that an expanded definition of "clean water" (i.e., inclusive of biological resources, physical habitat, and watershed linkages) would ensure that Delaware's basin approach is consistent with the goals and objectives of programs and agencies other than DNREC water programs. Maintaining the focus on "clean water" will allow the regulatory components of the basin approach to remain firmly grounded in legal and policy precedents provided by the CWA.
- Detailed discussion of whether to 1) proceed with immediate implementation of WBP in all basins at once, or 2) proceed incrementally, implementing the strategy in a single basin and then assessing the results and modifying the framework as appropriate.
- Tentative delineation of basin management units that combine groups of Delaware's 35 watersheds (Figure 3).

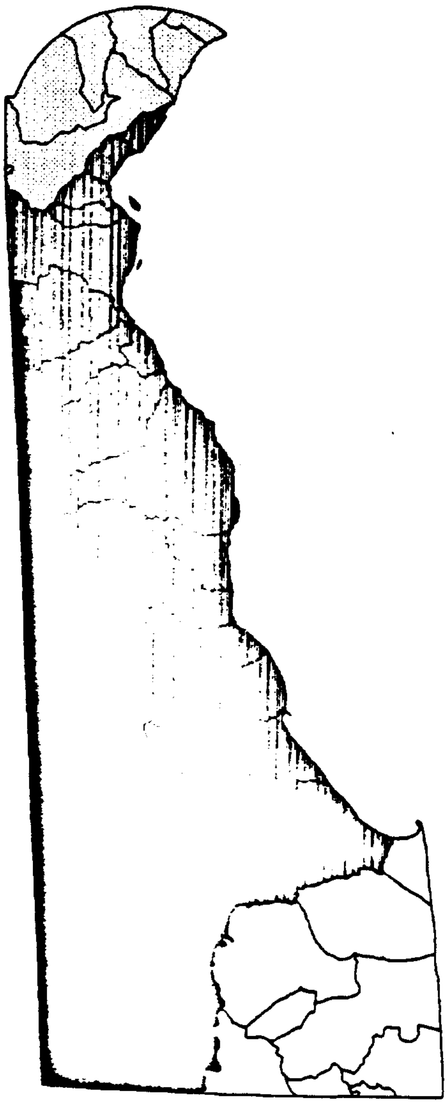

Figure 3. Tentative delineation of basin management units in Delaware.

Workshop participants identified a wide range of issues to address during the formulation of the basin planning framework. Review groups were established to explore these issues in greater detail and prepare specific components of a planning framework document. Topical areas being examined by these groups are:

- Implementation, coordination, and institutional barriers
- Management units, data management, and monitoring
- Public outreach and education

Next Steps

The review groups will be the focus of planning activities for several months. Following completion of their deliberations, a framework design workshop will be convened to review the components of the planning process proposed by the groups, to make appropriate modifications, and to establish a draft basin planning framework for subsequent review by stakeholders.

Washington

The Framework

The Washington State Department of Ecology (DOE) Water Quality Program (WQP), Environmental Investigations and Laboratory Services (EILS), and Central Programs are currently developing the water quality component of a broader DOE basin approach to natural resource management. The process is the culmination of a long-term planning program that satisfies a state-sponsored Efficiency Commission requirement and also fulfills the requirements of a Memorandum of Understanding between EPA Region 10 and DOE. The development of the basinwide water quality management program framework document is not yet final. Therefore, the summary description offered here is subject to change. The development of the basinwide approach in Washington was also assisted by an independent facilitator.

The Process

The Washington basin approach for water quality management involves coordinating issuance of wastewater discharge permits and nonpoint source planning conducted by the WQP and Central Program's Industrial Section (to the extent practicable). It also involves water quality monitoring, intensive field investigations, and TMDL development conducted by DOE's Environmental Investigations and Laboratory Services Program. Other programs within DOE also have developed or are developing basin approaches for their areas of responsibility (e.g., Coastal Zone Management, wetlands). All of the basin approaches within DOE will be merged into one resource management program at a later date.

Beginning in mid-1993, each of the WQP's four regions committed one basin per year to this geographically targeted, risk-based approach. The 64 Water Resource Inventory Areas (river basins) will be lumped into 20 basin management units. Each of the four regions will complete a basin water quality management plan each year. All of the basin management units across the state will be completed in a 5-year cycle. Each basin will be revisited every 5 years to restart the cycle of data collection, assessment, public outreach, planning, and implementation. Basin management teams are active in each basin management unit every year of the 5-year basin management cycle. Basins are simply staggered at different steps in the cycle. The Washington approach is viewed as a long-term commitment to a stable management structure that allows DOE to build on previous efforts.

Integration of the DOE program with local planning agencies is a key issue in Washington. DOE is placing a strong emphasis on stakeholder involvement through a public outreach program that is active at each step of the basin cycle. The roles and responsibilities of all of the participants on the basin planning team have not been finalized. DOE, however, is looking for a mechanism that promotes public and other agency involvement in all phases of the basin planning process. The exception would be when the regulatory activities of the basin planning team might directly affect a participant.

Next Steps

EPA flexibility is needed in numerous program components to facilitate DOE's transition to the basin approach, including:

- Using extended/expired permits to achieve synchronization of permits within basins, and because certain permits will receive a low priority ranking for risk of waterbody impairment.
- Allowing basin plans to fulfill various CWA reporting requirements (e.g., 305(b), 319).
- Using basin plans as both numeric and qualitative TMDLs.
- Administering staff/financial resources among various program components (e.g., number of inspections and audits).
- Focusing on the results of the water quality program rather than specific intermediate evaluation criteria.
- Recognizing that certain state discharge permits (e.g., ground water) may take precedence for management over certain NPDES permits.

EPA Region 10 and DOE are working together to resolve these issues to the extent possible within the current configuration of the CWA. The elimination of all institutional barriers between EPA regional offices and states may require some amendment of the CWA as part of its reauthorization.

Washington is continuing to resolve internal implementation barriers by establishing a cross-program work group to address issues that were identified at the development workshop. DOE also considers the basinwide water quality management framework document that is developed through this current consensus process the first phase of DOE's transition to basin resource management.

How Is Whole Basin Planning Working?

North Carolina

Although only one state is actually performing basin planning, the results so far are encouraging. EPA's Office of Water, Watershed Branch, sponsored a survey of the staff of the NCDEM Water Quality Section after basin planning was initiated there. Potential improvements and increased efficiency in North Carolina's water quality program were suggested in several areas.

Monitoring Program

Following implementation of basin planning, NCDEM was able to increase the number of water quality sampling stations and parameters measured. The respondents attributed this increase to the ability to optimize sampling strategies under a basin approach. The ambient water quality monitoring network has been maintained. NCDEM staff anticipate further improvements to the monitoring network as a result of increased coordination with other resource agencies and the larger role of the regulated community in the monitoring program.

Data Management, Analysis, and Assessment

During development of a basin planning approach, North Carolina identified major improvements to data management and analysis (both hardware and software) as being crucial to the success of the approach. Improved capabilities in this area are expected to reduce the Water Quality Section's reliance on North Carolina's central computing services and significantly reduce the Section's computing costs. Cost savings will be used to upgrade in-house hardware and software, which will in turn allow ready access to monitoring and geographic data needed to support basin planning.

Of particular note to municipalities is the ability to fund a staff position with the Water Quality Section to assist in the development of basin plans from the perspective of fulfilling municipal stormwater planning and control requirements. North Carolina cities will benefit from this arrangement by being able to reduce or eliminate redundant monitoring and modeling.

Significant improvements have been made in assessing water quality issues. The development of a framework for basin planning included integration of analysis time requirements with monitoring schedules, thus monitoring now more directly supports water quality modeling. By shifting to a basin focus, modeling is performed for a greater length of stream segments in the state. This expansion allows consideration of more innovative solutions to water resources management issues, such as pollutant trading, and enhances the state's ability to prepare TMDLs.

Administration

North Carolina's basin approach was designed to avoid agency reorganization. The approach has led to changes in roles and responsibilities for staff and branches within NCDEM. Staff resources have been shifted to place a greater emphasis on data acquisition and assessment. Information flow and coordination of activities between branches has significantly increased. A basin coordinator position was created to ensure the timely flow of information throughout the preparation of basin plans. In addition to improved communication and coordination within the NCDEM, there is increased cooperation with other local, state, and federal agencies.

Potential Benefits to the Regulated Community

Basin planning has not been in place long enough to have provided directly measurable benefits to the regulated community. However, the Water Quality Section identifies several anticipated benefits. Consolidation of dischargers into consortia along stream reaches will provide an economy of scale with respect to permit monitoring requirements. Dischargers in management units are expected to be able to combine permit monitoring activities and cooperate in the preparation of assessments. NCDEM also expects permits to be more stable because of the expanded spatial and temporal scope of assessments performed during the basin planning cycle. Basin planning allows more comprehensive assessment of existing and proposed pollution sources, and is more effective in accounting for future impacts. Thus, permit conditions would need to be updated less frequently, potentially reducing costs to both NCDEM and permittees. Increased accuracy in the assessment of a basin's assimilative capacity will allow better identification of the level and types of controls necessary to achieve and maintain desired aquatic resources quality. Basin planning will help lead to the selection of an optimal set of pollution control methods, potentially reducing costs.

Neuse River Basinwide Plan

North Carolina has implemented basinwide planning beginning with the Neuse River basin (Figure 4). Basinwide plans will be prepared for the remaining 16 basins in the state over the next 5 years and will be updated at 5-year intervals.

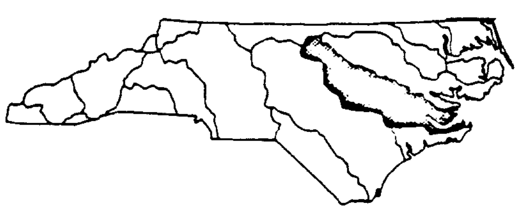

Figure 4. North Carolina basins (Neuse River highlighted).

North Carolina's basinwide planning process has as primary goals "to identify and restore full use of presently impaired waters, to identify and protect highly valued resource waters, and to manage problem pollutants throughout the basin so as to maintain full use of unimpaired waters while accommodating population increases and economic growth" (12). NCDEM identified near- and long-term objectives for its basinwide planning process that apply to the preparation of basin plans (illustrated conceptually in figure 2). Near-term objectives are defined as those fully or partially achievable during the initial 5-year planning cycle. They include implementing management strategies to significantly reduce point and nonpoint source pollution and making measurable improvements toward addressing major issues identified in each of the basin plans. Longer-term objectives include refining the recommended basinwide management strategies during subsequent planning cycles based on the results of monitoring and implementation activities from the initial round of planning (12).

The Neuse River basinwide plan is a comprehensive document that can serve as a model for other states considering basin planning. An outline of the contents of the document is provided in Table 2.

Practical Lessons From Framework Development

As noted earlier, several states are in the process of developing a whole basin planning framework, or have completed the framework and implemented basin planning. Several aspects of the framework development process in these states stand out as practical suggestions for other state, federal, and local agencies that may be considering basin planning:

- *Clearly define the specific objectives to be achieved:* This will determine the scope of the programs to be involved. The objectives are a positive statement of the issues to be addressed and resolved through the basin approach. This step eliminates uncertainty regarding the focus of the consensus process. Basin planning entails a considerable shift in thinking and practice regarding the manner in which resources will be managed. It moves agencies (and other stakeholders) from programmatic-based management to resource-based management. This shift does not necessarily require agency reorganization, but it does require emphasis on and sustained commitment to extensive communication and information sharing across programmatic lines.
- *Encourage stakeholder involvement at agency staff level:* The basin approach allows redefinition of functional relationships without formal reorganization.

Table 2. Neuse River Basinwide Plan

Introduction	Purpose of the Neuse Basin Management Plan
	Guide to Use of Document
	Introduction to the Basinwide Management Approach
	Basinwide Responsibilities Within NCDEM Water Quality Section
General Basin Description	Physical and Geographic Features
	Land Use, Population, and Growth Trends
	Major Surface Water Uses and Classifications
Sources and Causes of Water Pollution in the Neuse Basin	Introduction
	Defining Causes of Pollution
	Point Sources of Pollution
	Nonpoint Sources of Pollution
Water Quality Status in the Neuse Basin	Sources and Types of Water Quality and Biological Data
	Narrative Water Quality Subbasin Summaries
	Neuse River Mainstem
	Methods for Determining Water Quality "Use Support" Ratings
Existing Point and Nonpoint Source Control Programs	Introduction
	Integrating Point and Nonpoint Source Pollution Control Strategies
	Point Source Pollution Control Through North Carolina's NPDES Permitting Program
	Nonpoint Source Control Programs
Basinwide Goals, Major Water Quality Concerns and Recommended Management Strategies for the Neuse Basin	Major Water Quality Concerns and Priority Issues
	Recommended Management Strategies for Oxygen Demanding Wastes
	Management Strategies for Nutrients
	Toxics
Basinwide Plan Summary and Future Initiatives	Overview of Neuse Basinwide Goals and Objectives
	Neuse NPDES Permitting and TMDL Strategies
	Nonpoint Source Control Strategies and Priorities
	Future Modeling Priorities
	Future Monitoring Priorities
	Future Programmatic Initiatives

The more broadly based the transition effort, the less confusion in the implementation of the approach. The basin approach also "flattens" organizations by shifting more decision-making responsibility to basin teams. Therefore, staff involvement is critical to development of the basin approach. Staff made many valuable contributions to the process and more eagerly embraced the approach in those states where staff participation was encouraged.

- *Allow time for adequate, thorough discussion of ideas and iterations during the development of the process framework.* Development of a basin planning process is complex and, as noted above, requires a shift in agency thinking and practice. Although no hard-and-fast guidance can be given on the specific lengths of time that are needed for each of the phases of the framework development process, experience in three states suggests that a minimum of 12 to 18 months should be allowed. By allowing adequate time for agency staff to thoroughly explore potential requirements of basin planning and issues identified during the preparation of a planning framework, a much stronger process will result.

- *Build in flexibility to the development process as well as the whole basin planning process itself:* The three states discussed in this paper have all employed a consensus-building, workshop-based process to develop planning frameworks. On occasion, workshops have been rescheduled at the last minute when it became clear that adequate numbers of participants would not be available because of scheduling conflicts. Also, workshop agendas underwent substantial modification at the session when it became clear that participants needed more in-depth discussion of basin planning concepts or particular issues they had identified. These conditions should not be viewed in a negative light—they are almost certain to occur in a consensus process, and the ability to respond with flexibility is essential to maintaining the momentum generated earlier in the process.

- *Define issues to address in order to translate objectives for basin planning into specific tasks:* Identification of certain core issues is essential for translating state-specific basin planning objectives to specific tasks that will be accomplished in the development of basin plans. Some issues that have been commonly identified across several states thus far include cross-program coordination, roles and responsibilities in the existing resource management scheme versus modifications necessary to implement basin planning, policy and regulatory implications at the state and federal level, and human and capital resources needs.

As noted above, basin planning emphasizes cross-program communication and coordination. Institutional and regulatory constraints, which vary from state to state, may lead to some disruption of existing programs during the transition period. Such disruptions can be minimized by carefully considering the steps needed to move from programmatic to resource-based management during the framework development process.

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Application of Urban Targeting and Prioritization Methodology to Butterfield Creek, Cook and Will Counties, Illinois

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Abstract

This paper describes the applicability of a methodology, developed by a consultant for the U.S. Environmental Protection Agency, to select, target, and prioritize best management practices (BMPs) in an urban watershed. The methodology was demonstrated in the Butterfield Creek watershed in South Cook County, Illinois. This watershed was selected because there are no major point sources of discharge to the creek, thus the impacts due to nonpoint sources alone could be addressed.

The methodology considered watershed land use, contributing nonpoint sources, and stream use attainment to identify priority areas for BMPs and then to prioritize those areas. The primary focus of the methodology, as originally developed, was to reduce problematic pollutant loads via appropriate BMPs. One shortcoming of the procedure was that it was limited to pollutant loads and, therefore, was not readily able to address other factors, such as the physical habitat impairments that affect many urban streams. Several enhancements were added to the methodology to address this situation. Also, the watershed configuration made interpretation of the prioritization results less straightforward.

The targeting methodology was enhanced in this application by presenting stormwater runoff rate as an additional targeted factor. Similarly, BMP selection and quantification were enhanced by representing the control of stormwater runoff rate by detention retrofitting.

Introduction

Purpose

The purpose of this paper is to report on a demonstration of a methodology developed by Woodward-Clyde Consultants for the U.S. Environmental Protection Agency (EPA) to select, target, and prioritize best management practices (BMPs) in an urban watershed (1). This methodology considers watershed land use, contributing nonpoint sources, and stream use attainment to identify priority areas for BMPs. The primary focus of the methodology, as developed, is to reduce problematic pollutant loads via appropriate BMPs. The methodology does not, however, address other constraints to stream use attainment, such as hydrologic destabilization and loss of physical habitat.

Butterfield Creek was selected for this demonstration for several reasons. First, watershed impacts are primarily due to nonpoint sources; there are no major point sources of discharge to the creek. Second, a preliminary nonpoint source management plan was being developed under a Section 319 grant, and this methodology could be used to assist in development of that plan. As a result, this paper presents analyses and results from both the preliminary nonpoint source plan (2) and the targeting methodology application (3). These two projects were originally documented separately, as referenced.

Assessment of Butterfield Creek problems has benefitted from the presence of a group known as the Butterfield Creek Steering Committee. The committee includes representatives from seven local governments in the watershed, and its mission is to address comprehensive stormwater management issues. While the primary focus of the committee has been the reduction of existing flooding problems, it also has identified the protection and improvement of water quality as major objectives. While committee members are concerned about water quality, they are also concerned about the potential expense of retrofitting urban BMPs in already developed areas. Therefore, a goal is to target BMPs to priority areas, where their effectiveness is maximized.

Background

Butterfield Creek drains a 26-square-mile watershed in Cook and Will Counties in northeastern, suburban

Illinois. Its land use is largely residential and commercial in downstream areas. Much of the upstream watershed is presently undeveloped, although urbanization is anticipated. Existing water quality and stream use data indicate degraded conditions. There are no major permitted point source discharges to the stream, leading to the conclusion that nonpoint source impacts are the likely causative factors for the observed conditions.

Targeting and Prioritization Procedure

The elements of the targeting and prioritization procedure are as follows:

- Characterization of the watershed, including:
  - Subwatershed identification
  - Land-use identification
  - Nonpoint source impacts
- Incorporation of additional relevant factors, based on watershed conditions, into the documented targeting procedure.
- Calculation of pollutant loads and completion of targeting table.
- Prioritization of drainage areas for nonpoint control.

Characterization of Butterfield Creek

Subwatershed Identification

Butterfield Creek is composed of three primary subwatersheds; the mainstem, the east branch, and the west branch. The two branches are parallel systems that are tributary to the mainstem. Approximately 25 percent of the watershed drains to the east branch, and approximately 36 percent of the watershed drains to the west branch. The remaining 39 percent of the watershed drains directly to the mainstem, which is entirely downstream of the two branches.

Land-Use Identification

Land use in the Butterfield Creek watershed was interpreted from 1990 aerial photographs (1 in. equals 400 ft). This information was then digitized and entered into an ARC/INFO geographic information system. Subwatershed boundaries also were entered into the system, and land-use totals were cumulated for both the total watershed and the three distinct subwatersheds (west branch, east branch, and mainstem). This information is presented in Table 1.

About 55 percent of the watershed has been developed into the following urban land-use categories: industrial, commercial/institutional, residential, highway/arterial roadway, railroad, and urban park and golf course. The remainder, including woodland/wetland areas, agricultural land, and vacant land, remains undeveloped. Most of the undeveloped land lies in upstream parts of the watershed, particularly the west branch.

Stream Conditions

Stream conditions were assessed based on review of existing aquatic life, water quality, and sediment quality data as described in the preliminary nonpoint source plan (2). Physical habitat data were collected during development of the preliminary nonpoint source management plan.

Aquatic Life, Water Quality, and Sediment Quality

The existing data indicated degraded fish community conditions throughout the watershed. As is typical with many urban streams, species diversity and number are quite low relative to less urbanized streams in Illinois. Water quality conditions were also generally degraded, particularly in the more urban reaches. Sediment quality data paralleled the water quality data, with more elevated levels recorded in urban reaches.

Physical Habitat

Physical habitat conditions in Butterfield Creek were assessed during field visits to the creek. Data were collected on stream condition reporting forms created for the nonpoint source management planning effort. Conditions such as degree of channelization, stream and riparian vegetation, substrate material, erosion and sedimentation, and observations of benthics and macroinvertebrates and fish species were recorded. The site visits indicated highly variable conditions. The west and east branches tended to be highly channelized as a result of agricultural and urban drainage activities. Mainstem reaches tended to be less altered but appeared to suffer from the effects of flow destabilization due to urban stormwater runoff. Channel erosion and widening was prevalent in many downstream reaches.

Assessment of Nonpoint Source Impacts

Considering all available information from Butterfield Creek and comparing its characteristics to other streams in Illinois, the following conclusions were made regarding nonpoint source impairment in Butterfield Creek.

Stream Uses

Many potential stream uses identified by the Illinois Environmental Protection Agency (IEPA) are inherently constrained by the size and flow of Butterfield Creek. Uses that Butterfield Creek can be expected to support and that were evaluated are fish and aquatic wildlife (including warm water fishery), body contact recreation, and noncontact recreation. IEPA assessments indicate that present stream uses are moderately impaired.

Table 1. Watershed Land Use (square miles)

Land Use Category	Subwatershed			Total Watershed	
	West Branch	East Branch	Mainstem	Square Miles	Percent of Total
Industrial	0.037	0.079	0.022	0.14	0.54
Commercial/Institutional	0.196	1.027	0.669	1.89	7.38
Low-density residential	1.342	1.369	4.036	6.75	26.33
High-density residential	0.230	0.188	1.655	2.07	8.09
Vacant	0.980	1.238	0.657	2.87	11.22
Open land/urban park	0.171	0.152	1.552	1.87	7.32
Highway/arterial road	0.541	0.265	0.298	1.10	4.30
Agriculture	3.954	1.816	0.233	6.00	23.43
Woodland/wetland	1.828	0.274	0.568	2.67	10.43
Railroad	0.019	0.082	0.143	0.24	0.95
Watershed total	9.30	6.49	9.83	25.62	100.00
Watershed rank value	3.63	2.53	3.84	10.00	

While Butterfield Creek is not presently used to a great degree for water-based recreation, it is a potentially valuable unit of the downstream Thorn Creek and Little Calumet River systems. Also, Butterfield Creek is a valuable indicator of the nonpoint source effects of urbanization on receiving stream quality in northeastern Illinois. Improvement of uses in the larger streams will require the successful restoration of streams such as Butterfield Creek.

Stream Use Impacts

Based on existing data, the most readily identified impacts to uses in Butterfield Creek are related to degraded physical conditions. These conditions include degraded physical habitat, as evidenced by artificially modified or eroded channels, and impaired aesthetics, due in part to debris and trash. Low dissolved oxygen also appears to be a limiting constraint to improved aquatic life uses, particularly in the east branch and several reaches of the mainstem.

Several other water quality factors, including toxicity to aquatic life, turbidity, and siltation, were identified as contributing constraints to improved stream uses. Based on existing data from Butterfield Creek and other urban streams, however, whether these water quality factors by themselves limit the potential stream uses in much of Butterfield Creek is unclear.

Causes of Stream Use Impacts

The primary causes of stream use impacts in Butterfield Creek include physical habitat alterations, flow destabilization, channel erosion, bacterial contamination, nutrient enrichment, and noxious aquatic plants/algae.

Other suspected causes of use impairment include heavy metals, pesticides, oil and grease, unknown toxicity, organic enrichment, and suspended solids. Again, relying on the existing database, determining the degree to which these latter causes adversely affect stream use attainment is difficult.

Contributing Nonpoint Sources

The most prevalent nonpoint source responsible for use impairment in Butterfield Creek is urban runoff, which causes both physical and chemical degradation of the creek. Other significant nonpoint sources include streambank modifications, channelization, and removal of riparian vegetation.

Several other sources have been identified as contributing to stream use impairment, although their relative effects are much less certain. These include onsite wastewater systems, illicit sewer connections, golf course runoff, draining/filling of wetlands, construction site runoff, debris jams/beaver dams, carp/nuisance fish, and nonirrigated crop production.

Finally, potential point-source-related impacts were noted but could not be quantified. These included the treated wet-weather discharge from the former Homewood wastewater treatment plant, wastewater discharges from Ely's Mobile Home Park and Idlewild Country Club, and sanitary sewer overflows.

Application of Urban Targeting Methodology

Overview of Procedure

Objectives of Butterfield Creek Application

This section describes the application of the targeting methodology to Butterfield Creek. The major purpose of this effort is to assess the applicability of the methodology for nonpoint source watershed planning in northeastern Illinois streams.

Comparison of Butterfield Creek Application to Example Watershed

The assessment of nonpoint source impacts has led to some very important conclusions that drive the application of the targeting methodology for Butterfield Creek. Perhaps unlike many other urban watersheds, the nonpoint source assessment of Butterfield Creek did not identify pollutants delivered by urban runoff (e.g., heavy metals, toxic organics) as the primary cause of use impairment. Instead, physical disturbances, including stream channelization and flow destabilization, appear to be among the most significant causes of impairment. (Considering both physical and chemical effects, urban runoff is the most important nonpoint source requiring remediation in the mainstem of the creek.) This conclusion causes the BMP selection procedure to emphasize measures that control runoff rate as well as runoff quality. Because there is not a wide range of potential BMPs addressing this problem, BMP selection becomes more straightforward. As a result, this paper places more emphasis on the targeting aspect of the methodology.

Another difference between Butterfield Creek and the example watershed presented in the methodology report is that stream use attainment in Butterfield Creek does not vary dramatically among subwatersheds. All three subwatersheds of Butterfield Creek are significantly impaired, although the causes of impairment vary substantially among the subwatersheds.

Still another difference between Butterfield Creek and the example watershed is the orientation of the subwatersheds. In the example, there were three parallel stream segments. In Butterfield Creek, there are two parallel stream segments that are tributary to the third. Therefore, BMPs implemented in the two upstream watersheds affect both the local watershed and the downstream watershed. Similarly, adequately addressing problems in the downstream subwatershed without applying some BMPs in upstream areas may be impossible.

Further, the three watersheds differ significantly in the levels of potential use attainability. Both the west and east branches are headwater streams with low dry-weather flows. Mainstem flows are more substantial, and its larger channel dimensions allow greater potential for full stream use.

Computation of Pollutant Loadings

The methodology report describes a procedure for estimating pollutant loadings by land-use category. The procedure involves the assignment of runoff coefficients and pollutant concentrations to watershed land uses.

Runoff Coefficients

The first step is to assign a dimensionless runoff coefficient to each land use. The runoff coefficient is a measure of the watershed response to rainfall events and is intended to be equivalent to the total storm runoff divided by the total rainfall volume for runoff-producing rain events. The runoff coefficient (Rv) is estimated from the percent imperviousness of individual land uses by the following equation (4):

$$Rv = 0.05 + (0.009 * \text{percent impervious}). \quad \text{(Eq.1)}$$

While this methodology is quite simplistic with respect to true watershed hydrologic response, it is an appropriate way to represent the relative runoff responses of different land uses to pollutant-generating rainfall/runoff events. As such, it represents only the short-term surface component of runoff and is not intended to represent the complete storm hydrograph.

Pollutant Concentrations

The methodology report also includes suggested pollutant concentrations for different land uses. These concentrations can be used in conjunction with the runoff coefficients to estimate differences in expected pollutant loads for different land uses. The methodology report makes it clear, however, that these concentrations are not intended to be used in the estimation of actual pollutant loads for the area. Also, the methodology report provides concentrations for just six land-use types. Four additional land uses were used to represent Butterfield Creek, and pollutant concentrations for these were derived from both local sources (5) and the methodology report.

Table 2 summarizes the runoff coefficient and pollutant concentration assumptions for the Butterfield Creek land uses. These estimates are used to reflect relative differences in runoff rates and pollutant loads and are not intended to estimate actual loads.

Pollutant Loadings

Pollutant loads from runoff and concentration are computed as follows:

Table 2. Runoff Coefficients and Pollutant Concentrations by Land Use

Land-Use Category	Runoff Coefficient	Pollutant Concentrations (mg/L)			
		TSS	O&G	TP	Copper
Industrial	0.60	120	20	0.20	0.05
Commercial/institutional	0.70	80	20	0.20	0.05
Low density residential	0.20	100	5	0.60	0.03
High density residential	0.40	90	10	0.40	0.04
Vacant	0.10	60	0	0.20	0.01
Open land/urban park	0.10	50	0	0.60	0.01
Highway/arterial road	0.60	80	15	0.20	0.05
Agriculture	0.10	150	0	0.80	0.01
Woodland/wetland	0.05	50	0	0.20	0.01
Railroad	0.20	60	15	0.20	0.05

Mass load (pounds) =
Rv • area (acres) • concentration (mg/L) • 0.227. (Eq. 2)

This computation provides an estimate of the relative pollutant load per inch of runoff-producing rain.

Runoff Rates

As previously indicated in the summary of nonpoint source impacts to the watershed, pollutant loadings in stormwater runoff do not appear to be the limiting cause of stream use attainment. The quantity or rate of runoff from urban land uses, however, does appear to be a limiting constraint to improved stream uses, especially for aquatic life. In particular, the expansion of impervious surfaces increases the rate and volume of runoff for storm events and reduces stream base flow. This altered hydrology destabilizes the receiving stream channel and adversely affects habitat. Another cause of physical habitat impairment is channel modification (e.g., channelization, armoring).

Although runoff rate was not used as a targeting factor during development of the methodology, it can be incorporated readily. The runoff coefficient provides a similar indicator of runoff "load" as the product of runoff coefficient and concentration provides for pollutant load.

Comparison of Relative Loads: Targeting

Watershed Pollutant Loads

Using the methodology described in the previous section, pollutant and runoff loads were estimated by land-use category for each subwatershed and the overall watershed. Tables 3 through 6 summarize pollutant loadings for total suspended solids (TSS), oil and grease (O&G), total phosphorus (TP), and copper, and Table 7 summarizes storm runoff.

Total Suspended Solids. Evaluation of Table 3 indicates that TSS loads vary by subwatershed, but not to a great degree. There is, however, a great deal of variability in loadings between land-use categories. This variability is based on differences in runoff coefficients and pollutant concentrations (summarized in Table 2).

Figure 1 presents TSS loadings in a different fashion. This map visually represents loading intensity. It suggests, for example, that TSS loads could be reduced significantly by targeting just those areas of the watershed that contribute at high rates (e.g., greater than 4,000 lb/mi^2). The nonpoint source assessment of Butterfield Creek identified TSS as a contributing cause of use impairment, particularly for aquatic life and recreational uses. While TSS does not appear to be as important as some other identified causes of use impairment (such as flow destabilization, physical habitat alteration, and channel erosion), it still should be addressed in the final watershed management plan. The targeting information presented in this section will be useful in determining a comprehensive control strategy.

Oil and Grease. O&G loadings as presented in Table 4 vary dramatically by both subwatershed and land use. The reason for this greater variability is the fact that oil and grease is assumed to originate completely from developed urban areas. Therefore, there is a relatively small loading in the mostly nonurbanized west branch subwatershed.

As with TSS, if O&G control was a high priority for stream use remediation, it would be relatively easy to identify areas for BMP targeting by using a map similar to Figure 1 for O&G. As indicated in the nonpoint source

Table 3. Total Suspended Solids Loading (pounds per inch of rain)

	Subwatershed			Total Watershed	
Land-Use Category	West Branch	East Branch	Mainstem	Pounds	Pounds/ Sq. Mile
Industrial	389.0	827.1	233.8	1,450	10,357
Commercial/institutional	1,817.5	9,533.2	6,207.7	17,568	9,290
Low-density residential	3,892.9	3,970.8	11,700.0	19,564	2,898
High-density residential	1,200.3	983.5	8,641.3	10,825	5,229
Vacant	852.5	1,075.7	572.2	2,500	871
Open land/urban park	124.1	110.0	1,125.6	1,360	727
Highway/arterial road	3,765.5	1,846.2	2,061.7	7,673	6,976
Agriculture	8,601.9	3,951.8	505.8	13,060	2,177
Woodland/wetland	663.0	99.4	206.1	968	383
Railroad	44.1	189.3	332.4	566	2,357
Watershed total	2,1351	22,587	31,587	75,524	2,948
Watershed rank value	2.8	3.0	4.2	10.0	

Table 4. Oil and Grease Loading (pounds per inch of rain)

	Subwatershed			Total Watershed	
Land-Use Category	West Branch	East Branch	Mainstem	Pounds	Pounds/ Sq. Mile
Industrial	64.9	138.1	39.0	242	1,739
Commercial/institutional	455.1	2,387.1	1,554.4	4,397	2,319
Low-density residential	195.0	198.8	586.3	980	145
High-density residential	133.6	109.4	961.7	1,205	580
Vacant	0.0	0.0	0.0	0	0
Open land/urban park	0.0	0.0	0.0	0	0
Highway/arterial road	707.2	346.7	387.2	1,441	1,304
Agriculture	0.0	0.0	0.0	0	0
Woodland/wetland	0.0	0.0	0.0	0	0
Railroad	8.3	35.5	62.4	106	435
Watershed total	1,564	3,216	3,591	6,371	327
Watershed rank value	1.9	3.8	4.3	10.0	

assessment, O&G is identified as a potential, but not major, contributor to use impairment.

Total Phosphorus. Total phosphorus loadings as presented in Table 5 vary the least among the land-use categories. This is explained by the fact that relatively high concentrations are assumed for low-density residential and agricultural land uses, and these concentrations counterbalance the relatively low runoff coefficients for these uses.

Copper. The last pollutant to be presented is copper. Copper loadings are presented in Table 6 and Figure 2. Relative differences in copper loadings are similar to those observed for O&G in that the heaviest loadings come exclusively from intensely developed urban land uses. Figure 2 makes clear that effective reduction of total copper loadings could be achieved by targeting a relatively small fraction of the total watershed for BMPs.

Available data, however, suggest that copper is not a major cause of stream use impairment in Butterfield Creek. While violations of the copper water quality standard occur with some frequency, acute toxicity to fish due to copper concentrations in stormwater does not appear to be problematic. Nonetheless, copper may be used as an effective surrogate for other urban runoff toxicants, particularly other heavy metals, which are believed to play a role in limiting aquatic life in the creek.

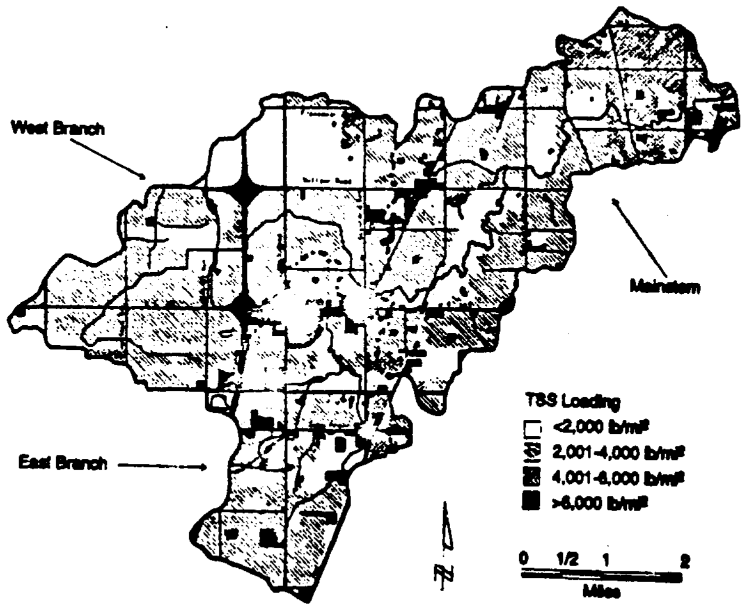

Figure 1. TSS loading per inch of rain, Butterfield Creek.

Table 5. Total Phosphorus Loading (pounds per inch of rain)

	Subwatershed			Total Watershed	
Land-Use Category	**West Branch**	**East Branch**	**Mainstem**	**Pounds**	**Pounds/ Sq. Mile**
Industrial	0.648	1.379	0.390	2.4	17.4
Commercial/institutional	4.544	23.833	15.519	43.9	23.2
Low-density residential	23.358	23.824	70.238	117.4	17.4
High-density residential	5.335	4.371	38.406	48.1	23.2
Vacant	2.842	3.586	1.907	8.3	2.9
Open land/urban park	1.489	1.320	13.507	18.3	8.7
Highway/arterial road	9.414	4.615	5.154	19.2	17.4
Agriculture	45.877	21.077	2.698	69.7	11.6
Woodland/wetland	2.652	0.397	0.824	3.9	1.5
Railroad	0.110	0.473	0.831	1.4	5.8
Watershed total	96.3	84.9	149.5	330.6	12.9
Watershed rank value	2.9	2.6	4.5	10.0	

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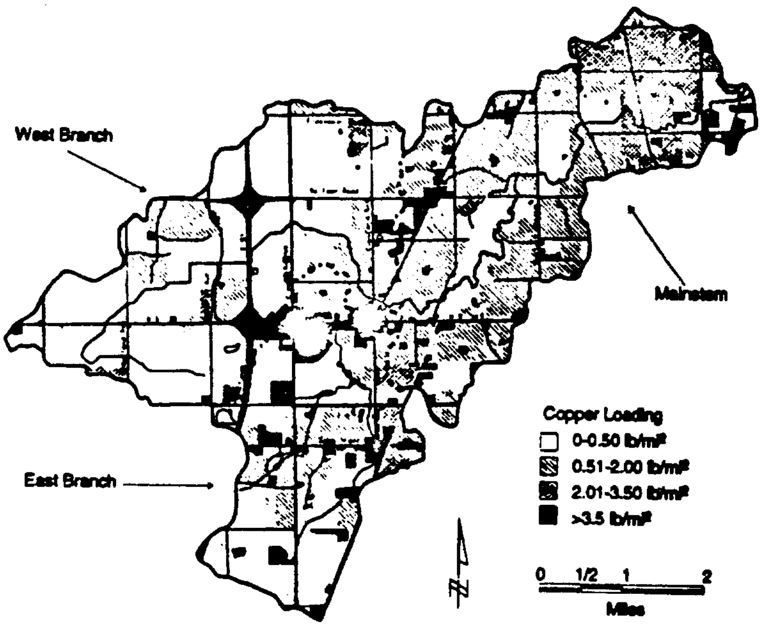

Figure 2. Copper loading per inch of rain, Butterfield Creek.

Table 6. Copper Loading (pounds per inch of rain)

	Subwatershed			Total Watershed	
Land-Use Category	**West Branch**	**East Branch**	**Mainstem**	**Pounds**	**Pounds/ Sq. Mile**
Industrial	0.16	0.35	0.10	0.6	4.3
Commercial/institutional	1.14	5.97	3.89	11.0	5.8
Low-density residential	1.17	1.19	3.52	5.9	0.9
High-density residential	0.53	0.44	3.85	4.8	2.3
Vacant	0.14	0.18	0.10	0.4	0.1
Open land/urban park	0.03	0.02	0.23	0.3	0.1
Highway/arterial road	2.36	1.16	1.29	4.8	4.3
Agriculture	0.57	0.26	0.03	0.9	0.1
Woodland/wetland	0.13	0.02	0.04	0.2	0.1
Railroad	0.03	0.12	0.21	0.4	1.4
Watershed total	6.3	9.7	13.2	29.2	1.1
Watershed rank value	2.1	3.3	4.5	10.0	

Storm Runoff. Although runoff is not a pollutant, it has been shown to be nearly as important as pollutant loading for causing degradation of stream uses. Storm runoff "loadings" in units of acre-inch/inch of rain are presented in Table 7 and Figure 3. Relative differences in storm runoff loadings are similar to those observed for O&G and copper, and high rates of runoff are from intensely developed urban land uses. Table 7 suggests that, as with the urban pollutants, targeting a relatively small area could reduce the overall loading by a substantial proportion. Figure 3 indicates that the same areas contributing high copper loads are contributing high storm runoff rates.

Evaluation of BMP Alternatives for Butterfield Creek

The methodology report describes several BMP types, including detention, retention, vegetative controls, and source controls. Each of these were discussed briefly in the Butterfield Creek targeting report (3), and that discussion will not be repeated here. The important conclusions from that discussion follow.

The feasibility of implementing certain BMPs differs dramatically between remedial applications (i.e., existing development) and preventative applications (i.e., new development or redevelopment). Most of the municipalities in the Butterfield Creek watershed have recently adopted comprehensive stormwater management ordinances that require implementation of effective detention designs for development activities and require site-by-site evaluation of other BMPs, such as infiltration trenches, filter strips, and vegetated buffers. The ordinance discussed here was developed by the Butterfield Creek Steering Committee.

The limiting cause of stream use impairment in Butterfield Creek is hydrologic destabilization and streambank modification/channelization. After addressing these problems, however, full uses still may not be supported without addressing contributing water quality factors. Thus, BMPs for Butterfield Creek must control both runoff rates or volumes and pollutant loadings.

Stormwater detention is a widely accepted practice in the watershed, and recent experience indicates that the stringent designs that accommodate pollutant removal functions are implementable. The generally accepted detention design for new development among watershed communities calls for limiting the runoff rate for the 2-year storm to 0.04 ft^3/sec/acre. This should provide effective pollutant removal as well as control of rates for most storm events. Virtually the only other management practice capable of controlling runoff volumes (and rates) is infiltration (retention devices). This practice, however, has not been widely applied in the watershed or throughout the northeastern Illinois region. The primary constraint to using infiltration practices is the relatively impervious soils of the region.

Most existing detention facilities in the watershed were built without consideration of pollutant removal functions or rate control of more routine events. Investigation of typical facilities, however, suggests that most could be readily retrofitted by installing new outlet controls and performing minor regrading to achieve substantial water quality and rate control benefits. Similarly, there are open areas (e.g., school yards, parks, vacant land) in the watershed where detention could be constructed adjacent to existing uncontrolled developments.

Detention retrofitting has the benefit of controlling both water quality and runoff rate to address stream use impairments as well as flood control benefits, which are often perceived as greater needs. Thus, detention retrofitting has the greatest potential for reducing constraints to stream uses as well as the greatest implementability. Targeting of detention retrofitting is discussed in the following section.

Reduction of Pollutant and Storm Runoff Loads via Detention Retrofitting

To demonstrate how targeting of BMPs can remediate high pollutant loadings in Butterfield Creek, it was assumed that detention basin retrofitting would be applied to land uses contributing high copper loads. These included industrial, commercial/institutional, and high-density residential uses, representing 16 percent of the total watershed area. For purposes of this evaluation, it is assumed that under existing conditions there is no effective detention-based control of copper runoff from these land uses. This is generally true in that much of the historical development in the watershed occurred without detention requirements. Further, most detention facilities built subsequent to the promulgation of ordinance requirements did not include pollutant removal features. Another significant contributor of copper loads, highways/arterial roads, was not considered for this BMP because of the general unavailability of land within right-of-ways to implement detention.

Targeting is also demonstrated for remediating high storm-runoff rates. Because the same land uses that contribute high copper loadings also contribute the highest runoff rates, the same 16 percent of the area will be targeted for runoff rate control. As with copper, it is assumed that under existing conditions there is no effective control of the 2-year and smaller storm events most affected by urbanization.

Effective detention retrofitting designs, based on fully detaining runoff from the 2-year storm (as now required by most Butterfield Creek communities), was assumed to remove 60 percent of the copper load. Table 8 and Figure 4 show the effects of this action. By controlling

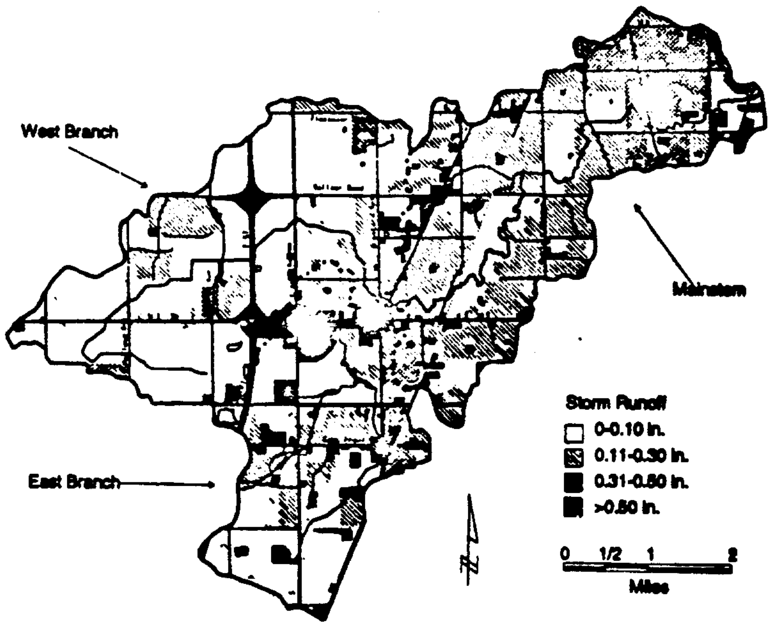

Figure 3. Storm runoff per inch of rain, Butterfield Creek.

Table 7. Storm Runoff (inch-acres per inch of rain)

Land-Use Category	Subwatershed: West Branch	Subwatershed: East Branch	Subwatershed: Mainstem	Total Watershed: Inch-Acres	Total Watershed: Inches
Industrial	14.3	30.4	8.6	53	0.80
Commercial/institutional	100.2	525.8	342.4	968	0.80
Low-density residential	171.8	175.2	516.5	863	0.20
High-density residential	58.8	48.2	423.7	531	0.40
Vacant	62.7	79.1	42.1	184	0.10
Open land/urban park	10.9	9.7	99.3	120	0.10
Highway/arterial road	207.7	101.8	113.7	423	0.60
Agriculture	253.0	116.2	14.9	384	0.10
Woodland/wetland	58.5	8.8	18.2	85	0.05
Railroad	2.4	10.4	18.3	31	0.20
Watershed total	940	1,106	1,598	3,644	0.22
Watershed rank value	2.6	3.0	4.4	10.0	

just 16 percent of the watershed via detention retrofitting, the total watershed copper load is reduced from 29.2 lb/in. of rain to 19.3 lb/in. of rain, a 34-percent reduction. This example demonstrates quite clearly the value of being able to target BMPs within a watershed.

It is assumed that effective detention retrofitting, which includes control of runoff from the 2-year storm to 0.04 ft^3/sec/acre, can limit the storm runoff rates (not volumes) for high-intensity land uses to the runoff rate from nonurbanized land. Table 9 and Figure 5 illustrate the effects of this control being applied to industrial, commercial/institutional, and high-density residential land uses. Comparing Table 7 to Table 9 indicates that the short-term, storm runoff rate is reduced by 35 percent for the entire watershed, from 0.22 in. per in. of rain to 0.14 in. per in. of rain. The reduction in storm runoff rate is even more dramatic for the mainstem (39 percent). In other words, if detention retrofitting can be implemented for just 16 percent of the creek watershed, short-term storm runoff can be reduced dramatically, thereby reducing downstream bank erosion and habitat destabilization effects. While detention retrofitting will have relatively little effect on total runoff volumes, it will dampen stormwater runoff peaks substantially and also produce significant pollutant removal benefits.

Application of Watershed Prioritization Analysis

The methodology report briefly describes a procedure for prioritizing subwatersheds for BMP targeting. This procedure relies on a number of factors (including water body importance; type, status, and level of use; pollutant loads, and implementability of controls) to rank subwatersheds. The relative importance of these factors is indicated by assigning weights. As discussed previously, the Butterfield Creek watershed orientation is different from the example presented in the methodology report and, as a result, may not be as appropriate for this type of prioritization as the example. Nonetheless, the suggested prioritization methodology is illustrated in the following example.

Assignment of Prioritization Factors

The methodology report recommends the assignment of factors based on relative rankings. For purposes of this evaluation, the ranking scale ranges from 0 to 10.

Water Body Importance/Stream Size

Stream size factors are assigned in proportion to the total drainage area providing flow to the stream. Subwatershed drainage area rank values were previously computed and are presented in Table 1.

Beneficial Use Type

Use-type ranks are based on the nature of potential use of the stream reach. The mainstem is assigned a relatively high rank because of the presence of riparian public open space and because its size and physical characteristics offer the most potential for aquatic life and recreational uses. The west and east branches are assigned relatively lower ranks because of their more limited potential and because of the perception, particularly for sections of the east branch, that the stream's primary function is drainage.

Table 8. Copper Loading[a] With Detention Basin Retrofitting for Industrial, Commercial/Institutional, and High-Density Residential Areas (pounds per inch of rain)

	Subwatershed			Total Watershed	
Land-Use Category	West Branch	East Branch	Mainstem	Pounds	Pounds/Sq. Mile
Industrial	0.07	0.14	0.04	0.2	1.7
Commercial/institutional	0.45	2.38	1.55	4.4	2.3
Low-density residential	1.17	1.19	3.51	5.9	0.9
High-density residential	0.21	0.18	1.54	1.9	0.9
Vacant	0.14	0.18	0.10	0.4	0.1
Open land/urban park	0.03	0.02	0.23	0.3	0.1
Highway/arterial road	2.35	1.15	1.29	4.8	4.3
Agriculture	0.57	0.26	0.03	0.9	0.1
Woodland/wetland	0.13	0.02	0.04	0.2	0.1
Railroad	0.03	0.12	0.21	0.4	1.4
Watershed total	5.2	5.6	8.5	19.3	0.8
Watershed rank value	2.7	2.9	4.4	10.0	

[a]60 percent loads reduction assumed for targeted areas

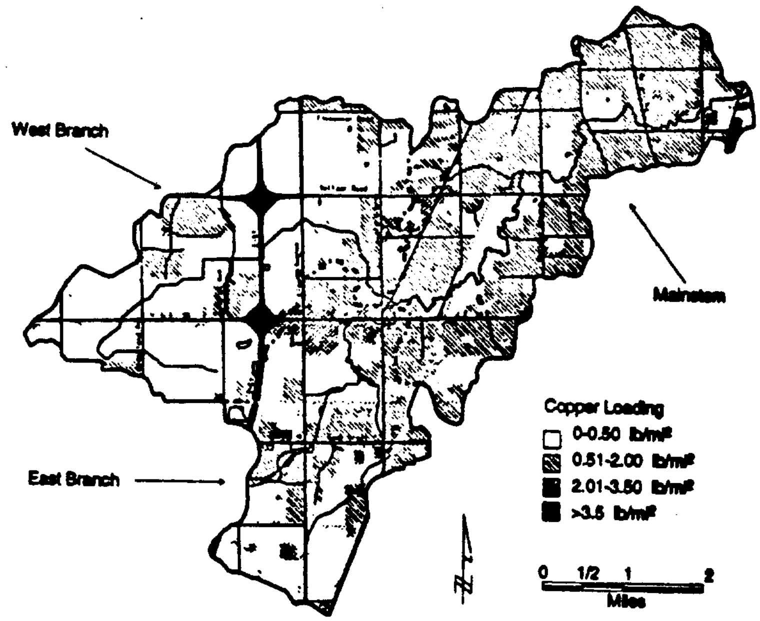

Figure 4. Copper loading per inch of rain, Butterfield Creek (with detention basin retrofitting for industrial, commercial/institutional, and high-density residential areas).

Table 9. Storm Runoff[a] With Detention Basin Retrofitting for Industrial, Commercial/Institutional, and High-Density Residential Areas (inch-acres per inch of rain)

Land-Use Category	Subwatershed			Total Watershed	
	West Branch	East Branch	Mainstem	Inch-Acres	Inches
Industrial	2.4	5.1	1.4	9	0.10
Commercial/institutional	12.5	65.7	42.8	121	0.10
Low-density residential	171.8	175.2	516.5	863	0.20
High-density residential	14.7	12.1	105.9	133	0.10
Vacant	62.7	79.1	42.1	184	0.10
Open land/urban park	10.9	9.7	99.3	120	0.10
Highway/arterial road	207.7	101.8	113.7	423	0.60
Agriculture	253.0	116.2	14.9	384	0.10
Woodland/wetland	58.5	8.8	18.2	85	0.10
Railroad	2.4	10.4	18.3	31	0.05
Watershed total	797	584	973	2,354	0.20
Watershed rank value	3.4	2.5	4.1	10.0	0.14

[a]Reduction of runoff coefficient to 0.1 for targeted areas

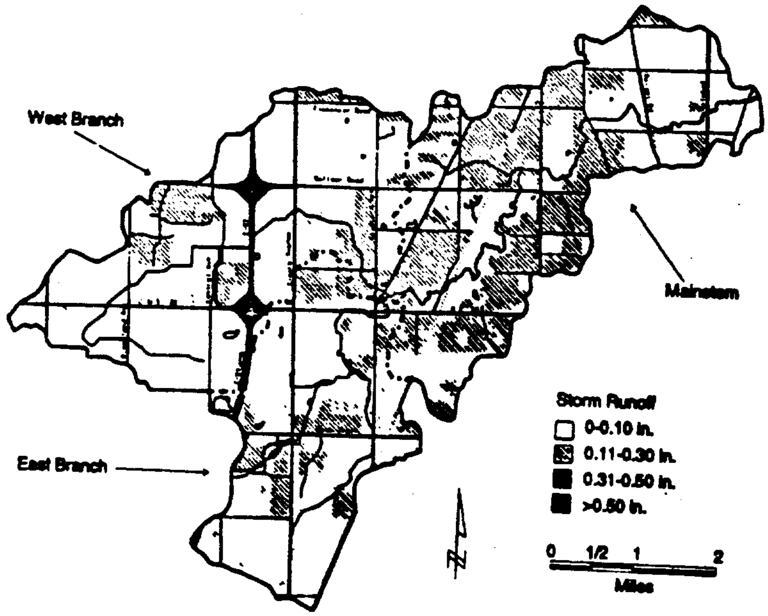

Figure 5. Storm runoff per inch of rain, Butterfield Creek (with detention basin retrofitting for industrial, commercial/institutional, and high-density residential areas).

Beneficial Use Status

The methodology report is somewhat unclear regarding the determination of this factor. It is assumed in this example that use status reflects the degree of restoration and protection needed to achieve desired beneficial uses. Because each of the branches is similar in its relative degree of aquatic life use impairment, similar factors are assigned. The mainstem's ranking is slightly lower, however, because of the greater level of streamside activities presently supported.

Beneficial Use Level

This factor reflects the level of stream use relative to other water bodies in the target watershed. For Butterfield Creek subwatersheds, use level considers accessible riparian and accessible open space (e.g., parks and golf courses) and the presence of residential land use adjacent to the stream corridor. With these factors considered, the mainstem is assigned the highest ranking, followed by the east branch and the west branch.

Pollutant Loads

This factor represents the degree of pollutant loading or some other cause that is impairing water body use. In this example, runoff rate (rather than quality) is used to reflect this factor. Storm runoff rate factors are derived from Table 7.

Implementability of Controls

This factor is assumed to represent the relative degree of implementability of control measures. In this example, the recommended control measure to reduce storm runoff rates is detention basin retrofitting. As was discussed previously, retrofitting of existing highway/arterial roads probably will not be feasible in most areas. Beyond that, distinguishing the relative implementability of retrofitting based on institutional or technical factors is not easy. For this reason, ranks are assigned on the basis of watershed size and the relative degree of high-density urban development. Another factor that could have been considered is the relative proximity of targeted land uses. Large concentrations of targeted land uses could more readily be addressed through more cost-effective regional controls.

Table 10 presents ranks for each of these factors by subwatershed. It includes an assignment of factors for the total watershed as well. The recommended basis for assignment of total watershed factors is not described in the methodology report. In the Butterfield Creek example, totals of the subwatershed ranks are used for both stream size and stormwater rate. For the remaining

Table 10. Butterfield Creek Prioritization Analysis

Watershed	Stream Size	Beneficial Use: Type	Beneficial Use: Status	Beneficial Use: Level	Stormwater Rate	Ability To Implement	Target Score
Weights	25	10	10	5	25	25	100
West branch	3.63	4	7	3	2.6	8	4.61
East branch	2.53	3	8	4	3.0	4	3.68
Mainstem	3.84	6	6	7	4.4	4	4.61
Total watershed	10.00	5	7	5	10.0	5	7.70

Target score = weighted average of rank points = sum (rank score • weight) / sum (weights)

factors, approximate averages of the subwatershed ranks are used.

Assignment of Relative Weights

The methodology report recognizes that some factors may be more important than others and suggests that these differences be accounted for by assigning different weights to each factor. The report also recognizes that considerable subjectivity is involved in the selection of factors and the assignment of ranks and relative weights.

Discussions with representatives from the watershed, primarily the Butterfield Creek Steering Committee, were considered in assigning relative weights for Butterfield Creek. The actual assignment, however, becomes somewhat challenging for several reasons. First, as indicated, evaluation of the different factors is quite subjective, and quantification, even in relative terms, is difficult. Second, while the listed evaluation factors are clearly important to the efficient remediation of use constraints in Butterfield Creek, they are difficult to compare and weight relative to each other. Third, as discussed previously, because two of the stream branches flow into the third, the remediation of problems in the third branch (the mainstem) is clearly not independent of remedial activities in the other branches. The example from the methodology report does not directly reflect this interdependence.

Bearing in mind these qualifications, weights were assigned to the identified factors by following the procedure described in the methodology report. As seen in Table 10, equal weights of 25 are assigned to the four factors. For the beneficial-use category, weights are assigned to the three subcategories so that they total 25.

Results of Watershed Prioritization

On the basis of the assignment of weights and factors as described above, stormwater rate controls should be applied first to the west branch, followed closely by the mainstem, and then the east branch. Just as in the example in the methodology report, however, the "total watershed" receives the highest target score, implying priority control of the entire watershed.

In evaluating the results of this prioritization to Butterfield Creek, the west branch apparently receives the highest subwatershed priority primarily because it scores quite well in the ability-to-implement category. In reality, its high score in this category is due to the relatively little high-density urbanization within its watershed and, therefore, its relative ease of control. The east branch receives the lowest targeting score because it is smallest in watershed size and because it scores poorly relative to potential beneficial uses.

The interpretation of the total watershed score of 7.7, higher than each of the subwatershed scores, is somewhat perplexing. The procedure applied to Butterfield Creek, which establishes total watershed ranks as averages or sums of the subwatershed ranks, always results in the total watershed receiving the highest score. This implies that problem remediation (or prevention) always should be addressed watershedwide, despite the results of subwatershed prioritization. It also may suggest that the assumptions used in arriving at total watershed ranks are not appropriate and, therefore, the total watershed score should not be compared with the subwatershed scores.

Overall, the results of this simple analysis are quite interesting. Intuitively, if limited funds are available for remedial measures, it makes sense to spend them in subwatersheds in which stream use has the most potential for improvement and in which remedial activities are most implementable. The results for Butterfield Creek, in which the mainstem and west branch receive similarly high targeting scores, are generally consistent with this logic. Because conditions in the mainstem also are dependent on nonpoint contributions from the east branch, however, it may not be possible to eliminate critical use constraints and to fully restore mainstem stream uses without applying effective BMPs watershedwide.

Other Prioritization Applications

Application of the prioritization in this watershed was not straightforward due to the configuration of the watershed. Based on the experience gained in this application, however, it is apparent that there are two cases in which the prioritization methodology would be more useful and straightforward. The first case would be in prioritizing restoration efforts between separate watersheds under a single management agency or funding source. The second case would be in prioritizing efforts within a single watershed tributary to a critical resource (e.g., recreational lake, high-quality stream segment, water supply reservoir).

Prioritizing Between Distinct Watersheds

During development of a statewide or regionwide nonpoint source control program, limited funds often must be prioritized between distinct watersheds within the region. This methodology provides a relatively objective method for assigning priorities to watersheds competing for funds. To ensure acceptance of the results of the prioritization and to avoid conflicts between competing watershed officials, involving the officials and interested parties from all of the watersheds in the assignment of ranking and weighting factors is very important. Because they all have participated in that process and agreed on the ranks and weights, it will be difficult for them to dispute the outcome of the prioritization results. Therefore, a rational schedule can be developed for expenditures and efforts in the various watersheds.

Prioritizing Within a Watershed

During development of a watershed nonpoint source management plan, a particular resource within the watershed often motivates development of the plan. The methodology could be used readily to prioritize targeted land uses within that watershed. In this case, however, the beneficial use and probably even the stream size factors would be meaningless because all subwatersheds would be tributary to the same resource whose uses are being protected. The only two factors that would be used would be the pollutant load (or stormwater rate) and the ability to implement.

Summary and Conclusions

This report has discussed some of the strengths and weaknesses of the urban targeting and prioritization methodology as applied to Butterfield Creek in northeastern Illinois. Highlights of this evaluation are discussed below.

Technical Representation

The methodology recommends a relatively simple methodology for generating pollutant loads and assessing BMP effectiveness. For purposes of this type of application, which emphasizes relative loadings among land-use types and subwatersheds, this simplicity is appropriate and appears to produce reasonable results for Butterfield Creek. One shortcoming is that the technical procedure is limited to pollutant loads. Inclusion of runoff rates was readily incorporated into the methodology, however, making it more useful for urban streams such as Butterfield Creek.

Urban Targeting

The urban targeting component of the methodology worked quite well, especially when combined with mapping, which highlighted relative pollutant contributions by land use. Targeting also provided a fairly clear indication of the relative pollutant (and high runoff rate) contributions by subwatershed.

BMP Selection

Effective BMP selection must take into account the causes of stream use impairment as well as the physical characteristics of the watershed and the drainage system. In the application of the recommended BMP selection methodology to Butterfield Creek, it was clear that BMPs that control both pollutant loads and runoff rates would be required. As a result, detention facility retrofitting became, somewhat by default, the selected BMP for evaluation. The quantification procedure recommended in the methodology report worked quite well and was enhanced by the mapping of pollutant loadings.

Watershed Prioritization

The application of watershed prioritization to Butterfield Creek, based on assigning ranks and weights to prioritization factors among subwatersheds, was accomplished with some difficulty. Part of this difficulty was related to the subwatershed orientation in Butterfield Creek, in which two stream segments were tributary to a third. The existing methodology is not structured to address this situation. A related difficulty was the subjectivity involved in assigning relative ranks and weights to unrelated prioritization factors. The methodology would be more useful for prioritizing between distinct watersheds or prioritizing within a watershed all tributary to a single critical resource.

Remedial Versus Preventative Applications

The Butterfield Creek application of the targeting and BMP selection methodology focused on BMPs to remediate existing stream use impairments. This methodology could potentially be applied to assess preventative BMPs as well. In this context, pollutant loads could be assessed for a nonurbanized watershed, for a fully urbanized watershed without BMPs, and for a fully urbanized watershed with BMPs. For a nonurbanized watershed, however, some of the stream-use prioritization factors become irrelevant, assuming that stream use is relatively unimpaired before urbanization. In the Butterfield Creek watershed, several preventative BMPs have already been chosen for newly urbanizing areas. These include soil erosion and sediment control measures, effective stormwater drainage and detention controls, and stream and wetland protection requirements. These preventative BMPs have been endorsed by most watershed communities because of their multipurpose benefits (i.e., nonpoint control, flood prevention, channel erosion control, and aesthetic enhancement) and implementability. Partly for reasons of equity, local officials have no strong desire to target or prioritize these BMPs to particular land uses or subwatersheds.

Conclusions

One of the major benefits of this approach is that the user can document the decision-making process in a systemized fashion. The methodology also forces consideration of the interdependence of various technical and institutional factors in the decision-making process. In addition, the methodology enables the presentation of complex decision-making factors in a visual format. As a result, this methodology could be very useful in targeting BMPs in stream watersheds throughout northeastern Illinois. For successful application of the methodology, however, existing stream use impairments, causes, and nonpoint sources must be clearly understood. In most watersheds, this will require the collection and assessment of additional stream use and water quality data.

The primary limitations of the methodology may be its subjectivity and the fact that it attempts to represent complex watershed interrelationships in a relatively simple fashion. These shortcomings can be addressed by properly qualifying assumptions and providing thorough documentation of results, as well as by involving all of the interested parties in the ranking and weighting process. Without the proper awareness of critical assumptions, however, the methodology is capable of producing misleading or counterintuitive results. Another potential shortcoming of the methodology, revealed in its application to Butterfield Creek, is the difficulty in representing interdependent (i.e., upstream-downstream) subwatersheds and stream reaches.

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Development of a Comprehensive Urban Nonpoint Pollution Control Program

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Abstract

Comprehensive urban nonpoint pollution control is a new, rapidly developing multidisciplinary field. Significant water quality improvements will be achieved when all state and local governments have the necessary resources, knowledge, skills, and vision to implement effective programs. Urban nonpoint pollution has traditionally been addressed by relying heavily on structural stormwater control devices to treat contaminated runoff. Yet, this "band-aid" approach has proven relatively ineffective for controlling such a ubiquitous and poorly defined problem.

The objective of this paper is to illustrate some of the many problems, issues, and obstacles that federal, state, and local government agencies must address to facilitate further advancements in urban water quality control. A more comprehensive, watershed approach must be developed, specifically focusing on source prevention programs, improved technology, and intra-agency coordination. Measuring the effectiveness of innovative source control programs, such as public education, will become essential for targeting problems, focusing goals, and allocating resources to areas needing improvement.

Guidance for implementing these nonpoint pollution control strategies is needed to assist state and local governments. The nature, magnitude, and scope of urban nonpoint source pollution, one of the most fundamental and universal problems facing local governments, are issues that have yet to be adequately resolved. Without program guidance and leadership, the urban nonpoint pollution problem will persist and the quality of our nation's waters will further deteriorate.

Introduction

To address the complex nature of the national water pollution problem and the comprehensiveness of nonpoint pollution control, all states and municipalities must have access to the understanding, expertise, knowledge, resources, and insight needed to respond to difficult challenges and provide the most appropriate services and solutions. Effective water quality improvement will depend on the ability of municipalities to appropriately implement an array of preventative measures, management strategies, and treatment technologies for dealing with all aspects of water pollution.

Traditional offsite structural treatment is only one of the tools available for addressing this national problem. At the local level a variety of other innovative tools must be tailored to the unique problems and characteristics of a particular site, land use, community, or watershed. Nonpoint source pollution will be fully and effectively controlled only when municipalities understand how to identify problems, evaluate alternatives, and implement solutions.

Discussion

The magnitude and scope of critical issues associated with current urban nonpoint source control programs, such as the National Pollutant Discharge Elimination System (NPDES) program, must be appreciated to ensure success. To effectively implement the NPDES regulations, municipalities must address the following questions:

How Will the NPDES Goals Be Met?

The success of the municipal NPDES program in achieving the water improvement objectives of the Clean Water Act will depend heavily on the ability and commitment of each municipality to develop focused and effective comprehensive pollution control programs. To reduce nonpoint pollution to the maximum extent possible, local governments must be prepared to support and effectively implement the full range of necessary program components and to shift their programs to a more balanced approach between prevention and treatment.

Municipal governments need active leadership that empowers each jurisdiction with the necessary knowledge, tools, skills, and resources to implement effective programs. Ultimately, each municipality's success will be judged based on the ability to effectively implement program constituents related to planning, coordination, integration, education, prevention, management, maintenance, inspection, enforcement, funding, and appropriate use of technology. Many roadblocks, however, will inhibit the ability to accomplish these objectives. Funding and competition with other local programs are obvious barriers, while misunderstanding the nature of the problem, setting incorrect priorities, and focusing programs on nontraditional prevention strategies are less obvious pitfalls.

What Does Each Jurisdiction Need?

The successful integration of effective nonpoint source pollution reduction programs into traditional local stormwater programs is more easily accomplished if implementation problems are identified and thoroughly addressed. These problems can concern:

- Legal, financial, and political liabilities and issues.
- Public awareness, acceptance, and education.
- Development and implementation of adequate inspection programs for construction and maintenance.
- Development and implementation of effective enforcement programs.
- Funding options for various programs.
- Integration, coordination, and enhancement of existing programs.
- Allocation and sharing of private, public, and corporate resources.
- Understanding the techniques, approaches, strategies, and philosophies of comprehensive water quality planning.
- Development of mechanisms for technology transfer and implementation of innovative practices.
- The need for practical guidance on program development.

Local governments will be looking for guidance on how to overcome these obstacles. Thus guidance on effective model programs must take into account the effect policy decisions have at the local level.

Can We Depend on Treatment Technology?

Historically, stormwater programs have addressed water pollution from a treatment standpoint, making them rather symptomatic and ineffective. Typical programs rely heavily on structural treatment devices to control contaminated runoff from new development. As a result, current water pollution control programs address problems through a "band-aid" approach instead of a more comprehensive approach in which both preventative and treatment measures are employed within a watershed.

With the many years of experience that some municipalities now have using treatment devices, it is becoming clear that many current treatment practices are riddled with inherent problems that may be difficult, if not impossible to overcome. Problems such as burdensome maintenance, improper construction, inadequate design, ineffective site management, and the latest obstacles posed by federal and state wetland permitting requirements have left many local governments frustrated. Thus the proper role, long-term impacts, and effectiveness of current treatment practices in urban nonpoint source pollution control need to be carefully evaluated.

Reliance on treatment technology as the primary approach to pollution control can result in failure of a program. Many current treatment practices cause problems that limit, restrict, or prohibit their use. Thus, in a more recent study, Prince George's County, Maryland, found that of 151 urban nonpoint source treatment devices constructed or put into operation within the past 5 years, only 60 percent were functioning as designed. Given such limitations, it would be inappropriate to guide other local jurisdictions to heavily rely on treatment technology in the hope of greatly improving water quality.

Do We Effectively Control New Development?

One problem that has yet to be adequately addressed is an effective and comprehensive approach to environmentally safe development. Current programs primarily focus on treatment controls for new development and generally do not consider or incorporate other important pollution reduction and prevention strategies.

New development must be designed in such a manner that onsite treatment of stormwater runoff can be effective. In addition, prevention must become an integrated part of site development through public education, implementation of site maintenance and management plans, and industrial process changes.

The goal of an effective stormwater management site plan should be the integration of preventive, management, and treatment devices that can effectively mitigate all adverse water quality impacts associated with the development. New development can be easily regulated and pollution abatement requirements selected from a broad range of options can be imposed, including:

- Greater use of open and surface drainage systems.
- Limited and creative grading to encourage onsite retention and to enhance ground-water recharge.
- Treatment of surface water by maximizing biological, chemical, and physical treatment devices.

- Requiring grounds maintenance plans.
- Education programs for developers and the public.
- Use of effective construction and maintenance inspection and enforcement programs.
- Greater preservation of existing natural water quality and habitat features.

What Do We Do About Existing Development?

Controlling nonpoint source pollution from existing development represents the greatest challenge but offers the most potential for attainment of overall pollution reduction goals. Water pollution problems associated with existing development are the most difficult to control and require the most complicated mix of approaches. Typical issues include a lack of regulations requiring retrofitting of facilities, a lack of available space to construct onsite controls, limited incentives, difficulty in identifying problems and solutions, a lack of public awareness, a lack of funding, and limited experience with source control and prevention programs. To address these issues, municipalities should consider the following:

- A community and/or watershed-based approach.
- Baseline data collection needs.
- A comprehensive nonpoint source reconnaissance study.
- Investigative approaches and tools.
- Water quality data collection and use.
- Public outreach programs.
- Regulatory actions.
- Inspection.
- Enforcement.
- Comprehensive maintenance and management plans.
- Retrofit opportunities.
- Innovative control technology.
- Lake, stream, and wetland restoration and enhancement.

How Comprehensive Is Comprehensive?

A comprehensive program not only uses dedicated local government personnel, but also integrates existing programs and personnel at the state and federal level. Coordination, cooperation, communication, and participation among all agencies involved with programs related to water quality improvements are essential for efficient use of available resources.

Many important water quality-related programs have been independently developed over time that achieve a variety of environmental objectives. Identifying all such programs and directing and focusing them on a common goal would be extremely valuable and useful. Although many water quality-related pollution control programs exist, few coordinate oversight in order to pool resources and combine efforts.

Existing water quality protection and community outreach programs can be easily enhanced or expanded to incorporate additional water quality education and enforcement programs. For example, in Prince George's County, the police community relations program is working with the state's Department of Environmental Resources, the U.S. Attorney's Office, and local citizens groups to incorporate water pollution control educational information into the program. In conjunction with a state, federal, and local enforcement training program, this effort focuses on the enforcement of water quality regulations.

The final aspect of a comprehensive program is to consider all possible sources of water pollution, point and nonpoint source alike. Combining the investigation and enforcement efforts of both programs could help eliminate loopholes in the system and facilitate effective use of existing resources. Investigators and enforcement agents at all levels of government must pool their resources and continuously exchange information regarding known sources of water pollution. Leadership will be critical for facilitating such communication and coordination.

How Will We Measure the Effectiveness of NPDES Programs?

Municipal governments, scientists, environmentalists, and the public will continue to ask, How effective are source controls? Various plans have been discussed as a result of the NPDES stormwater permit application requirements to quantify the effectiveness of municipal programs. Among these is the water quality standards approach that is currently used in the NPDES industrial point source discharge program.

The water quality standards approach to measuring the effectiveness of urban nonpoint source control/prevention programs will require extensive water quality base-flow and storm-event monitoring. In the past, however, water quality monitoring programs, either with automated equipment or manual sampling, have proven to be difficult and costly to implement. Problems with drought conditions, weather predictions, equipment errors, and the physical constraints associated with manual sampling present particular challenges. Ultimately, municipalities, which will be responsible for implementing source control programs and measuring their effectiveness, will need to rely on the availability of low-cost, flexible alternatives.

The success of source control programs will rest on the ability of small and medium-size municipalities to implement comprehensive and effective water quality control programs. How these programs are structured and the number of programs implemented will ultimately determine the effectiveness of urban nonpoint source pollution control efforts. The focus of efforts should not be on the development of water quality standards but on the development and implementation of a wide range of prevention, management, and treatment programs.

Summary

Significant reductions in urban nonpoint pollution will be achieved only when effective treatment, prevention, management tools, strategies, and programs have been fully developed and implemented. Given the clearer picture of the nature and scope of the problem, how the pieces will fit together is better understood. Nonetheless, effective efforts will require time, patience, and cooperation. All governments, agencies, and organizations dealing with these issues must work together to develop the technology necessary for a nationally comprehensive urban nonpoint source control program. Momentum for change must be sustained by continued strong leadership, and expertise in this ever-growing and complicated field must be appropriately channeled to develop state-of-the-art technology, and not just to restate it.

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Site Planning From a Watershed Perspective

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Abstract

The site planning review process involves consideration of the impacts on water resources that can result from the proposed activity, including changes in water quality and quantity. These changes can affect areas immediately adjacent to the site, as well as distant areas of the watershed. Therefore, site-specific and watershed issues must be considered when developing solutions for proper management.

An important first step in the process involves locating the project site within the watershed and becoming familiar with the watershed characteristics. Secondly, analysis of the impact of site development on the resource areas within the watershed should be conducted so that management objectives can be identified. This aids in the identification of best management practices that can meet management objectives for the site and the watershed.

Introduction

Site planning tends to occur on a limited scale, usually when developing individual sites, such as subdivisions, commercial developments, industrial parks, residential areas, and schools, as well as infrastructure such as roadways and bridges. Together, these sites compose an urban area.

As sites within the urbanizing area develop, water resources such as streams, lakes, wetlands, and ground water degrade. Because of the incremental nature of development and the cumulative effect that development can have on resources, the site planning process must involve consideration of the watershed within which the development is occurring. The watershed approach, which allows for a comprehensive evaluation of the development process, contains several elements that together form a review process: 1) delineation of the watershed and subbasins, 2) inventory of soils, 3) inventory of natural systems, 4) identification of impacts from development, 5) development of management goals and objectives, and 6) development of recommendations for mitigation.

Delineation of the Watershed

A watershed is an area of land that drains to a water resource such as a wetland, river, or lake. Depending on the size and topography, watersheds can contain numerous tributaries, such as streams and ditches, and ponding areas such as detention structures, natural ponds, and wetlands.

Rainwater and snowmelt that do not evaporate or infiltrate into the soil run off into a nearby tributary or ponding area, then flow to the main wetland, river, or lake within that watershed. Through this linkage, the upper portions of a watershed can affect downstream areas. Thus, the quality of a wetland, stream, or lake often reflects the land use and other activities being conducted in upstream areas. Because the relationship of cause and effect can extend for large distances throughout the entire watershed, it is important to address environmental management issues from a watershed perspective.

Use of topographic maps is a common method of locating and delineating the boundaries of watersheds. To locate a site on a topographic map, the site plan should be closely examined. A topographic map represents the physical features of the land such as hills, valleys, basins, ridges, and channels. The mapping technique used is based on elevation data (usually mean sea level) and contour intervals (commonly of 10 ft). Distinctive features such as road intersections and curves, towns, agricultural field boundaries, streams, and lakes make acceptable landmarks. These landmarks can be used to locate the approximate site on a topographic map. The next step is to delineate the watershed that contains the site. Below is an outline of steps necessary to delineate a watershed:

1. Use a topographic map(s) to locate the river, lake, stream, wetland, or other water bodies of interest (see Figure 1).
2. Trace the watercourse from its source to its mouth, including the tributaries. This step determines the general beginning and ending boundaries (see Figure 2).
3. Examine the lines on the topographic map that are near the watercourse; these are referred to as contour lines (see Figure 3). Contour lines connect all points of equal elevation above or below a known reference elevation. The thick contour lines have a number associated with them, indicating the elevation. The thin contour lines are usually mapped at 10-ft intervals, and the thick lines are usually mapped at 50-ft intervals. Contour lines spaced far apart indicate that the landscape is more level and gently sloping. Contour lines spaced very close together indicate dramatic changes (rise or fall) in elevation over a short distance (see Figure 4). To determine the final elevation of a location, simply add or subtract the appropriate contour interval for every thin line or the appropriate interval for every thick line.
4. Check the slope of the landscape by locating two adjacent contour lines and determine their respective elevations. The slope is calculated as the change in elevation divided by the distance. A depressed area (valley, ravine, swale) is represented by a series of contour lines "pointing" towards the highest elevation (see Figure 5). A higher area (ridge, hill) is represented by a series of contour lines "pointing" towards the lowest elevation (see Figure 6).

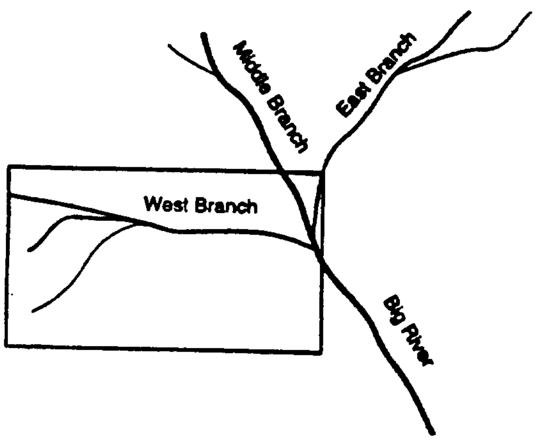

Figure 1. Big River watershed.

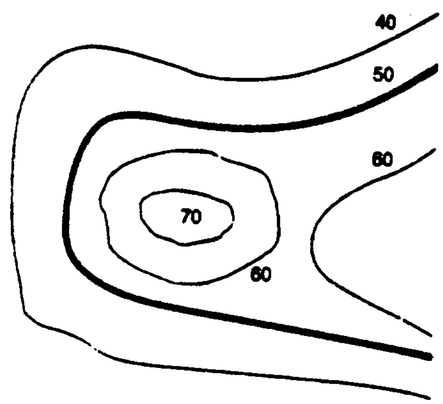

Figure 3. Contour lines.

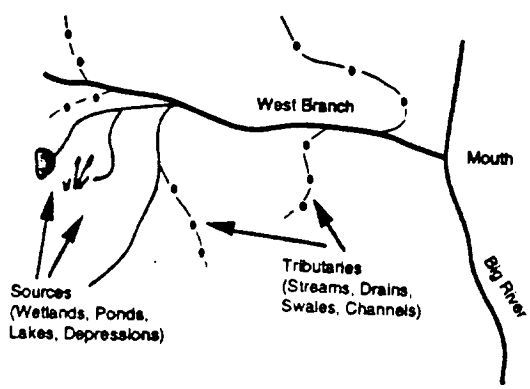

Figure 2. West Branch subwatershed.

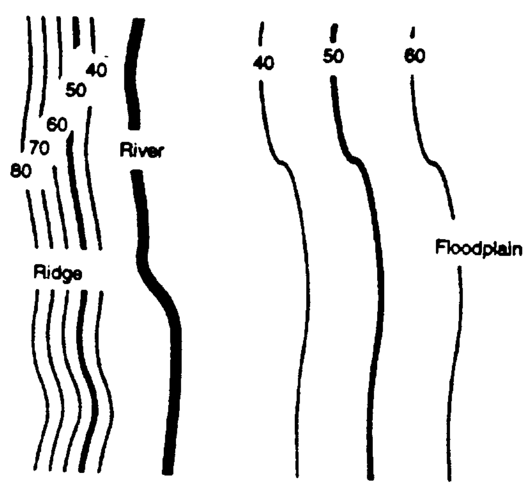

Figure 4. Floodplains and ridges.

5. Determine the direction of drainage in the area of the water body by drawing arrows perpendicular to a series of contour lines that decreases in elevation. Stormwater runoff seeks the path of least resistance as it travels downslope. The "path" is the shortest distance between contours, hence a perpendicular route (see Figure 7).

6. Mark the break points surrounding the water body. The "break points" are the highest elevations where half of the runoff would drain towards one body of water and the other half would drain towards another body of water (see Figure 8).

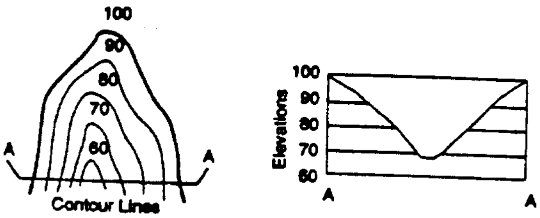

Figure 5. Valley.

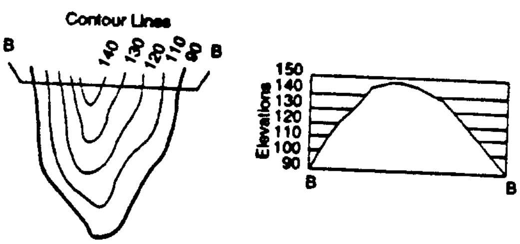

Figure 6. Ridge.

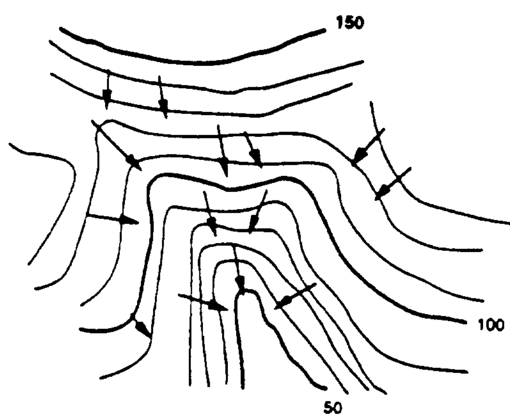

Figure 7. Direction of drainage.

7. Connect the break points with a line following the highest elevations in the area. The completed line represents the boundary of the watershed (see Figure 9).

Inventory of Soils

Locating the site on the soils map requires a U.S. Department of Agriculture (USDA) Soil Conservation Service (SCS) soil survey of the county. Select the appropriate soil sheet for the site by examining the *Index to Map Sheets*. Each numbered section corresponds to a soil sheet. After obtaining the necessary soil sheet, locate the site by using distinguishing landmarks, such as road intersections, field outlines, creeks, and rivers. Note the map unit symbols that are in that area. Map unit symbols in a soil survey may consist of numbers or letters, or a combination of numbers and letters. Soil surveys differ from state to state and county to county. Some soils are symbolized by letters and others by numbers. Figure 10 depicts a typical soils map found in an SCS soil survey.

A variety of information that can be used to evaluate sites is contained within the soil survey and maps. The different types of information contained in the soil survey include land capability classification, suitability tables, slopes, erosiveness, wetness, permeability, and drainage patterns.

Land Capability Classification

The land capability classification shows the suitability of the soils for various types of activities, from farming to engineering. The capability classification, denoted by roman numerals, suggests ways to manage and use the soils and highlights any potential hazards. Included in the capability classification are subclasses of erosion, wetness, shallowness, and climate limitations, indicated by small letters after the roman numerals. These subclasses signal a soil's tendency, for example, towards erosiveness or wetness.

Suitability Tables

Suitability tables are found in the section located after the soil descriptions and management capability groupings. They designate the soil's suitability for various categories of uses, including wildlife plantings, septic fields, building foundations, and road subgrades. This table can highlight some potential hazards for sites planned on questionable soils. For example, soils that are appropriate for a road subgrade may not always do as well for septic fields.

Slopes

Steepness of slopes can be easily determined by looking for the capital letter posted behind the first series of numbers or letters. The "A" slopes are usually very

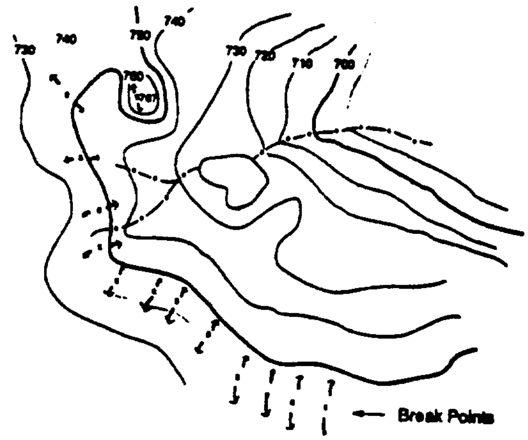

Figure 8. Identify break points.

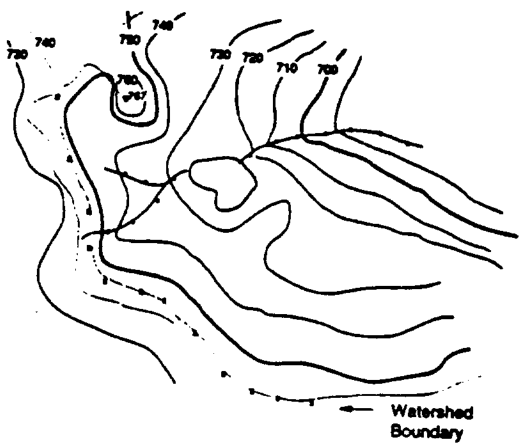

Figure 9. Watershed boundary.

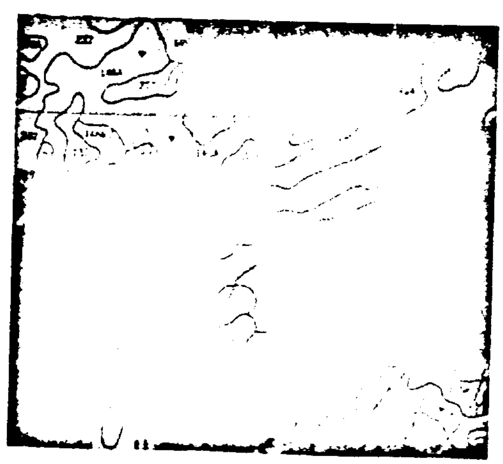

Figure 10. Soils map.

gentle, with B, C, and D slopes progressively steeper. Knowing the slopes on the site helps determine the amount of grading required and the amount of earth to be moved. Slope steepness also indicates the potential for problems with erosion and stabilization of the site.

Erosiveness

The soil survey sections entitled "Detailed Soil Map Units" and "Classification of the Soils" provide more specific information regarding the soils and their formations and uses. It is important to scan these sections for any potential erosion problems. Knowing a soil is erosive in nature is useful when analyzing how construction, mass grading, and clearing could affect the site. This can help predict how much soil loss could occur and pinpoint the best erosion and sediment controls to be used on the site. An erosion problem already present on the site may be indicated by the use of a number after the symbol depicting the soil type and slope on the map (e.g., 104B2).

Wetness

To determine if the soil present on the site is hydric or "wet," the soil description section and land capability classification indicate whether or not that soil has a water table at or near the surface. Most of the wet soils occur in valley bottoms or depressional areas. On the soil map itself, the wetness may be designated with a "W" preceding or following the soil symbol. Knowing if a soil has a tendency towards wetness can signal potential hazards. A site originally planned for septic systems may have to turn to sewer and water, or a site could contain wetlands that require protection.

Permeability

Soil permeability is important to a variety of people when looking at a potential construction site. The permeability of the soil can determine if the site is appropriate for a detention pond, a septic field, or an infiltration trench. In addition, knowing if the soil has a slow or fast permeability can alert the planner to the potential for ponding or ground-water vulnerability.

Drainage Patterns

Soil surveys typically have a smaller scale than a topographic map; therefore, more detail pertaining to the landscape can be shown. Drainage patterns are important to identify. Drainage patterns highlight how the land slopes and drains and in what direction. This is important when considering a site for development, as it is advisable to keep the natural drainage pattern intact wherever possible. Utilizing natural drainage can eliminate the need for regrading and rerouting of runoff from the site.

Other Information

Other symbols used on a soil survey may denote a wetland or marsh, or the presence of heavy clays, depressional areas, intermittent streams, springs, and erosion spots. These features are not always found on a topographic map. This information is particularly important when doing cursory site evaluations.

The most important point to remember when using the information in a soil survey is to recognize that it has inherent limitations. Due to the scale in the field versus that of an aerial photograph, the soil survey can only point towards a situation that may need further investigation. Any questions raised by the soil survey should be followed by an onsite soil determination by a qualified soil scientist.

Inventory of Natural Systems

Most areas have National Wetland Inventory (NWI) maps produced by the U.S Fish and Wildlife Service. On the NWI maps, the wetlands are defined as "lands transitional between aquatic and terrestrial systems where the water table is usually at or near the surface, or the land is covered by shallow water." In addition, the definition requires that one or more of the following three attributes be present: "1) at least periodically the land supports predominantly hydrophytes, 2) the substrate is predominantly undrained hydric soil, or 3) the substrate is nonsoil and is saturated with or covered by shallow water at some time during the growing season of each year." Therefore, these maps contain information on sites that have lakes, rivers, and streams, as well as such areas as marshes, bogs, and swamps.

Some counties have advanced wetland mapping that delineates critical areas in need of protection from construction disturbances using the NWI maps as one of their criteria. Recently, SCS has inventoried wetlands in agricultural fields and adjacent areas. In addition, SCS has also identified highly erodible cropland fields. These areas, if developed, will have special needs for soil erosion and sediment control measures.

Other natural systems that need to be included in the watershed review process are ground-water resources, such as aquifers, and recharge areas to public and private wells. Many states have mapped their ground-water resource areas, and local municipalities should have maps showing the location of and contribution zones to public wells.

It is important to examine several additional maps to gain a proper perspective on other developments in the watershed. Comprehensive zoning and plan maps reveal current land use and plans for the future of the area. These maps are invaluable when determining what stormwater best management practices (BMPs) should be applied to the site. If development currently exists upstream or more development is planned, caution may need to be taken when situating homes or businesses near a stream. Conversely, if the proposed development will be upstream of existing developments, detention measures may be needed to prevent downstream flooding. Whatever the situation, knowing where developments are and where they will be helps determine what means and methods of prevention and protection need to be taken.

Identification of Impacts From Development

Once the locational information for the project has been gathered and the contributing watershed identified, it is necessary to consider the impacts the development will have on the watershed. In general, the major impacts will be alterations in water quality, water hydrology, and terrestrial and/or aquatic habitat. Some simple methods allow initial judgments to be made as to the extent of the impact and the level of mitigation required to protect the surrounding ecosystem (1).

Changes in Water Quality

As people inhabit and use the lands around them, they deposit various pollutants on the land. When rainfall and runoff occur, these pollutants are washed into receiving waters. As urban development occurs within the watershed and the land use changes, pollutants, loading rates, and the concentration of pollutants discharged to the receiving waters also change. Many studies have been conducted during the past 20 years to characterize the types and amounts of pollutants associated with various land uses, including urban land uses. A review of the results indicates that different types of land use generate "typical" pollutants, at amounts within a range of values (2). (These values have been consolidated into a single value based on statistical analysis of all data.)

Pollutant Concentration

Some pollutants are more likely to have short-term (acute) effects on environmental systems because of the pollutant concentration. Typically, the pollutants considered to have an acute impact on water quality are oxygen-demanding substances and bacteria. Using an equation that considers normal probability, median pollutant concentrations, and variability, estimates can be made of the probability that pollutant concentrations will exceed acceptable water quality standards. The equations used for estimating concentrations and probability of exceedances are found in Equations 1 and 2 (2).

To estimate expected concentrations, use the equation

$$C_x = C_m (\exp [Z (1n \{1+COV\}^2)^{1/2}]) \qquad \text{(Eq. 1)}$$

where (for log-transformed data)

C_x = expected concentration of pollutant x
Z = standard normal probability (for specified probability of occurrence)
C_m = median pollutant concentration
COV = coefficient of variation

To estimate probability, use the equation

$$Z = (\ln[C_x/C_m])/[\ln(1+COV^2)^{1/2}] \qquad \text{(Eq. 2)}$$

Pollutant Loads

Some pollutants are likely to have long-term (chronic) effects on environmental systems because of pollutant loading rates. Typically, the pollutants considered to have a chronic impact on water quality are nutrients, sediments, toxic metals, organics, and some oxygen-demanding substances. One approach relies on the development of unit area loading rates for various pollutants for different land uses. The unit area loading values are generally a numerical value based on the area of land use (1).

Many methods have been developed to estimate the pollutant load that would be expected from a proposed development. The anticipated value can be compared with the existing pollutant loads to determine the increase in pollutant loading. One of the easiest methods to use is the Simple Method (3). This method uses readily available information but is limited to sites less that 1 square mile in area. Loading information gathered can be used to judge whether some type of runoff treatment will be needed before discharging to the receiving waters. The equation for estimating pollutant loads is found in Equation 3.

When concentration is in mg/L,

$$L = (P)\,(P_j)\,(R_v)\,(C)\,(A)\,(0.227) \qquad \text{(Eq. 3)}$$

where

L = annual mass of pollutant export (lb/yr)
P = annual precipitation (in.)
P_j = correction factor for smaller storms that do not produce runoff (dimensionless)
R_v = runoff coefficient (dimensionless)
C = average concentration of pollutant
A = site area (acres)

When concentration is in μg/L,

$$L = (P)\,(P_j)\,(R_v)\,(C)\,(A)\,(0.000227) \qquad \text{(Eq. 4)}$$

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Changes In Water Hydrology

As development occurs within the watershed, the degree of imperviousness within the watershed often increases. Impervious surfaces do not allow rainfall to infiltrate as would occur in an undeveloped setting; as a result, more rainfall becomes runoff. As the amount of imperviousness increases, so does the amount of runoff from the site. Taken individually and cumulatively, the increase in runoff will change the hydrology of the watershed. Depending on the location of the site within the watershed and on development conditions in other areas of the watershed, changes in watershed hydrology can negatively affect downstream properties, causing flooding and property destruction, and also lead to downstream bank destabilization, erosion, and scouring. In some areas of the country, land subsidence becomes an issue if the water table is lowered because of the lack of ground-water recharge. This problem can be addressed through ordinances that stipulate all pre- and postdevelopment runoff rates for the entire watershed be considered when a single site is being developed.

A commonly used method for determining the pre- and postdevelopment runoff rates for a site and watershed is SCS Technical Release 55, "Urban Hydrology for Small Watersheds." TR55 can serve as an initial screening procedure for estimating runoff values. An advantage of the procedure is its ease of use through charts and availability on computer disk (4).

Alterations In Terrestrial and Aquatic Habitat

As more undisturbed lands near shore areas are converted into urban and suburban land uses, areas once inhabited by terrestrial and aquatic animal and plant species are minimized or destroyed. As native habitats have continued to decrease over the years, more attention has been given to the need to protect and preserve them. In many areas, endangered species laws serve to protect habitat areas for those plants and animals appearing on state and federal endangered species list. Although this is helpful, it does little to protect more prolific and less sensitive plant and animal species that are burdened by urban development. Consideration of and accommodations for plant and animal species should and can be incorporated into the individual site planning process as well as the watershed management strategy.

Development of Management Goals and Objectives

An effective method to review site development is to first consider what the overall watershed management objectives are. One place to start looking for this type of information is within the existing state water quality standards. Water quality standards give numerical values and narrative descriptions for various pollutants, at levels that are protective to human and biological health, and assign designated uses for the resource. A management approach can consist of a review of the existing and potential designated uses for the resources within the watershed, and can attain or preserve these uses. In addition, local agencies may have developed management objectives through such mechanisms as watershed protection districts.

A simple hierarchy of management objectives has been presented by Schueler et al. (5), which consists of the following:

- Reducing increases in pollutant loading and concentration.
- Reducing the severity of impacts of pollutant loading and urbanization.
- Addressing specific pollutants.
- Protecting sensitive areas.
- Controlling floods.
- Restoring the area.

Whipple (6) also uses a hierarchical method of designated uses as management objectives:

- Habitat of threatened or endangered species and outstanding natural resource waters.
- Water supply from both surface and ground.
- Other areas to be protected.
- Those not needing protection.

Figure 11 presents a resource area hierarchy consisting of:

- Baseline urban nonpoint source pollutant control
- Baseline urban resource protection
- Control of specific pollutants
- Protection of sensitive resource areas
- Flood control

Management Objectives

"Baseline" Urban Nonpoint Source Pollutant Control

"Baseline" Urban Resource Protection

Control of Specific Pollutants

Protection of Sensitive Resource Areas

Flood Control

Figure 11. Resource area hierarchy.

Development of Recommendations for Mitigation

After consideration has been given to the degree to which changes in water quality, hydrology, and habitat alterations potentially affect the watershed and the site and after management goals and objectives have been identified, it is necessary to develop management strategies that mitigate impacts to the level desired. This is accomplished through the use of mitigation techniques, commonly referred to as BMPs. These practices can take the form of engineered practices, called structural BMPs, or nonengineered practices, called nonstructural BMPs. BMPs can be implemented on a site-specific basis and on a regional or watershed basis. The overall management objectives and the severity of impacts from development may dictate the degree of mitigation required (7).

In selecting BMPs for a site, it is important to consider 1) how the BMPs will function as a system; 2) how the practice will meet watershed- and site-specific management objectives, such as pollutant load and concentration reduction, control of storm volumes, and provision of habitat; and 3) what some of the limitations and uses of the practices are.

Best Management Practice Systems

Structural and nonstructural BMPs differ in their design, limitations, and optimal applicability (i.e., addressing pollutant loads, habitat, or hydrology). While some BMPs are implemented to provide a primary objective, secondary mitigation and benefits also are commonly provided. For example, a wet detention pond optimally functions to improve water quality through pollutant load reduction but can also function to balance water hydrology and provide habitat. BMPs can be grouped into discrete functional units that address different aspects of stormwater management. These units are pollution prevention, habitat protection, runoff attenuation, runoff conveyance, runoff pretreatment, and runoff treatment. The units, taken together, form the BMP system. The BMPs selected to meet watershed- and site-specific objectives generally will be from all of these functional units. Figure 12 depicts a BMP systems approach, described below:

- *Pollution prevention:* An effective approach to managing pollutants in urban settings is to prevent or reduce the potential for pollutant loading. Many of the pollution prevention practices are referred to as nonstructural BMPs. These practices can include such activities as public education, zoning ordinances, site planning procedures, restricted use policies, and overlay districts.
- *Habitat protection:* An effective tool for the restoration and management of habitat areas is the implementation of measures to ensure long-term protection. Habitat protection is usually accomplished through nonstructural BMPs, such as river corridor programs, wetland protection programs, critical habitat protection programs, and zoning tools such as open space requirements and creative land-use planning techniques (cluster development).
- *Runoff attenuation:* One of the most effective ways to manage stormwater flows is to prevent and reduce them. Much of this can be accomplished through a reduction in site impervious cover. Reduction in impervious cover allows for increased infiltration. Other practices that attenuate runoff are drywells, depression storage, and appropriately placed infiltration trenches. Implementing these practices reduces the other impacts of development by reducing runoff volume, flood occurrence, pollutant loads and concentrations, and stream degradation.
- *Runoff conveyance:* Runoff conveyance systems serve to transport the storm flows from the point of origin to the runoff pretreatment and treatment system. Runoff conveyance systems can allow for limited treatment levels, as in the case of grassed swales with check dams and exfiltration devices. Other conveyance systems for stormwater include structural elements, such as pipes with flow splitters.
- *Runoff pretreatment:* Runoff pretreatment is the process whereby runoff is diverted through pretreatment practices. These practices usually prolong and improve the efficiency of the treatment device. Pretreatment practices include vegetated filter strips, riparian systems, settling basins, and water quality inlets.
- *Runoff treatment:* Runoff treatment practices are devices designed to treat stormwater runoff and remove pollutants through a number of processes, including adsorption, transformation, and settling before entry to

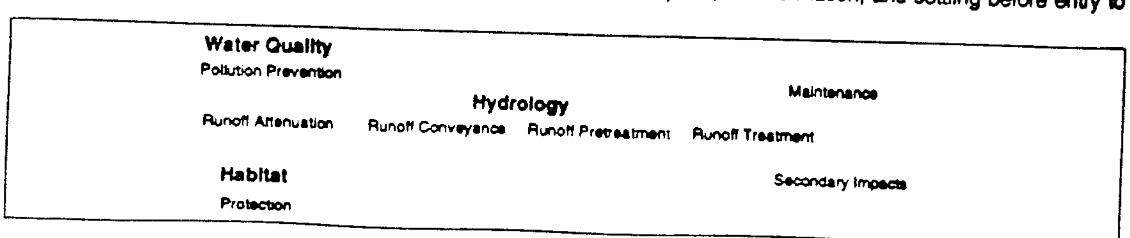

Figure 12. BMP systems approach.

the resource area. Treatment devices are considered the final component of the BMP system. Some familiar treatment devices include detention, retention, and infiltration.

Several additional issues need to be considered when developing recommendations for practices. Among these are acceptance of practices by landowners and the aesthetic quality of the practices. Although these issues seem minor, disgruntled landowners can inhibit implementation of effective long-term management programs.

A frequently overlooked but critical consideration for stormwater management is the development of long-term maintenance and financing programs. BMPs, once installed, require upkeep and periodic repairs. Long-term urban runoff management programs require a commitment to maintain technical and program support staff.

Determine Reduction or Protection Measures Necessary To Achieve Objectives and Meet Watershed and Site-Specific Needs

To develop a management strategy, it is important to integrate watershed needs with site-specific needs. The simplest approach is to first consider the broader watershed needs and then "work in" site-specific needs around them. Examples of broad watershed management needs are protecting public water supplies, river corridors and riparian areas, wetlands and wildlife habitat; preserving/expanding open space; or meeting a watershedwide pollutant reduction goal. To address these needs, management practices such as no construction/no disturbance buffer zones, creative site layout practices, impervious cover limitations, tree disturbance restrictions, total site disturbance limitations, and riparian enhancement zones may be utilized. These management practices tend to define or refine areas for the actual site development and site-specific practices.

On the site level, with broader watershed management practices incorporated, more specific needs can be addressed. Examples of site-specific management needs are preventing or managing soils loss, lowering the postdevelopment discharge rate and volume, enhancing riparian areas, and reducing pollutant loads from the site. To address these needs, management practices such as developing and implementing a preventive soil erosion control plan, and installing such items as temporary sediment basins, siltation fencing, dry wells, infiltration trenches, wet ponds, and native plant species planting may be utilized.

It is important to remember that a combination of BMPs is often necessary to achieve desired objectives. No one single practice will provide all necessary mitigation or benefits. Table 1 provides an example of how watershed objectives can direct selection of various practices.

Best Management Practice Limitations

To provide information on the limitations and uses of BMPs, several charts have been developed. The most recently completed of these is found in Schueler et al. (5). Summary information can also be found in Schueler (3) and U.S. EPA (8). Information contained in the charts includes advantages, disadvantages, cost efficiency, limitations for ground-water depth, and soils. Schueler and colleagues consolidated information on reported BMP efficiency in a similar chart form (5). All of this information can help the decision-maker determine the most effective mix of practices to meet stated objectives. Figures 13 and 14 provide an example of the BMP limitation charts available.

Benefits of Watershed Planning

The most obvious benefit realized from a watershed planning approach is the installation of BMPs to mitigate water management issues before serious problems result. Advance planning saves valuable resources at the state and local level, which could be used in other areas.

Economies of scale can also be realized as a result of the watershed approach. When installing regional practices, larger areas within the watershed can be treated on a per unit area cost basis. This will be beneficial to the development community and the local jurisdictions.

Restoration is always more expensive than prevention. Most restoration costs are associated with damage off site and downstream by runoff and sedimentation. As emphasized earlier, the amount and velocity of runoff flowing off site can cause severe erosion of streambanks and watercourses. Watershed planning can eliminate restoration costs by examining the surrounding area proposed for development. With preliminary runoff control measures, much downstream and offsite damage can be prevented and controlled.

Another hazard of poor planning involves dredging of sediment-laden streams, channels, and lakes. Dredging is a very expensive solution to a problem that could have been prevented for a fraction of the cost. Again, proper examination of an area on a watershed basis can target erosive soils and extensive urbanization with BMPs to keep offsite erosion and sedimentation from occurring.

Mitigation involves creating sensitive habitat areas, usually wetlands, after they have been replaced by filling or construction. Mitigation can often be avoided if some advanced watershed planning is undertaken. By delineating sensitive areas early, alterations in construction plans can be worked around the sites. In planning large areas, sensitive areas can be designated and protected through land acquisitions and greenbelt planning.

Finally, by doing advanced watershed planning the potential for court actions in the case of flooding, erosion

Table 1. Tools To Achieve Watershed Objective

Watershed Objective	BMP System Component	Tools
Baseline nonpoint source pollutant control	Pollution prevention	Erosion control
		Buffer requirements
		Pesticide/Fertilizer reduction
	Runoff conveyance	Grassed swales with check dams
	Runoff pretreatment	Vegetated buffer strips
Baseline urban resource protection	Pollution prevention	Steep slope restriction
		Site fingerprinting
		Minimum site disturbance
		Cell closure/opening
		Construction phasing
		Erosion control
		Buffer requirements
	Runoff attenuation	Infiltration trenches
		Drywells
		Reduced directly connected impervious areas
	Runoff pretreatment	Stream buffers
		Wetlands buffers
	Runoff treatment	Infiltration basins
Specific pollutants	Pollution prevention	Septic system density
		Restricted use areas
		Nitrogen overlay district
	Runoff conveyance	Grassed swales with check dams
	Runoff pretreatment	Vegetated buffer strips
		Riparian buffers
		Water quality inlets
	Runoff treatment	Wet extended detention ponds
Sensitive areas	Pollution prevention	Hazardous waste recycling
		Stenciling storm drains
		Industrial cross connections
		Underground storage tank regulations
		Protection districts
		Restricted uses
		Decreased DCIA
		Nitrogen overlay zones
		Septic density requirements
		Extensive erosion/sediment control
		Wellhead protection program
	Habitat protection	River corridor program
		Open space requirements
		Cluster development
		Wetlands protection program
		Critical habitat program
		Riparian zone requirements
		Resource area buffer requirements
Flood control	Runoff attenuation	Infiltration trench
		Drywells
	Runoff conveyance	Riprap swales
		Detention ponds
		Retention ponds

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BMP	Slope	High Water Table	Close to Bedrock	Proximity to Foundations	Space Consumption	Maximum Depth	Restricted Land Uses	High Sediment Input	Thermal Impacts
Extended Detention Pond	●	●	◑	●	○	●	●	◑	●
Wet Pond	●	●	◑	●	○	○	●	◑	○
Infiltration Trench	○	○	○	○	●	○	●	○	●
Infiltration Basin	◑	○	○	◑	◑	○	●	○	●
Porous Pavement	○	○	○	○	○	○	○	○	●
Water Quality Inlet	●	●	○	○	●	○	○	○	●
Grassed Swale	○	○	◑	◑	●	●	○	○	●
Filter Strip	◑	◑	◑	◑	●	●	◑	○	●

○ May Preclude the Use of a BMP
◑ Can Be Overcome With Careful Site Design
● Generally Not a Restriction

Figure 13. Other common restrictions on BMPs (3).

damages, sedimentation removal, dredging, and sensitive habitat areas may be lessened. By looking at the watershed area in total and addressing probable hazards both upstream and downstream, the chances of causing damage downstream will be minimized.

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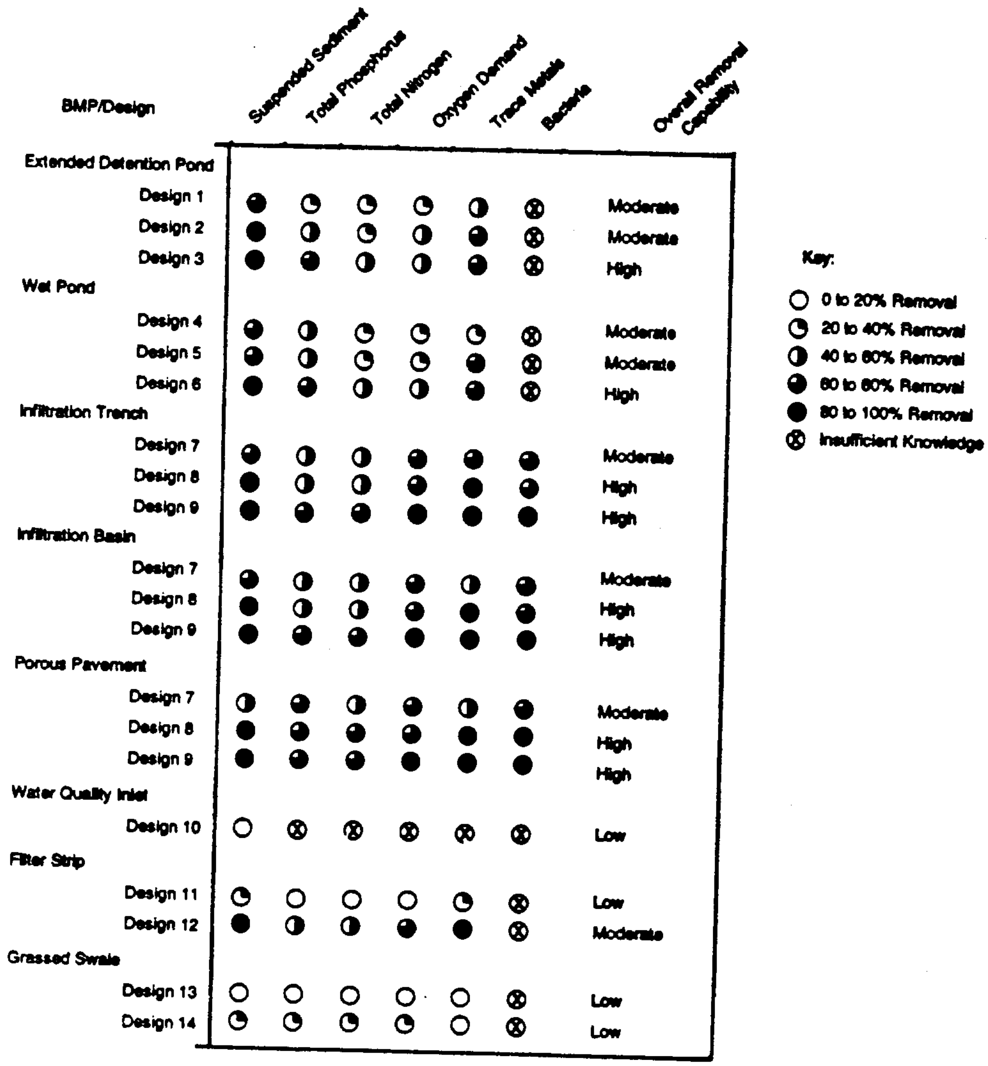

Design 1: First-flush runoff volume detained for 6 to 12 hr.
Design 2: Runoff volume produced by 1.0 in., detained for 24 hr.
Design 3. As in Design 2 but with shallow marsh in bottom stage.
Design 4: Permanent pool equal to 0.5 in. of storage per impervious acre.
Design 5: Permanent pool equal to 2.5 (Vr), where Vr = mean storm runoff.
Design 6: Permanent pool equal to 4.0 (Vr); approx. 2 weeks of retention.
Design 7: Facility exfiltrates first-flush; 0.5 in. of runoff/impervious acre.
Design 8: Facility exfiltrates 1-in. runoff volume per impervious acre.
Design 9: Facility exfiltrates all runoff up to the 2-year design storm.
Design 10: 400 ft^3 of wet storage per impervious acre.
Design 11: 20-ft-wide turf strip.
Design 12: 100-ft-wide forested strip with level spreader.
Design 13: High-slope swales with no check dams.
Design 14: Low-gradient swales with check dams.

Figure 14. Comparative pollutant removal of urban BMP designs (3).

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The Soil Conservation Districts' Role in Site Plan Review

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Abstract

Officially organized nearly 50 years ago, both the Kent and Sussex Conservation Districts have been at the forefront of soil and water conservation. The more specific role of the conservation districts in sediment control and stormwater management is tied to two legislative initiatives. In 1978, the Delaware State Legislature passed an Erosion and Sediment Control Law (Chapter 40, Title 7, Delaware Code). In 1991, this law was amended to include stormwater management.

Because certain types of construction can increase sediment yields by 2,000 times, sediment control is a necessary first step on any construction site. The conservation districts' role in reviewing site plans is based on the importance of sediment control for limiting the degradation of surface water.

The conservation districts review site plans for stormwater management quantity control to ensure that the risk of downstream flooding is reduced and stream channel erosion is controlled. This is achieved by sustaining predevelopment runoff rates for the 2-, 10-, and 100-year storm events at the postdevelopment state and maintaining similar hydrograph timing for peak flows before and after development.

When reviewing site plans, the conservation districts also consider the quality of stormwater runoff. The order of preference for practices to improve water quality, according to Delaware law, is as follows: ponds with a permanent pool, extended detention ponds without a permanent pool, and infiltration systems. The acceptability of other practices that can remove up to 80 percent of the suspended solids in runoff is determined on a case-by-case basis. The Kent and Sussex Conservation Districts have promoted sand filtration systems and biofiltration swales for water quality treatment where applicable.

Background

Delaware, the first state to ratify the Constitution, in 1787, has a rich history dating back to pre-colonial times. Delaware is 1,978 square miles; only Rhode Island has less land mass. Located entirely on the DelMarVa (Delaware, Maryland, and Virginia) Peninsula, Delaware is a 2- to 3-hour drive from Baltimore, Maryland; Washington, DC; Philadelphia, Pennsylvania; and Norfolk, Virginia.

Location between the Chesapeake and Delaware Bays and the Atlantic Ocean provides for a moderate climate. Delaware receives 45 in. of rainfall annually, and Kent and Sussex Counties experience an average of 187 frost-free days a year. New Castle County, the northernmost of the three Delaware counties, is partially located in the Piedmont region, while the rest of the state is in the Atlantic coastal plain. Delaware's gently rolling topography starts at sea level and peaks at 368 ft in the northern part of the state.

With a statewide population of just over 666,000, Delaware has unique demographics. Currently, two-thirds of the population is located on less than one-third of the land in the state. Northern New Castle County, in which the city of Wilmington lies, is within easy commuting distance of Philadelphia and northeastern Maryland.

The city of Dover, located in Kent County in the central portion of the state, is not only the state capital but in 1992 was officially designated a metropolitan area. Kent County, which has considerable land in agricultural production, is also the home of Dover Air Force Base, a central military airlift command facility. Both of these factors have combined to produce considerable growth around the capital city.

Sussex County, the southernmost of the three counties, has two areas of interest that have brought considerable development to a primarily rural area. One is a 25-mile stretch of Atlantic Ocean shoreline. The other area is commonly referred to as the "Inland Bays" region, which has 80 miles of shoreline located directly behind the coastal barrier dune system. Although the resident population of Sussex County is just over 113,000, during the peak of the tourist season (July 4th weekend) the population balloons to an estimated 300,000 people.

In 1969, Governor Russell Peterson assigned a task force to study the steady decline of shellfish and finfish populations as well as related environmental issues of concern for the Inland Bays region. Reports and studies over the subsequent two decades pointed to the necessity of encouraging land-use planning and establishing various water quality initiatives regarding agricultural land and land that could be developed.

Steady growth in the state's metropolitan areas was not surprising. The increasing development in the two more rural counties of Kent and Sussex, however, brought the conservation districts to the forefront of soil and water conservation efforts at land development projects.

The Role of the Conservation Districts

In their first 50 years, the conservation districts were primarily involved in agricultural issues affecting local landowners. Historically, each district has been run by a board of seven elected supervisors, most of whom are local farmers, and has functioned as a clearinghouse for current information about the construction and maintenance of drainageways, wildlife ponds, and water control structures; updates on the availability of technical and financial assistance for farmers and other residents; and education activities related to resource management and protection.

In 1978, Delaware passed an Erosion and Sediment Control Law covering most types of residential, commercial, industrial, and institutional construction. In 1980, the conservation districts were enlisted to implement the law by the Delaware Department of Natural Resources and Environmental Control (DNREC). DNREC turned to the conservation districts because of their intimate knowledge of the counties in terms of constituents, soils, topography and local and county governmental structure. Moreover, the conservation districts had a proven ability to run cost-effective programs with a minimum of "red tape."

From 1980 to 1987, development authorities were primarily concerned with erosion and sediment control in regard to all types of new construction. Stormwater management was handled by various state and municipal agencies on an "as needed" basis to control flooding. Then, in 1989, DNREC began the long process of establishing a statewide stormwater management law to address both runoff quantity control and water quality concerns. Using an approach that involved not only the regulators but also the regulated community, DNREC encountered a minimal amount of public opposition and gained the full support of the state legislature.

Thus, on July 1, 1991, the Erosion and Sediment Control Law was amended to include stormwater management. The conservation districts are now the lead agencies implementing this law. The program is considered by many to be a model of efficiency, not only from a cost perspective but also in terms of the rapid turnaround time for plan reviews, which is extremely important for interested parties in this age of fax machines, electronic mail, and cellular phones.

Scope of Site Plan Review

Review of site plans for construction projects has evolved from mere suggestions provided by a district employee concerning what might work best at a particular location to an engineered topographic plan showing the project's location, the site's details, and specifications for all practices to be used. To illustrate the plan review process, we occasionally refer in this paper to a project for "Running Brook Estates and Business Park" (Figure 1).

Plan review goes beyond looking at blueprints to see that specifications meet minimum standards set forth in state laws and regulations. Material that district inspectors frequently use to assess a project include:

- The state erosion and sediment control handbook.
- The district sediment and stormwater manual.
- County soil surveys.
- U.S. Geological Survey topographic maps.
- Federal Emergency Management Agency floodzone maps.
- State/Federal wetland inventories.
- The Delaware Department of Transportation (DelDot) specification book.
- Equipment manufacturer specifications and literature.

The most important tool for ensuring a thorough design as well as a consistent and efficient review is the management plan checklist. Figure 2 presents the checklist used by the Kent Conservation District.

Sediment Control

A plan for sediment control and stormwater management usually evolves from the site or grading plan but includes the location, dimensions, and details for the required erosion and sediment controls.

In some cases, designers or developers choose to use the stormwater facility as a sediment trap or basin. This is easily accomplished by modifying the facility's outlet control structure to include the necessary filtration devices (Figure 3). Although use of an infiltration basin

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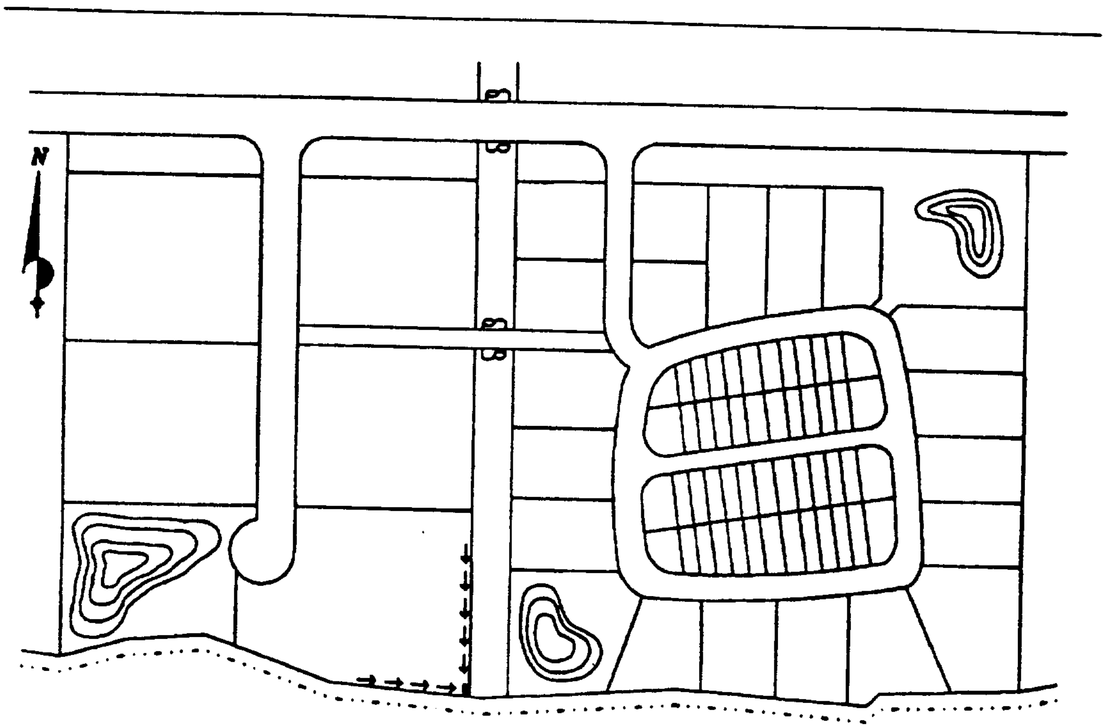


Figure 1. Site map for Running Brook Estates and Business Park.

as a sediment trap is generally discouraged, on occasion it may be necessary. For such cases, several approaches are recommended. One is to direct any sediment-laden runoff to a trap (Figure 4, northeast corner). Another is to leave the basin 12 to 24 in. above finished grade until the site is stabilized; excess material is then removed and the basin graded according to the plan's specifications.

The management plan must describe the construction sequence and establish the points at which various control installations must be added, removed, completed, or activated. For certain features, such as embankment ponds, the contractor may be required to notify the district inspector when construction is about to commence. This gives the inspector the opportunity to reemphasize the importance of such aspects of the installations as a cutoff trench and the emergency spillway's dimensions and to visually inspect riser structures, antiseep collars, and the foundation preparation.

Additional sediment control features commonly presented in the plan include the following (see also Figure 4):

- *Rock-check dams:* Used for velocity and erosion control in ditches and swales.
- *Perimeter dikes/swales, earth dikes, temporary swales:* Used to convey runoff to a trap or as a clean-water diversion.
- *A stabilized construction entrance:* Stone structure used to minimize sediment tracking onto roadways.
- *Vegetative requirements list (permanent and temporary):* Used to specify amounts and types of seed, mulch, and soil amendments needed.
- *A silt fence:* Commonly used downstream of disturbed soils as a perimeter filtration device.

Often the review process reveals unique or unexpected site features requiring that the district inspector make additional site visits, hold meetings with designers, and seek technical guidance from the Soil Conservation Service or the DNREC Division of Soil and Water Conservation. For example, because of the unique soils on the DelMarVa Peninsula, erosion problems necessitated that a list of soil erodibility (K) values (Figure 5), as determined by the Universal Soil Loss Equation, be compiled for the predominant soil types shown on the sediment and stormwater plan for Running Brook Estates and Business Park (Figure 6). Such lists not only expedite the review process but also help designers better prepare for the review comment period.

Stormwater Management for Quantity Control

The adverse impacts of stormwater runoff have been well documented. Damage caused by flooded streams and rivers has cost millions of dollars in property losses and has degraded the quality of the nation's waters. Reducing the risk of downstream flooding and stream-channel erosion after land development is the primary

KENT CONSERVATION DISTRICT
SEDIMENT AND STORMWATER MANAGEMENT PLAN

SUBMISSION REQUIREMENTS

1_____Review is predicated upon receipt of one set of plans and applicable review and inspection fee.

2_____Upon notification of approval, one additional set of plans must be submitted to be stamped and kept available on the construction site at all times.

REQUIRED STATEMENTS

1_____Provide the name, mailing address, and phone number of the owner of the property, the land developer, the engineer or consultant and the applicant. Provide names of adjacent property owners on the plan.

2_____Include the following notes:

A_____The Kent Conservation District must be notified in writing five (5) days prior to commencing with construction. Failure to do so constitutes a violation of the approved Sediment and Stormwater Management Plan.

B_____Review and or approval of the Sediment and Stormwater Management Plan shall not relieve the contractor from his or her responsibilities for compliance with the requirements of the Sediment and Stormwater Regulations, nor shall it relieve the contractor from errors or omissions in the approved plan.

C_____If the approved plan needs to be modified, additional sediment and stormwater control measurer may be required as deemed necessary by the Kent Conservation District.

D_____The Kent Conservation District reserves the right to enter private property for purposes of periodic site inspection.

E_____Following soil disturbance or redisturbance, permanent or temporary stabilization shall be completed within 14 calender days as to the surface of all perimeter sediment controls, topsoil stockpiles, and all other disturbed or graded areas on the project site.

3_____Include signed Owner's Certification of the following statements (these must be signed in ink on each plan submitted):

A_____I, the undersigned, certify that all land clearing, construction and development shall be done pursuant to the approved plan.

B_____I, the undersigned, certify that responsible personnel certified by DNREC will be in charge of on-site clearing and land disturbing activities.

GENERAL REQUIREMENTS

1_____Provide a legend on the Sediment and Stormwater Management Plan.

2_____Provide a "limit of disturbance" line and the disturbed area in acres.

3_____Provide a vicinity map with a scale of 1" = 1 mile.

4_____Provide a north arrow on the plan.

5_____Maximum plan scale of 1" = 100'

6_____Plans must be submitted on 24"x36" sheets.

7_____When two or more sheets are used to illustrate the plan view, an index sheet is required, illustrating the entire project on one 24"x36" sheet.

8_____Provide existing and proposed contours based on mean sea level datum provided at one foot intervals. Total contributing drainage area must be shown regardless of being located on or off-site.

9_____For small projects, provide existing and proposed spot elevations on a 50 foot grid system, based on mean sea level datum, with high and low points.

10____State and Federal wetlands must be accurately delineated.

11____Delineate the National Flood Insurance Program 100 Year Flood Zone.

12____Provide soils mapping on plan with a general description of each soil.

13____Streams must be delineated.

Figure 2. Sample sediment and stormwater management plan checklist.

EROSION AND SEDIMENT CONTROL

1_____All erosion and sediment control practices shall comply with the Delaware Erosion and Sediment Control Handbook 1989.

2_____Projects must be phased so that no more than 20 acres is cleared at any one time. Once grading is initiated in one 20 acre section, a second 20 acre section may have stumps, roots, brush, and organic material removed. Grading of the second 20 acre section may not proceed until temporary or permanent stabilization of the first 20 acre section is accomplished.

3_____Stone check dams are required in all swales, ditches and channels. Provide details, cross sections and specifications, including check dam station locations. Check dam depth must be such that a maximum stone depth is achieved while ensuring that flow will continue over the center of the dam. A minimum 6" depth from the weir to the top of the structure is required.

4_____All stone, with the exception of check dams, must be underlined by a filter fabric. Filter fabric specifications must be provided for various applications.

5_____Outlet protection is required at all points of discharge from pipes, channels, and spillways. Provide details, cross-sections and specifications, including d50 stone size, stone depth, outlet dimensions and type of filter fabric.

6_____Provide inlet and outlet invert elevations for all drainage structures and facilities.

7_____Provide profiles for all outfall pipes and channels.

8_____Erosion control matting is required on slopes of 3:1 or greater.

9_____Provide corner and lowest floor elevations for all buildings.

10_____Specify what stabilization measures will be used if dust control becomes a problem.

11_____Sediment traps and basins shall be utilized and sized to accomodate 3600 cubic feet of storage per acre of contributing drainage area until project stabilization is complete. These structures must be located at the base of the drainage area. The following information is required: top of slope, bottom, and outlet elevations, dimensions, proposed and required volumes, type of trap or basin, and contributing drainage area. Include details, cross sections and specifications; a minimum 2:1 length to width ratio is required.

12_____Diversions must be used to direct runoff into traps. When sediment-laden stormwater is directed to traps or basins by closed pipe systems, temporary diversions must be used to direct stormwater to traps and basins until closed pipe systems are operational.

13_____Provide a detailed sequence of construction, at a minimum, include the following activities: clearing and grubbing those areas necessary for the installation of perimeter controls, construction of perimeter controls, remaining clearing and grubbing, road grading, grading for remainder of site, utility installation and whether storm drains will be used or blocked until after completion of construction, final grading, landscaping or stabilization, and removal of sediment control practices.

14_____Soil stockpile areas must be delineated, locate stockpiles on areas with little or no slope. Stockpiles must be surrounded with silt fence or a stabilized earthen berm.

Figure 2. Sample sediment and stormwater management plan checklist (continued).

STORMWATER MANAGEMENT

1_____ Show drainage calculations considering off-site contributing drainage. Provide pre and post-development velocities, peak rates of discharge, and inflow and outflow hydrographs of stormwater runoff at all existing and proposed points of discharge from the site for the 2 year and 10 year frequency storms. Show site conditions around points of all surface water discharge including vegetation and method of flow conveyance from the land disturbing activity and design details for structural controls.

2_____ All hydrologic computations shall be accomplished using the most recent version of USDA Soil Conservation Service TR-20 or TR-55, with the Delmarva Unit Hydrograph. The storm duration for computational purposes shall be the 24 hour rainfall event. The pre-development peak discharge rate shall be computed assuming that all land uses in the site to be developed are in good hydrologic condition.

3_____ Sub-watershed areas must be delineated on the plan for both the pre and post-development conditions. Provide the area in acres of each sub watershed.

4_____ Provide directional stormwater flow arrows for all existing and proposed channels, pipes, etc.

5_____ QUANTITY: Post-development peak rates of discharge for the 2 and 10 year frequency storm events shall not exceed the pre-development peak rates of discharge for the 2 and 10 year frequency storm events.

6_____ QUALITY: Water quality structures having a permanent pool shall be designed to release the first 1/2 inch of runoff from the site over a 24 hour period. Practices not having a permanent pool shall be designed to release the first inch of runoff from the site over a 24 hour period.

INFILTRATION

1_____ Infiltration practices shall be used only when the following criteria can be met or exceeded:

A_____ Systems shall be designed to accept, at least, the first inch of runoff from all streets, roadways and parking lots. (Including all contributing drainage areas.)

B_____ Areas draining to these practices must be stabilized and vegetative filters established prior to runoff entering the system.

C_____ A suspended solids filter accompanies the practice, when vegetation is used there shall be at least a 20 foot length of vegetative filter.

D_____ The bottom of the infiltration practice is at least 3 feet above the seasonal high water table.

E_____ The system shall be designed to drain completely in 48 hours.

F_____ Infiltration practices are limited to soils having an infiltration rate of at least 1.02 inches per hour. On site soil borings and textural classifications must be done to verify site conditions and seasonal high water table. This information must be submitted with the plan.

G_____ Infiltration practices greater than 3 feet deep shall be located at least 20 feet from basement walls.

H_____ Infiltration practices designed to handle runoff from impervious parking areas shall be a minimum of 150 feet from any public or private water supply well.

I_____ Infiltration practices shall have overflow systems with measures to provide a non-erosive velocity of flow along its length and at the outfall.

J_____ The slope of the bottom of the infiltration practice shall not exceed 5 percent.

K_____ Infiltration practices shall not be installed on or atop a slope whose natural angle of incline exceeds 20 percent.

L_____ Infiltration practices shall not be installed in fill material.

M_____ Unless allowed on a specific project, infiltration practices will only be permitted for the primary purpose of water quality enhancement.

Figure 2. Sample sediment and stormwater management plan checklist (continued).

PONDS

1_____All ponds constructed for stormwater management shall be designed and constructed in accordance with USDA Soil Conservation Service Small Pond Code 378, dated September 1990, as approved for use in Delaware.

2_____All ponds shall have a forebay or other design feature to act as a sediment trap, a 10 foot reverse slope bench must be provided 1 foot above the normal pool elevation for safety purposes, a 10 foot level bench 1 foot below the normal pool elevation, and all embankment ponds having a permanent pool shall have a drain installed.

DETAILS

1_____Provide details and specifications for all erosion and sediment control and stormwater management practices used.

2_____Provide details of temporary and permanent stabilization measures.

3_____Provide details, cross-sections and specifications (including stabilization) for diversions, ditches, ponds, swales, infiltration structures, etc.

4_____Specify details of any unusual practices used.

MAINTENANCE

1_____Specify whose responsibility it will be to maintain and repair all erosion and sediment control and stormwater management practices during utility installation.

2_____Maintenance set aside areas for disposal of sediments removed from stormwater management facilities must be provided. Set aside areas shall accomodate at least 2 percent of the stormwater management facility volume to the elevation of the 2 year storm volume elevation, maximum depth of set aside volume shall be 1 foot, and the slope of the set aside area shall not exceed 5 percent.

3_____A clear statement of defined maintenance responsibility shall be established during the plan review and approval process.

Figure 2. Sample sediment and stormwater management plan checklist (continued).

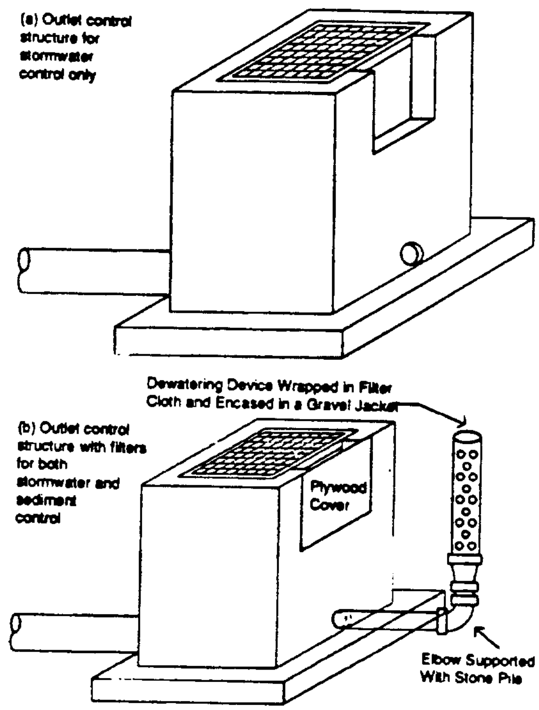


Figure 3. Outlet control structures for sediment and stormwater control.

reason for establishing a program that encourages stormwater management quantity control. Indeed, it has also been shown that flood peaks after development can increase by more than 500-fold.

The conservation districts' role in stormwater management quantity control is to ensure that discharge rates for the 2- and 10-year, 24-hour duration storm events do not increase following development. The districts also review management plan data on hydrograph timing and runoff volumes to ensure that areas downstream of development sites are not adversely affected. The districts prefer multiple-storm control because it is generally accepted as the most appropriate management approach for a wide range of storm discharges.

To compute stormwater discharges, procedures described in the Soil Conservation Service's Technical Release (TR) 20 and TR55 are used. Along with being generally user friendly, TR20 and TR55 procedures facilitate the production of required hydrographs and the computing of runoff storage requirements. Sussex and Kent Counties—and the DelMarVa Peninsula generally—fall under the TR20 and TR55 Type II rainfall distribution.

Early in the model's development, concerns were expressed that this rainfall distribution did not accurately represent the DelMarVa Peninsula, with its generally gently rolling topography, sandy soils, and limited outfalls. As a result, studies were performed and a new

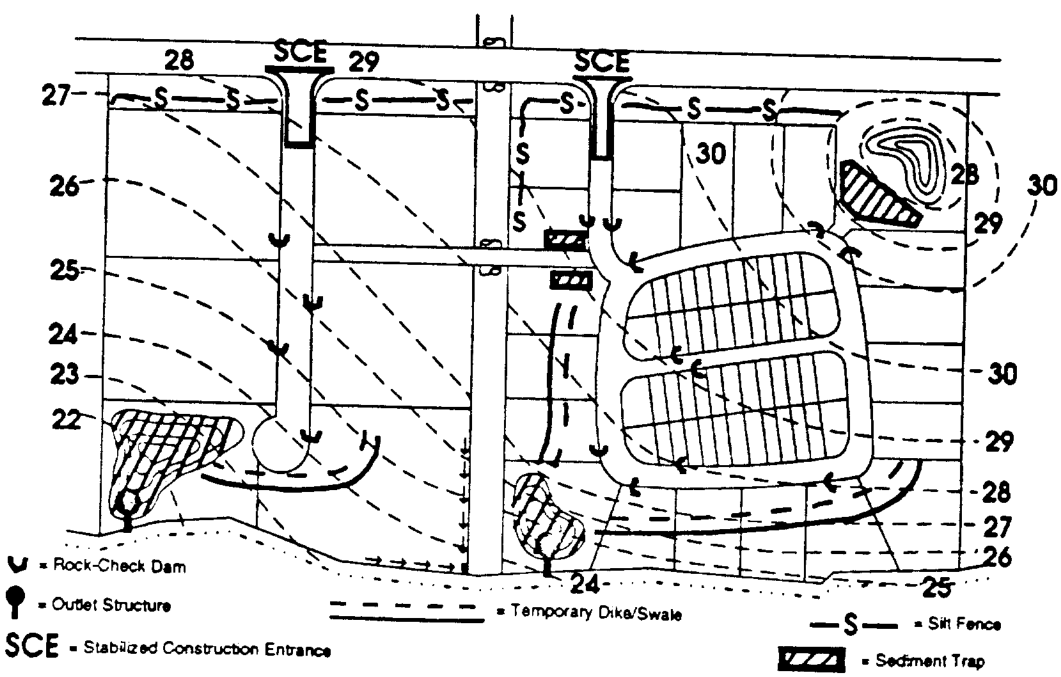


Figure 4. Sediment control features at Running Brook Estates and Business Park.

Sussex Conservation District
P.O. Box 8 · Georgetown, Delaware 19947 · Phone (302) 856-2105 or 7219

LIST OF HIGHLY ERODIBLE SOILS*

*S.C.S. FIELD OFFICE TECNNICAL GUIDE ("K" VALUE OF 0.20 OR GREATER)

SOIL NAME	SOIL SYMBOL	"K" VALUE	
ELKTON SANDY LOAM	El	0.43	
ELKTON LOAM	Em	0.43	
EVESBORO SAND (0-15%)	EoB-D	0.43	
FALLSINGTON SANDY LOAM	Fa	0.28	
FALLSINGTON LOAM	Fa	0.28	
KALMIA SANDY LOAM	Ka	0.28	
KENANSVILLE LOAMY SAND (0-5%)	KbA/B	0.24	
KEYPORT FINE SANDY LOAM (0-5%)	KfA/B2#	0.43	#ERODED
MATAWAN LOAMY SAND	Mm	0.28	
MATAWAN SANDY LOAM	Mn	0.32	
POCOMOKE SANDY LOAM	Pm	0.28	
PORTSMOUTH LOAM	Pt	0.28	
RUMFORD LOAMY SAND (0-10%)	RuA-C	0.20	
SASSAFRAS SANDY LOAM	SaA/B/C2#/D	0.28	#ERODED
SASSAFRAS LOAM (0-5%)	SfA/B	0.28	
WOODSTOWN SANDY LOAM	Wo	0.28	
WOODSTOWN LOAM	Ws	0.28	

Figure 5. Erodibility values for predominant soils on the DelMarVa Peninsula.

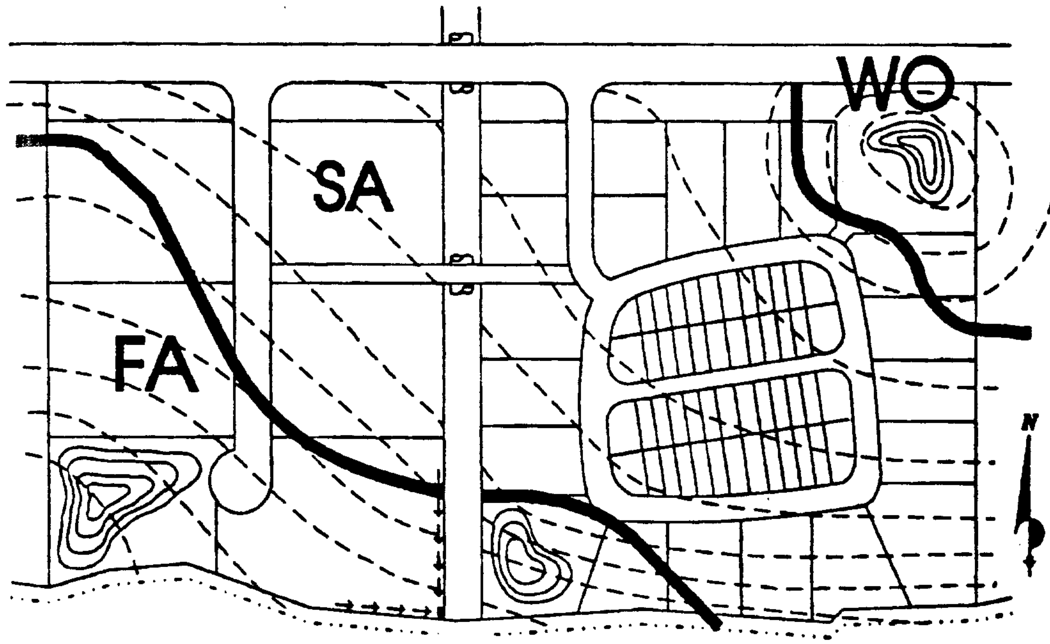


Figure 6. Predominant soils at Running Brook Estates and Business Park.

dimensionless, synthetic unit hydrograph was developed to be used with the Type II rainfall distribution. This hydrograph, named the DelMarVa Hydrograph, is used in Kent and Sussex Counties. The DelMarVa Hydrograph can develop peak flow rates up to 60 percent of those using just the given dimensionless synthetic hydrograph with the Type II rainfall distribution.

Stormwater is primarily managed for quantity control with ponds. In the Running Brook Estates and Business Park example, three stormwater management ponds are used (see Figure 7). The two ponds at the south side of the site were sized in accordance with standard criteria (i.e., using the 2- and 10-year, 24-hour duration storm events for discharge rates). The third pond is sized for a watershed with no positive outfall, a unique situation that often exists on the DelMarVa Peninsula. In such situations, when all possibilities to achieve an outfall have been exhausted, the facility is sized for the 10-year storm event runoff volume. A modified 100-year flood zone is then determined to establish finished floor elevations for any properties that could be affected by storms larger than the 10-year event. Infiltration can be factored in to reduce the size of such structures.

When development is proposed in urban areas and site space is limited, the district inspector has the flexibility to reduce the stormwater management quantity requirements to those related to quality, as discussed in the next section.

Stormwater Management for Quality Control

The preferred method for water quality treatment is use of a retention, or "wet," pond. Such a pond has a permanent pool capable of holding up to 1/2 in. of runoff over the drainage area. The elevation of the pool is determined by the low flow orifice of the outlet structure (Figure 3), from which the first 1/2 in. of runoff flows. Thus, above this elevation, 24-hour extended detention is provided for the 1/2 in. of runoff. Another feature required in the construction of a wet pond is the level bench. The bench is a 10-ft wide ledge around the perimeter of the pond, approximately 1 ft below the design elevation of the permanent pool, on which vegetation may be planted or allowed to grow naturally. The establishment of a thick mat of vegetation offers water quality improvements through sedimentation, filtration, and nutrient uptake. In addition, once this marshy area is established, it may help deter public access to the permanent pool area. Conservation districts often encourage addition of a wet pond as a water quality measure when soil and ground-water conditions are appropriate.

Figure 7 shows a wet pond in the southwest corner of Running Brook Estates and Business Park that was installed to capture and provide water quality treatment for a majority of the site's runoff. The pond's irregular shoreline and its proximity to wetlands (south of the site) make the pond aesthetically appealing and provide an

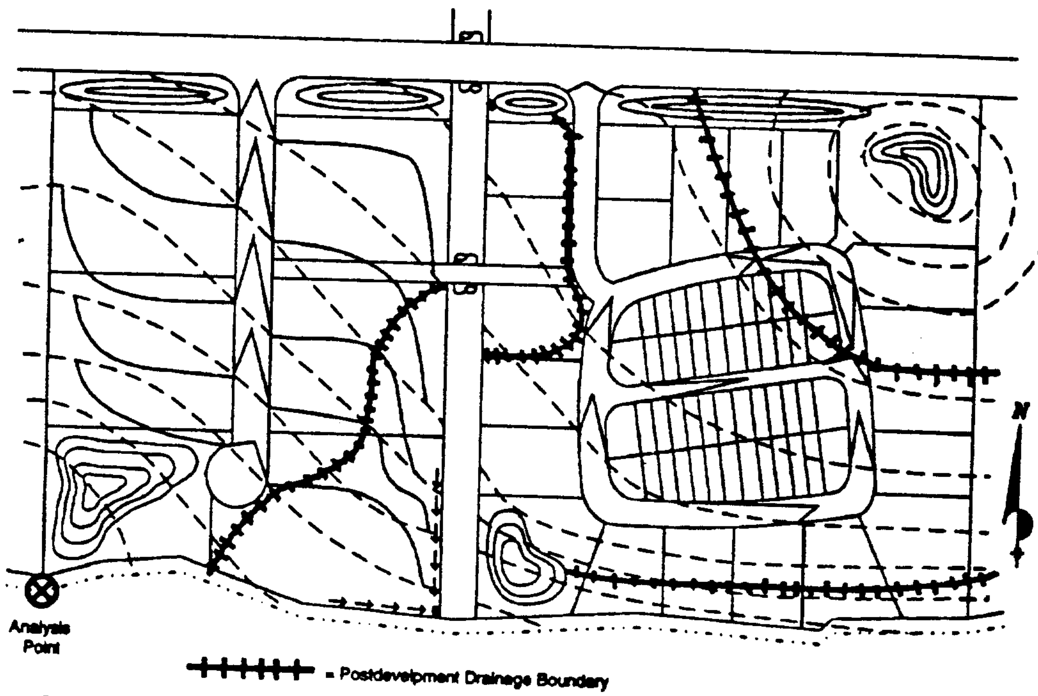


Figure 7. Stormwater management ponds at Running Brook Estates and Business Park.

extension of the natural area. Picnic tables were placed in the area for tenants' use.

More common for new construction projects is the detention, or "dry," pond, which detains runoff during a storm but then drains completely to a dry state. To meet regulations, a dry pond must be designed with a low flow orifice that provides extended detention of the first inch of runoff for a 24-hour period. While this appears to be an increase from the 1/2 in. required for wet ponds, actually the reverse is true. The first flush is generally accepted to be the first inch of runoff, but because wet ponds have been shown to provide better sedimentation and nutrient uptake, a volume credit is given for the use of a wet pond. This reduces the extended detention requirements by 50 percent.

Figure 7 shows a pond at the southern edge of Running Brook Estates and Business Park that provides extended detention for runoff from a large portion of the residential development. Discharge is to the wetland areas south of the site. Based on studies by the Mercer County Conservation District in New Jersey, the bottom and sides of this pond need to be planted with a wildflower mix. This type of vegetation will reduce the necessity of mowing to once a year, in the fall, greatly reducing maintenance expenses and increasing visual appeal. While state law requires a 3:1 side slope ratio for ponds in residential areas, the conservation districts encourage owners and consultants to design milder slopes.

If the use of ponds is not feasible on a site, an infiltration system should be considered. Infiltration trenches, in which perforated pipe is placed on a stone bed surrounded by filter fabric, are often preferred for urban sites, where higher land values make such systems particularly cost efficient. Infiltration trenches are generally considered less cost-effective for larger sites.

Another type of infiltration system is the basin. The infiltration basin depicted in the northeast corner of Running Brook Estates and Business Park in Figure 7 is used for the no-positive-outfall situation described above. The infiltration method of runoff management is encouraged for water quality enhancement but is discouraged for water quantity control due to the high potential for failure.

State law also allows the use of any practice that can achieve 80-percent removal of suspended solids in stormwater runoff. One such practice, the use of sand filters, has been effective in Delaware. Sand filtration can also be effective for capturing hydrocarbons, which can escape from ponds. Such systems function much like a septic system, with a sediment chamber leading to a filtration chamber (Figure 8); however, the majority of runoff is stored ahead of the structure in two grassed swales. Because this design is new, a strict maintenance schedule has been developed that must be followed until

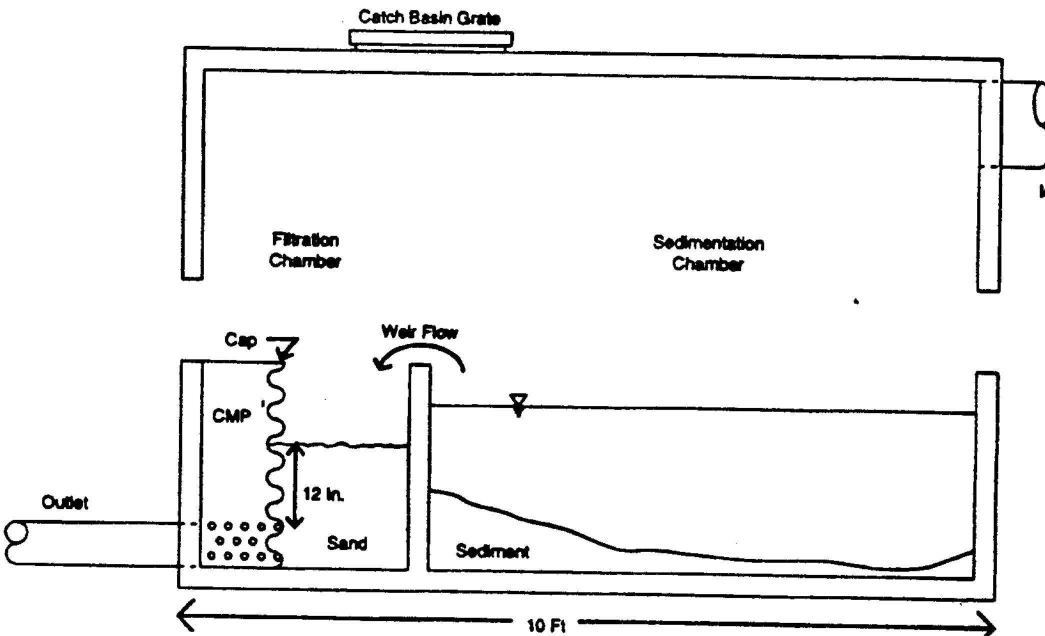


Figure 8. Septic tank modified for sand filtration.

performance can be verified. The system must be inspected every 3 months and any large debris removed. Once a year, the sedimentation chamber must be evaluated and the polluted top layer of sand removed and replaced. Every 5 years, the entire volume of sand must be replaced.

Another acceptable method of infiltration is the use of vegetated swales, an approach referred to as biofiltration. Given their linear configuration, vegetated swale systems may be especially appropriate for space-limited urban sights where a water quality pond might otherwise be used.

Runoff from the northwest corner of Running Brook Estates and Business Park is treated in two biofiltration swales before it enters the tax ditch that separates the residential subdivision from the business park. The swales are located on either side of the forestry lane leading to the tax-ditch crossing. The forestry lane, which was installed because fire laws require two access points for developments of this size, is demarcated with a combination of fescue and a wildflower mix, which the conservation district mandates for the quality and aesthetic aspects of swales.

Because these swales at Running Brook Estates and Business Park only receive water quality treatment, a TR20 analysis was performed on the entire site to assess flows at the analysis point shown in Figure 7. Other factors were also considered in finalizing review of the site plan (see Figures 9, 10, and 11).

Site Inspection

Plan review is not the only element of sediment control and stormwater management delegated to the conservation districts. To keep day-to-day operation of the program within one agency, the conservation districts also conduct site visits periodically during construction and then on an annual basis to perform maintenance inspections of all completed facilities. A long-term maintenance plan for each facility, identifying the responsible parties, must be established during the plan review stage.

Conclusion

The most important role the conservation districts have in site plan review is providing technical assistance to landowners, designers, and contractors with respect to sediment control and stormwater management. The districts' staff pride themselves on their working relationships and knowledge of the evolving situations in the state's counties.

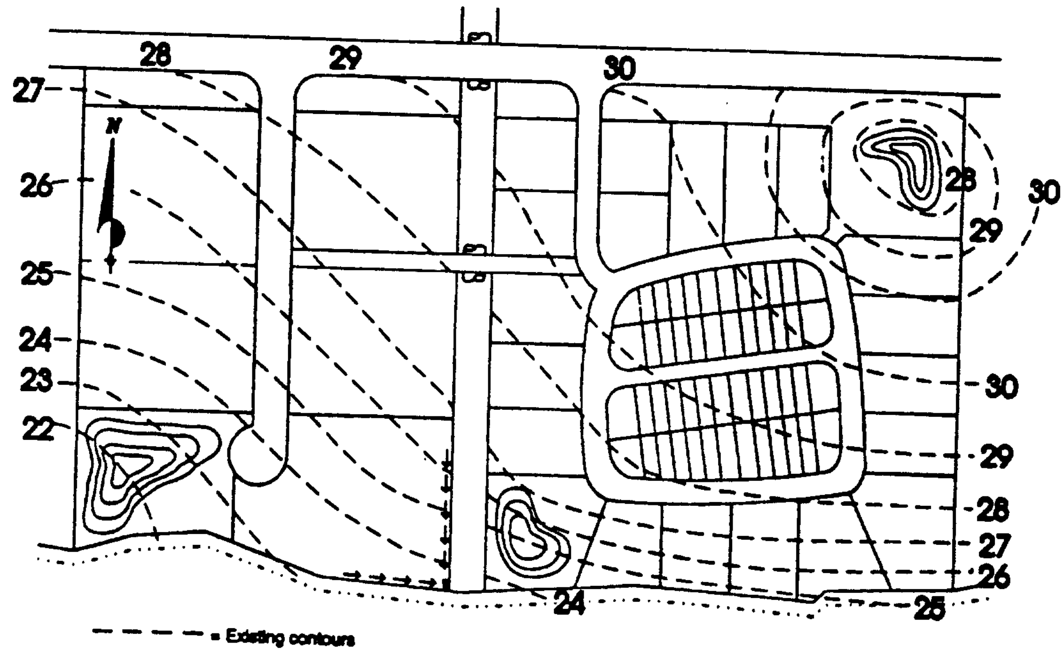


Figure 9. Existing contours at Running Brook Estates and Business Park.

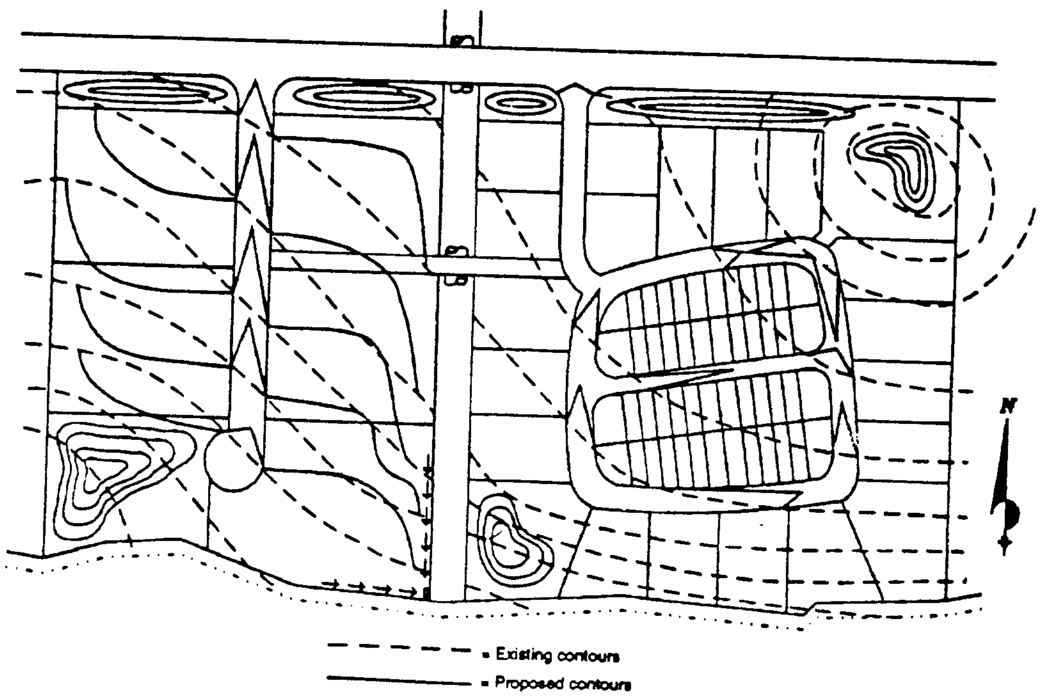
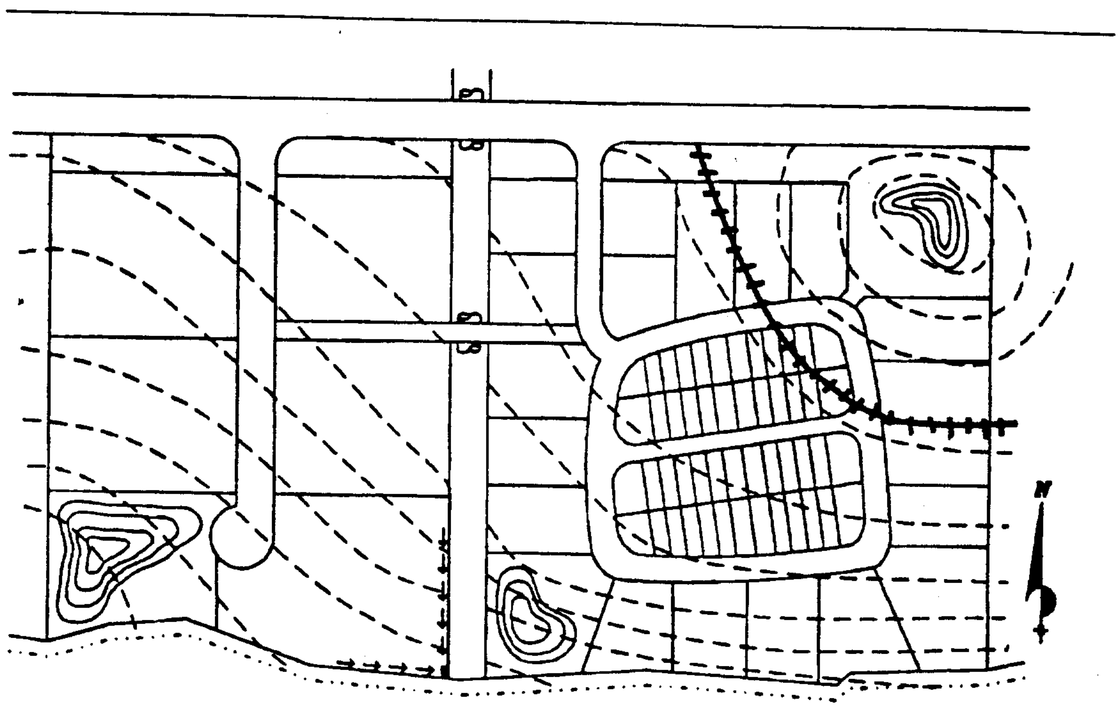


Figure 10. Existing and proposed contours at Running Brook Estates and Business Park.



+++++++ = Predevelopment Drainage Boundary

Figure 11. Predevelopment drainage boundary at Running Brook Estates and Business Park.

The Role of Landscapes in Stormwater Management

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Applied Ecological Services, Inc.,
Brodhead, Wisconsin

Abstract

This paper presents evidence that many existing streams did not have conspicuous channels and were not identified during presettlement times (prior to 1830s in the midwestern United States). Many currently identified first-, second-, and third-order streams were identified as vegetated swales, wetlands, wet prairies, and swamps in the original land survey records of the U.S. General Land Office.

The data presented show that significant increases in discharge for low, median, and high flows have occurred since settlement. Stream channels have formed inadvertently or were created to drain land for development and agricultural land uses. Currently, discharges may be 200 to 400 times greater than historical levels, based on data from 1886 to the present for the Des Plaines River in Illinois, a 620-square-mile watershed. Historic data document how this river had no measurable discharge or very low flow conditions for over 60 percent of each year during the period from 1886 to 1904.

This study suggests that land-use changes in the previous upland/prairie watershed have resulted in a change from a diffuse and slow overland flow to increased runoff, concentrated flows, and significantly reduced lag time. Preliminary modeling suggests the following results: reduced infiltration, reduced evaporation and evapotranspiration, greatly increased runoff and hydraulic volatility, and increased sediment yields and instream water quality problems caused by destabilization of streambanks.

The opportunity to emulate historical stormwater behavior by integrating upland landscape features in urban developments and agricultural lands offers stormwater management options that are easier to maintain, less expensive over time, attractive, and possibly more efficient compared with many conventional stormwater management solutions and the use of biofiltration wetlands.

Introduction

Diverse and productive prairies, wetlands, savannas, and other ecological systems occupied hundreds of millions of acres in presettlement North America. These ecological systems have been replaced by a vast acreage of tilled and developed lands. Land-use changes have modified the capability of the upland systems and small depressional wetlands in the uplands to retain water and assimilate nutrients and other materials that now flow from the land into aquatic systems, streams, and wetlands. The historical plant communities that were dominated by deep-rooted, long-lived, and productive species have been primarily replaced by annual species (corn, soybeans, wheat) or shallow rooted non-native species (bluegrass lawns, brome grass fields). The native vegetation was efficient at using water and nutrients, and consequently maintained very high levels of carbon fixation and primary productivity. Modern communities, in turn, are productive but primarily aboveground, in contrast to the prairie ecosystem where perhaps 70 percent of the biomass was actually created belowground in highly developed root systems. These changes in the landscape and vegetation coupled with intentional stormwater management have changed the lag time for water to remain in uplands and consequently the rate and volume of water leaving the landscape.

The Des Plaines River

Changes that have occurred on the uplands and how these changes have affected the hydrology of wetlands and aquatic systems can be illustrated using historical and more recent data to illustrate trends in discharge of major river systems. The Des Plaines River was chosen as a study watershed because of available historical data and trackable changes in watershed land uses.

The Des Plaines River originates southeast of Burlington in southeastern Wisconsin, flows for over 90 river miles through agricultural, urban, and suburban landscape through northeastern Illinois and the Chicago region, then flows west and south, meeting with another river and becoming the Illinois River. The historical data presented are from a case before the Illinois Supreme Court and a circuit court (U.S. Department of War vs. Economy Power and Light, 1904) that dealt with the navigability of the Des Plaines River. The data were derived from a gauge station installed and operated at present-day Riverside, Illinois, from 1886 to 1904. The U.S. Geological Survey has maintained this same station since 1943. Historical data from 1886 to 1904 include a single-stage measurement per day and weekly discharge measurements (rating curves). For our studies, duration flow curves were created for the years 1886 to 1904 and 1943 to 1990. The data were compared using median values of discharge (50 percent) and also using low and high levels of discharge as indicated by the 75 percent and 10 percent values derived from the annual duration flow curves 1886 to 1904 and 1943 to 1990. The watershed area gauged at Riverside is approximately 620 square miles (400,000 acres).

In the late 1800s, about 40 percent of the watershed had been tilled and/or was developed. In contrast, approximately 70 to 80 percent of the watershed is now developed or under annually tilled agriculture land uses. Annual duration flow curve values based on linear regression analysis suggested very significant increases in discharge since 1886; perhaps 250 to 400 times (Figure 1). In 1886, the median discharge was 4 ft^3/sec. In contrast, in recent years the median discharge has been 700 to 800 ft^3/sec. Trends in low, medium, and high flow values for the Des Plaines River have undergone very significant increases.

Preliminary watershed hydrologic modeling suggests that the watershed and discharge data for 1886 to 1904 had already been modified by development and agricultural land uses; the Des Plaines River watershed was settled in the late 1830s, and thus 50 years of land use and development had passed before the 1886 data were collected. Other data resulting from the litigation suggested very clearly that the discharge of water from the Des Plaines River was significantly less between 1886 to 1904 compared with present day discharge. Because the litigation contested navigability, evidence was presented using daily stage, discharge, and water depth data on the opportunity for commercial navigation on the river. The data suggested that between 1886 and 1904, for an average 92 days per year, the river had no measurable discharge. An additional 117 days per year, the river had 60 ft^3/sec or less discharge, which was equal to a depth of less than 3 in. at Riverside. Based on these statistics, over 60 percent of the year the 400,000 acre watershed yielded no water or such low flows that navigation was not possible or reliable. Another 10 to 25 percent of the year the river was covered with ice.

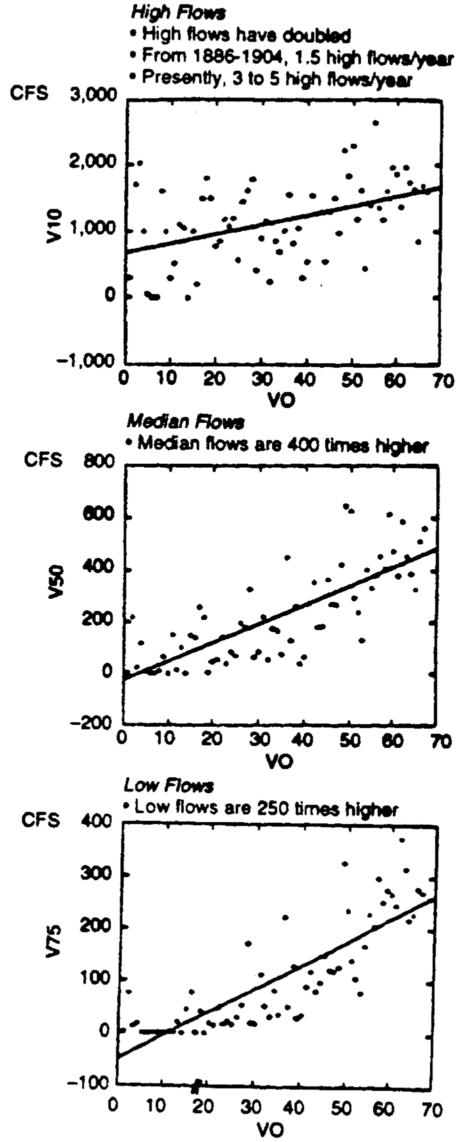

Figure 1. Linear regression analysis and raw data plots of Des Plaines River discharge at Riverside, Illinois, 1886 to 1988. Low, median, and high flow data were derived from duration-flow curves for 75, 50, and 10 percentile annual flow levels (1).

Additional supporting evidence of the significance of changes in the watershed and river is available. The original land survey records for parts of the Des Plaines River where section lines were surveyed identified that reaches of the river had no discernable channels. Where channels now occur, in the 1830s surveyors found wet prairies, swamps, and swales but usually no conspicuous or measurable channel widths. Channels and

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"pools" were identified in some locations and with greater frequency downstream in the watershed. The original land surveyors were under contract by the U.S. Government Land Office to document the vegetation types covering the land and to identify, where possible, the widths and depths of streams when they were encountered during the process of laying out the section lines.

Conclusions and Applications of the Findings

These data suggest very clearly that highly significant changes in the hydrology, hydraulics, and water yield from the Des Plaines River watershed have occurred since settlement. Other major river and watershed systems have yielded similar results, suggesting the transferability of the concepts and general conclusions reached from the studies of the Des Plaines River. These findings and their applications are discussed below.

Natural Ecological System Functions and Processes Should Be Emulated

Water Yield

The historical landscapes "managed" stormwater very differently than it is managed by present-day strategies. Historical data clearly indicate that a relatively small percentage of the precipitation in a watershed actually resulted in measurable runoff and water leaving the watershed. In fact, preliminary analysis suggests very strongly that an average 60 to 70 percent of the precipitation in the watershed did not leave the watershed from the Des Plaines River; this water was lost through evaporation and evapotranspiration. Analysis predicts that approximately 20 to 30 percent infiltrated and may have contributed indirectly to base flow in the streams and directly to base flow in wetlands in the watershed. During a full year, the balance of the water directly contributed to flow in the "river," where an identifiable river channel now occurs.

Present-day water management strategies involve collection, concentration, and managed release of water. These activities are generally performed in developed parcels in the lower topographic positions. Historically, a greater percentage of water was lost through evaporation and evapotranspiration from upland systems. In these situations, microdepressional storage and dispersed rather than concentrated storage occurred. Weaver (1) documented the ability of the foliage of native perennial grassland vegetation to intercept over an inch of rain with no runoff generated.

Sediment and Pollutant Management

Because many pollutants in stormwater require water to dislodge and translocate the suspended solids to which they are adsorbed, there is a great opportunity to emulate historical functions by using upland systems to perform biofiltration functions, increase lag time, and reduce total volume and rate of runoff.

Increased discharge and velocity of water moving through channels has been documented to greatly affect instream water quality. Perhaps as much as 70 percent of instream sediment loads come from channel and bank destabilization associated with the higher velocity waters and with solufluction and mass wasting of banks after flood waters recede (2). Stabilizing (or at least reducing) hydraulic pulsing in streams can best be accomplished by desynchronization and reduction of tributary stormwater volumes and runoff rates from uplands. This can be accomplished by integrating substantial upland perennial vegetated buffers throughout developments and agricultural land uses. Buffers are designed not only to convey water and minimize erosion (i.e., grassy waterways) but also to attenuate hydraulic pulsing, settle solids and adsorbed nutrients, and reduce and diffuse the velocity, energy, and quantity of water entering rivers, wetlands, and other lowland habitats. Using upland microdepressional storage, perhaps in the form of ephemeral wetland systems and swales in the uplands, also would emulate the historical landscape conditions and functions.

Applications

Several example projects of "conservation developments" are now being completed, which integrate up to 50 to 60 percent of the urban development as open space planted to perennial native prairie, wet swales, and other upland communities (as site amenities). Hybernia is a 132-acre residential development in Highland Park, Illinois, designed and constructed by Red Seal Development Corporation, Northbrook, Illinois. Empirical data from Hybernia suggest that the use of upland vegetation systems in combination with ponded areas has resulted in the rate and volume of discharge being essentially unchanged before and after development. Another project, Prairie Crossing, is a 677-acre residential project designed to offer comprehensive onsite stormwater management in uplands and created lake systems. Extensive upland prairie and wet swale systems biofilter runoff and enhance the quality and reduce the quantity of water reaching wetlands and lakes in the development.

In these types of projects, upland vegetation takes several years to fully offer stormwater management benefits. In planted prairies, surface soil structure develops a three-dimensional aspect in 3 to 5 years. The development of this structure seems to have an important role both in offering microdepressional storage and increasing the lag time for retaining water in upland systems.

Restoration and native species plantings also have provided benefits where ecological system degradation has led to increased water and sediment yields. Where ecological degradation is occurring indirectly because human activities on the landscape have reduced or eliminated major processes (such as natural wildfires), restoration can provide vegetation and stormwater management benefits. Wildfires have been all but eliminated since human settlement has occurred, especially in areas that contain forests, savanna, or oak woods. In the absence of fires in many oak woods and savannas, a dense shading develops caused by increased tree canopy and dense shrub development. Where this has occurred, a reduced ground cover and soil stabilizing vegetation grows under the low-light conditions. Consequently, highly erodible topsoils containing the seeds, roots, and tubers of the soil stabilizing vegetation and higher volumes and rates of water can run off from these degraded savanna sites. The process of savanna deterioration has been documented; restoration has used prescribed burning and other strategies (3-5). Reestablishment of ground cover vegetation is key to reducing runoff, improving water quality, and reestablishing an infiltration component in degraded, timbered systems.

Should Wetlands Be Used for Sediment Management, or Should This Occur on the Uplands?

Because wetlands often provide what little wildlife habitat remains in developed landscapes, and because they are attractive to wildlife, their use for stormwater management must be carefully considered. Currently, a national movement is afoot to use created (and often natural) wetlands for stormwater management and biofiltration. Many studies of existing high-quality wetlands, however, provide little or no evidence that they historically served important biological filtration and sediment management functions. Sediment deposition was generally episodic (e.g., after wildfires), was of short duration, and yielded small sediment loads compared with loads from present-day agricultural and developed lands.

Use of wetlands for biofiltration can actually aggravate existing problems for many wetland wildlife species. For example, in the Chicago region it is not unusual to find 100 to 200 parts per million lead (and other contaminants) in tadpoles (especially in frog species with a 2-year tadpole stage, such as leopard frogs, bullfrogs, and green frogs) found in wetlands receiving highway stormwater. It is imperative to understand the potential long-term toxic effects on biological systems associated with stormwater management in wetlands and contaminant mobility.

Proposals have been made to allow the materials concentrated in biofiltration wetlands to simply be buried by each additional sediment load or to be intentionally buried by adding additional soil. Contaminant mobility through biological pathways still occurs, however, from beneath considerable sediment burial. In fact, in the Great Lakes, contamination from PCBs that are often several feet below the surface of the sediments have contributed to major increased mortality rates and major morphological problems in predacious birds such as cormorants, terns, and gulls (6, 7). The literature on wetland biofiltration inadequately addresses contaminant mobility routes through biological systems and the potential threat to the viability of biological systems. Because wetlands are so attractive to biological organisms (and, in fact, the biological organisms are often key to the successful functions of the biofiltration wetlands), it is necessary to rethink and carefully design biofiltration wetland systems in the future.

Far too often, people view the lowland environments (i.e., rivers, wetlands) as the locations for treating or physically removing problems created in the upland environments. The studies briefly described in the previous section, however, suggest that stormwater, sediment loads, and the varied contaminants may be best managed on upland systems. Although the land cost for using upland rather than lowland environments for stormwater management may be higher, the efficiency and reduction in potential contaminant problems may be greater. A landscape with many upland microdepressional storage opportunities and a large buffering capacity might offer more efficient processing than would a single biofiltration wetland at the downstream end. Each buffer or depressional wetland would need to treat a smaller volume of water and contaminants. Also, upland or dispersed stormwater treatment facilities would have significantly reduced long-term maintenance costs and represent a more sustainable approach to management of stormwater. Centralized biofiltration wetlands, on the other hand, have high maintenance requirements and potential problems that include decreases in removal efficiency for some materials in the short and long term.

There Are No Controlled Year-Round (and Long-Term) Studies of Removal Efficiencies Comparing Uplands and Wetlands

The stormwater treatment literature indicates that use of wetlands and measurements of removal efficiencies have been based primarily on removal during storm events passing through the biofiltration wetlands. Year-round contaminant mass-balance data are largely unavailable. Nongrowing season studies have documented the export of materials to be significant; consequently, removal efficiencies for some materials (e.g., metals, phosphorus) are not likely to be significantly reduced from what has been documented for storm event sampling. Wetland efficiencies need to be experimentally controlled and compared with upland removal efficiencies, which also have not been studied in detail (with the exception of removals for several key elements such as phosphorus). The ability of upland (soil colloids) systems to provide reliable and long-term binding and retention for many contaminants has been demonstrated (8).

Acknowledgments

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The U.S. Environmental Protection Agency's Advanced Identification Process

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Abstract

Advanced Identification (ADID) is a planning process designed to identify and help protect high-quality wetland resources. The ADID process is a joint effort between the U.S. Environmental Protection Agency (EPA) and the U.S. Army Corps of Engineers, in which wetland functions and values are evaluated to determine which wetlands within an ADID study area are high quality and should be protected from future fill activities or, in some cases, which wetlands are of ecologically low value and could be considered as potential future fill sites. ADID provides the local community with information on the value of wetland areas that may be affected by their activities as well as a preliminary indication of factors that are likely to be considered during permit review of a Section 404 permit application.

Final ADID products usually consist of a technical report that includes the data gathered during the ADID study, a description of how the wetland evaluation was done, and a set of maps that identify the sites determined to be either unsuitable or suitable for filling activities. EPA works closely with other federal, state, and local agencies as well as the public throughout the ADID process. Each ADID process is designed a little differently to meet the specific wetland planning needs of the local area.

Introduction

In an effort to provide protection to remaining wetlands, the U.S. Environmental Protection Agency (EPA), in cooperation with the U.S. Army Corps of Engineers (COE) and other federal, state, and local agencies, may identify wetlands and other waters of the United States as generally unsuitable or suitable for the discharge of dredged or fill material before receiving a Section 404 permit application. This Advanced Identification (ADID) process is authorized by the regulations pertaining to Section 404 of the Clean Water Act. During the ADID process, EPA, COE, and other federal, state, and local agencies collect information on the values of wetlands and other waters of the United States to determine which wetlands in the ADID study area are of high functional value and should be protected from future fill activities and, in some cases, which wetlands are of low functional value and could be considered as potential fill sites.

What Is an ADID?

ADID is an advanced planning process designed to provide an additional level of protection to wetlands and other waters of the United States. The ADID process is one of the few tools currently available to EPA and other regulatory agencies that can help address resource-specific issues from a broader perspective. Typically, Section 404 permitting actions are considered on a case-by-case basis. ADID provides the opportunity to evaluate permit requests against wetland resource concerns from a watershed or regional perspective. Therefore, ADID can be used to address large geographic issues such as regional wetland loss, to provide the information needed to better evaluate cumulative loss impacts, and to provide more detailed ecological information than is typically available to regulatory decision-makers.

A planning tool, ADID is advisory not regulatory in nature. ADID provides landowners and developers with advance information, allowing them to plan with more predictability regarding the Section 404 permitting program. ADID can provide environmental groups, resource agencies, or other groups with information that can be used to guide protection or restoration efforts. ADID also can give information on local wetland loss trends. Most importantly, ADID can provide local communities with information on specific values of local wetlands that can be used to help develop local ordinances or other planning efforts designed to protect wetlands with values important to the community.

ADID projects vary in size and scope. Study areas range in size from 100 acres to 4,000 square miles and have been initiated throughout the country. Nationally, 35 ADID projects have been completed, and 36 are ongoing. The ADID process can be very resource intensive, depending on the scope of the project. From start to finish, the time to complete the ADID process can range from 6 months to several years.

Final ADID products vary from project to project. Typically, a completed ADID includes a map that identifies areas that are either unsuitable or suitable for fill, a database that contains the information used to make the ADID determination, and a technical summary document that explains how the wetland evaluations were done and what criteria were used to make the unsuitable/suitable determinations. Before ADID is completed, a joint public notice is issued by EPA and COE and a public meeting is held to solicit public comment on the products. Public comments are considered before the final ADID determinations are made. The final maps, supporting data, and technical summary document are all available to the public upon request.

In Region 5's experience, ADID is most effective where there is strong local support for such a project. ADID projects that involve local agencies can be tailored to address local needs or problems, such as flood control, water quality problems, or habitat loss. Participation of local agencies in the ADID process not only provides valuable local perspective and expertise but also the opportunity for ADID determinations to be included in local comprehensive planning efforts and wetland protection ordinances.

Lake County ADID

EPA Region 5, in cooperation with COE and several other federal, state, and local agencies, completed an ADID project in Lake County, Illinois, in January 1993. The following is a brief overview of how the ADID process worked in Lake County.

Lake County is 460 square miles and is located in northeastern Illinois. This county has been under intensive development pressure for the last 5 to 10 years. Lake County also contains a significant proportion of the wetlands and lakes within Illinois. The majority of wetlands within Lake County are isolated or above the headwaters; therefore, many small wetland fills (less than 10 acres) were authorized under Nationwide Permit 26. EPA and COE were concerned that, cumulatively, these fills could have a significant negative effect on aquatic resources in Lake County.

Lake County was interested in supporting an ADID study because local citizens were raising many wetland development issues. The county hoped that the ADID process would provide an additional level of protection for the high-quality wetlands, as well as an opportunity for the county to work with federal agencies to resolve local wetland issues. In addition, the county was beginning to work on a stormwater and wetland protection ordinance. The county viewed the ADID process as an opportunity to work with federal and state agencies to develop an evaluation methodology for local wetlands that could be used to guide implementation of the proposed ordinance.

The Lake County ADID process was started in the fall of 1989. The first meeting included representatives from federal, state, and local agencies and public interest groups. The goals of the ADID process were explained, and the wetland functions and values to be evaluated were selected based on local needs. A technical advisory committee was formed consisting of representatives from EPA, COE, the U.S. Fish and Wildlife Service, the Soil Conservation Service, the Illinois Department of Conservation, the Lake County Forest Preserve District, the Lake County Department of Management Services, the Lake County Department of Planning, the Lake County Soil and Water Conservation District, the Lake County Stormwater Management Commission, and the Northeastern Illinois Planning Commission. The committee's task was to develop the methodologies to evaluate the selected wetland functions and values. Due to resource constraints, the committee decided to focus on identifying high-quality wetland sites only. Sites identified as being of high functional value would be considered unsuitable for filling activities.

Lake County, Illinois, contains many lakes and wetlands and is undergoing rapid urban development. Issues such as degradation of water quality, flooding problems, and habitat loss are of local concern. Based on these concerns, the committee selected the following five wetland functions to evaluate for the ADID study:

- Biological community value
- Stormwater storage value
- Shoreline/bank stabilization value
- Sediment/toxicant retention value
- Nutrient removal/transformation value

In considering evaluation methodologies, the committee immediately determined that the selected approach must be capable of dealing with a very large number of wetlands. The final evaluation methodologies developed for use in the Lake County ADID process were combinations of portions of the Wetland Evaluation Technique (WET) developed for COE (1) and the Minnesota Wetland Evaluation Methodology (2) developed by the St. Paul District of COE. Portions of these methodologies were adapted to meet the needs of the Lake County ADID process. The evaluation methodologies and the criteria used to determine which wetlands and streams were of high functional value are described in detail in the Lake County ADID final report (3).

The wetlands identified as being of high functional value were considered generally unsuitable for filling activities. A wetland was determined to be of high functional value, or unsuitable, if the site included high-quality biotic communities or if the site provided three of the four stormwater storage or water quality functions. This ADID study also identified high-quality stream corridors that are designated as being unsuitable.

The preliminary Lake County ADID designations were published in a joint public notice issued by COE and EPA. Also available for public review and comment were the evaluation methodologies used, scale maps (1 in. = 1,000 ft) showing the location of all sites of high functional value, and data sheets corresponding to each site identified as being of high functional value. A public meeting also was held to gather further public comment. After considering all the public comments, five sites were added to the list of areas of high functional value.

Approximately 24,000 acres of wetlands, lakes, and streams were identified as high functional value sites. These sites include both public and privately owned property and represent about 39 percent of the wetlands and lakes remaining in the county. The Record of Decision, final public notice, report, and finalized maps were published in January 1993.

Results and Effectiveness

It is difficult to accurately assess how effective the Lake County ADID study was in providing an additional level of protection for wetlands. The ADID maps have been used by both developers and public entities such as the Illinois Department of Transportation during site planning. In addition, COE relies heavily on the information provided by the ADID study to guide permit decisions for ADID sites. The county, however, has not yet implemented its wetland protection ordinance. Once the county's wetland protection ordinance is in place, not only will the county provide protection for ADID sites but the ordinance will also require that a buffer area be maintained around all ADID sites.

While ADID or similar advanced planning processes are resource intensive, these types of studies can be well worth the effort if the projects are well designed and the resulting information is incorporated into local comprehensive planning efforts that will guide local land-use decisions. In addition to focusing on Section 404 issues, ADID can be tailored to provide information needed for a variety of other wetland related issues. For example, ADID can be designed to provide information that assists in the selection of wetland restoration sites. Advanced wetland planning studies also can be components of larger planning efforts (e.g., watershed protection strategies) or parts of geographic initiatives (e.g., remedial action plans and lakewide management plans).

Summary

ADID is one of the few tools available to EPA and other regulatory agencies that can substantially address resource-specific issues from a broader ecological perspective. ADID can be used in an innovative manner to address large, geographically based issues. Within an urban setting, ADID can provide information to communities regarding the functions and values of local wetlands and can guide local protection and restoration efforts while focusing on local problems or concerns.

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Wisconsin Smart Program: Starkweather Creek

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Abstract

Starkweather Creek drains a 23-square-mile urban watershed in the city of Madison, Wisconsin. Urban runoff had resulted in elevated levels of biochemical oxygen demand, mercury, lead, zinc, cadmium, and oil and grease in the sediments and a severely degraded fish and macroinvertebrate habitat. Historically, the creek had received significant amounts of stormwater and industrial waste discharges. Industrial activities in the watershed had included metal fabrication, battery manufacturing, meat packing, and food processing. Starkweather is the second largest tributary and the largest source of mercury to Lake Monona, a principal recreation lake for the Madison area. Downstream transport of sediments and associated pollutants from the Starkweather watershed effects the quality of this important lake, which is under a fish advisory to anglers to restrict consumption of larger walleyes due to elevated mercury levels.

To address contamination in the creek and Lake Monona and to implement the recommendation of the local priority watershed plan, Wisconsin's Sediment Management and Remediation Techniques program selected Starkweather as a sediment remediation demonstration project. A joint U.S. Environmental Protection Agency, Wisconsin Department of Natural Resources, county, and city project was developed to 1) reduce nonpoint loading, 2) control the impacts of in-place contaminants, and 3) restore the recreational value and aquatic habitat of the creek. This $1 million program included the dredging of 17,000 yd^3 of contaminated sediments, construction of stormwater detention ponds, development of streambank erosion controls, and aquatic habitat restoration.

Introduction

Starkweather Creek, located on the northeast side of Madison, Wisconsin, is the city's largest urban watershed, draining 23 square miles (Figure 1). The creek discharges to Lake Monona, a principal recreation lake located in the city of Madison. The creek and its watershed have been extensively altered as a result of urbanization. Extensive ditching, channelization, wetland draining and filling, and impervious structure development have shaped the hydrology and water quality of the creek.

Starkweather Creek has been affected by both point and nonpoint pollution over time. The creek drains a heavily industrialized portion of the city where metal fabrication, battery manufacturing, meat packing, and food processing occurred. Urban nonpoint runoff is believed to have contributed significant levels of pollutants in recent years.

Recent monitoring indicated that the creek had elevated levels of sediment oxygen demand, biochemical oxygen demand (BOD), mercury, lead, zinc, cadmium, and oil and grease in the sediments and a severely degraded fish and macroinvertebrate habitat. Concern for the levels of contaminants in the sediments of the creek extended beyond the stream channel and its habitat and also encompassed the downstream impacts of the sediments on Lake Monona.

Lake Monona has a mercury advisory on large walleye due to excessive levels of the metal in the tissues of this fish. Starkweather Creek, identified as the largest source of mercury to the lake, was targeted for remediation to restore the aquatic habitat of the creek and to protect Lake Monona.

Wisconsin Sediment Management and Remediation Techniques Program

In response to the growing awareness of natural resources managers of the continuing impacts of in-place pollutants associated with sediment deposits in the state's waterways, the Wisconsin Department of Natural Resources (DNR) established an interdisciplinary team to develop necessary assessment and remediation tools to restore affected waters of the state. The Wisconsin Sediment Management and Remediation Techniques (SMART) Program has brought together

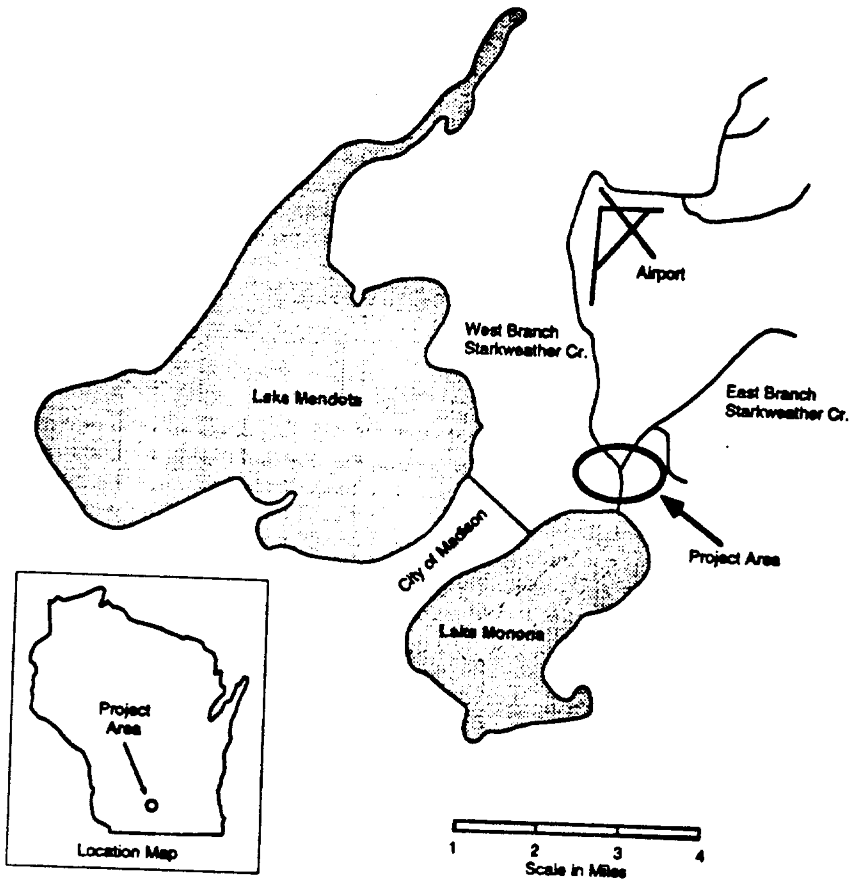

Figure 1. Location map of Starkweather Creek and the restoration project area.

expertise in environmental toxicology, aquatic habitat assessment, hydrographic surveying, sediment mapping, sediment engineering, and remedial technology. The SMART Program has two basic responsibilities: 1) define the extent of sediment contamination and impacts on the waters of the state and 2) guide the remediation of contaminated sediments.

The SMART Program coordinates the state's contaminated sediment activities with various universities and federal programs, such as the U.S. Environmental Protection Agency's Superfund and Great Lakes National Program Office Assessment and Remediation of Contaminated Sediment (ARCS) programs.

Monitoring Data

Starkweather Creek, the first sediment cleanup demonstration of the Wisconsin SMART Program, provided an opportunity to use advance monitoring of the many components of an aquatic system affected by contamination in sediments. Several assessment techniques were used to define the degree of sediment contamination, stream water quality, and aquatic habitat (Table 1). Later sections of this paper address monitoring performed during dredging to assess on- and offsite impacts of the cleanup. Postremediation monitoring will continue for 2 years to document the changes and response of the creek.

Remediation Planning

Starkweather Creek was selected as the first sediment remediation demonstration for the SMART Program based on recommendations from the state's DNR management districts, on the relative small scale of the site, and on ranking of the site with the SMART selection criteria. This criteria included:

- Impaired uses of the water body
- Adequate data for feasibility analysis
- Upstream pollution source controls
- Local support

- Adequate access
- Integration with other state and local programs

The specific project goals and objectives were developed by a project implementation team assembled from representatives of relevant state and local agencies and bureaus who guided the development of the project work plan, schedule, and budget. Individual members were responsible for ensuring that their program's relevant regulations were followed and the work plan was consistent with program policies and goals.

Table 1. A Summary of Starkweather Creek Preremediation Monitoring Data

	Range	Average	Total Weight
Sediment Chemistry			
Mercury	<0.1–3.5	1.1 ppm	40 lb
Lead	33–320	130 ppm	2.4 tons
Chromium	9–31	19 ppm	0.35 tons
Oil and grease	1,500–3,600	2,800 ppm	51 tons
PCBs	<0.14 ppm	<0.14 ppm	
Bulk density	65–106	80 lb/ft^3	18,400 tons
Water Column			
Mercury (total)	1.69–1.70 ng/L		
Mercury (methyl)	0.033–0.050 ng/L		
Lead	<3–10 μg/L		
Chromium	<3–18 μg/L		
Phosphorus–P	0.03–0.37 mg/L		
DO	3.3–14.6 mg/L (37.5–120% saturation)		
COD	10–38 mg/L		
Ammonia–N	0.04–1.8 mg/L		
Fish Tissue			
Freshwater drum (three samples, 10–19 in.)	0.16–0.48 ppm mercury		
Carp (three samples, 18–26 in.)	0.09–0.11 ppm mercury		
Caged Fish Bioaccumulation			
Minnows, 2-wk exposure	0.012–0.018 ppm mercury		
Minnows, 4-wk exposure	0.012–0.016 ppm mercury		
Toxicity Characteristic Leaching Procedure (TCLP)			
Sediment leaching test (three samples)	<1 mg/L lead		
Sediment Mapping			
Surveyed cross sections at 100-ft intervals			
17,000 yd^3 of soft sediment measured			

Following the development of the initial work plan, public informational meetings were held to solicit comments and suggestions. Presentations were also given to neighborhood associations and local environmental groups. Fact sheets outlining the proposed scope of work were distributed at these meetings. These meetings provided the implementation team with feedback on the scope and schedule of the work plan and a sense of the public's priorities regarding the restoration. Most of the public responses were requests for further clarification of the monitoring data, the permitting process, environmental safeguards during remediation, and potential exposure of local residents to contaminants in the sediments. One of the most frequent concerns for local residents was the removal of trees along the creek. The comments provided by the public and interested organizations were, where practical, incorporated into the work plan. For example, the replanting and vegetative restoration aspects of the project were developed in greater detail and the scope of the replanting was increased to address the concerns expressed at the public meetings.

Press releases and direct mailing to interested citizens and residents were used to keep the public involved and informed on the progress of the project.

Work Plan

The Starkweather Implementation Team developed the remediation work plan to achieve the goals of reducing pollutant loading to Lake Monona, restoring the aquatic habitat and fishery, and improving recreational use and access to the creek. The work plan included the following tasks to achieve these goals:

- Dredge 17,000 yd^3 of contaminated sediments.
- Improve the habit for fish and aquatic life through riprapping.
- Regrade and stabilize the eroding creek banks.
- Establish shoreline buffer zones.
- Use vegetative management to improve terrestrial habitat.
- Create public access paths and fishing platforms.
- Enhance public awareness and stewardship.

Dredging was selected as the means to remove the contaminated sediments, eliminate downstream loading of these contaminants, and restore the depth and diversity of the aquatic habitat. Survey cross sections of the creek were established at 100-ft intervals through the project site and were measured for water depth and sediment thickness. These data were used to model the volume and mass of contaminated sediments to be removed from the channel. In addition to removing contaminants from the creek, the enlarged cross-sectional area of the channel would maintain a greater depth of water capable of holding more dissolved oxygen and would provide more cover and structure for aquatic life.

The dredging of the creek channel increased the average depth from 1.5 to 4 ft. The average maximum depth of the channel thalweg was increased from 2 to 7 ft. Figure 2 is a typical cross section of the creek showing the pre- and postproject channel geometry and changes in water depth and streambanks.

Hydraulic studies of the creek channel and Lake Monona were performed to assess the local and regional impacts of dredging Starkweather Creek. This work was performed to assess issues related to changes in water surface elevations, channel stability, base level lowering, and potential upstream bed erosion. Starkweather Creek throughout the project area is in the backwater of Lake Monona. The water surface elevation of the creek is the same as the downstream lake. Therefore, the deepening of the creek by dredging would not decrease the water surface elevation or promote upstream bed or bank erosion.

Riprapping was selected for shoreline protection to protect the bank soils from waves and currents and to provide structure for fish and aquatic life. Sheet pile was used in selected areas where the steepness of the shoreline required vertical protection and regrading was not feasible (e.g., near buildings, roadways, and bridges). Vertical shore protection (sheet pile) was avoided in most areas because it presents a less than natural appearance and forms a barrier to aquatic life migration from water to land.

The banks of Starkweather Creek exhibited significant undercutting and failure and were a significant source of sediment to the creek. The failure of the creek banks undermined shoreline trees and vegetation and produced a perpetuating process of landward erosion of

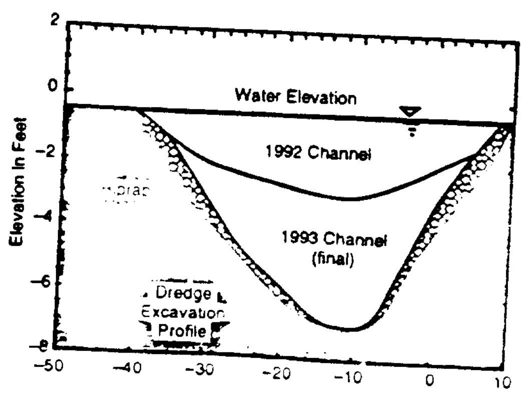

Figure 2. Starkweather Creek example cross section showing the channel profile before and after dredging.

increasingly steep banks. Eventually, the creek would have reached a hydraulic equilibrium by reshaping the channel geometry to a much wider and shallower channel. This process would have eliminated the fishery and small boating uses, however, and would have undermined local structures such as roadways, bridges, and buildings.

The banks of the creek were stabilized by regrading the abovewater slopes from vertical to 3:1 (horizontal:vertical), covering with protective riprap, and finally topping with a 6-in. seed bed planted to native grasses, shrubs, and trees. The near shore areas of the creek banks were planted to provide a vegetative buffer zone to filter pollutants carried by overland flows to the creek.

The terrestrial habitat along Starkweather Creek, although degraded, did provide important food and cover to insects, birds, and animals. Principal goals of the remediation project were to carefully manage all construction activities to minimize disturbances to the existing vegetation, to restore quality terrestrial areas disturbed by the creek restoration construction activities, and to improve the habitat where possible. A vegetation management and restoration plan was developed by the city's landscape architects to identify existing important tree and shrub specimens along the creek that were to be protected during construction work. The management and restoration plan was integrated with the construction plans, and close cooperation between the landscape architects, contractors, the DNR, and city engineering staff was used to resolve conflicting needs for access and mobility of the heavy equipment and the need to preserve desirable species. Trees and shrubs were initially either classified for saving or removal before construction. To reduce disturbance to the site and the costs of revegetation, the landscape architects and construction supervisors performed a final walking tour of the site to identify additional trees and shrubs, initially classified for removal, that could be saved if practical. This process provided the supervising field engineer with the discretion to either modify the construction plans and activities in the field to try to preserve existing vegetation or to permit the construction contractors to remove the specimens to facilitate access and work activities.

The project area was scheduled for replanting in the early spring of 1993. In addition to native and park grasses, 1,400 trees and shrubs were to be planted, including white ash, basswood, oak species, and maples. Planting would be located and spaced to provide optimal habitat areas along the shore of varying species, heights, and distribution.

Public access was provided to allow pedestrians to walk the site without disturbing the wildlife areas or trampling the banks of the creek. Landscape architects designed walkways to connect the project site with existing city parks and natural areas. Access to the creek was provided by low-lying shore areas and fishing/canoe

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access platforms constructed into higher creek banks near the water line.

Public awareness and stewardship was encouraged from the start to involve local groups throughout the project from early project design through final restoration. Regular press releases, media interviews, talks to neighborhood groups, direct mailings on project activities, aquatic education tours, fishing-for-kids clinic, and a volunteer planting event were used to keep people involved in and informed about the restoration.

Permits and Regulatory Review

The environmental restoration of Starkweather Creek included construction activities that were under the administrative and regulatory jurisdiction of several programs and agencies. Guidance from members of the implementation team representing the state's Water Regulation and Zoning, Solid Waste, and Environmental Assessment Bureaus were incorporated in the development of the project work plan and construction plans. City personnel guided the planning for compliance with local ordinances and coordination with local utilities. Permits were necessary for dredging and shoreline excavation and filling. In addition, regulatory review and approval was requested for the management of sediments dredged from the creek. Related regulations requiring compliance were historical and archeological site assessment, floodplain zoning regulations, and state environmental assessment guidelines. The city of Madison was the applicant for the construction work. Because many portions of the creek shoreline in the work area are privately owned, the permit required that either all riparian landowners individually apply for permits or that they assign the city to act as their agent for the permit application. A form letter was sent to the riparian landowners requesting their approval for the city to apply for the permit in their behalf. All riparian landowners in the project area approved, and copies of the signoff letters were then submitted to the U.S. Army Corps of Engineers and DNR.

Construction

Following completion of the construction plans, sealed bids were requested from qualified, interested contractors. The lowest of five bids was accepted. Speedway Sand and Gravel, Inc., of Madison, Wisconsin, was awarded the contract with a bid 17 percent lower than the highest bid.

Retention Site

The sediment retention and dewatering facility, 6 miles southeast of the project area, was built in January 1992. The site covered 2.8 acres and was built on county-owned land at the local municipal landfill. The sediment retention facility was designed to dewater the sediments and contain the sediment and carriage water. The facility is square in plan view with 7-ft berms built of local clay soils. The bottom was unlined but consisted of several feet of clay. Local monitoring wells provide data on potential leachate from the facility. A concrete drop inlet spillway was built into the facility to allow excess water to be pumped to a sanitary sewer if necessary.

The retention site was built to contain 17,000 yd of sediment with a 25-percent bulking factor and to provide a minimum of 1.5 ft of freeboard to contain direct precipitation and provide a margin of safety.

Dewatered sediments from the facility are available for use as cover on the landfill.

Site Preparation

A double silt curtain of geotextile fabric was placed across the creek at the downstream end of the project in mid-November 1992. The silt curtains were intended to trap debris in the streamflow generated by construction activities. In addition, the porous fabric was intended to trap sediments resuspended by the dredging. The curtains were held in place at the top by a half-inch steel cable tied to trees on the bank and weighted at the bottom by a heavy logging chain.

Utility representatives identified and marked all pipelines, cables, and utility facilities along the creek in the project area.

Site clearing and grading for heavy equipment access followed the installation of the silt curtains. Access roads and trees to be left undisturbed were clearly identified to minimize site disturbances and the cost of restoring vegetation.

Dredging

Dredging began on the upstream end of the west branch of Starkweather Creek on November 19, 1992. Dredging was performed with a backhoe. Construction activities were staged through the project area such that approximately 100 yd of streambed was dredged, the banks were shaped to a stable slope, and then the site was riprapped. The goal of this sequence was to minimize the size of the project area opened by construction. In addition, because the project is in a residential neighborhood, keeping the principal work confined to a limited area at one time minimized noise and dust in the area.

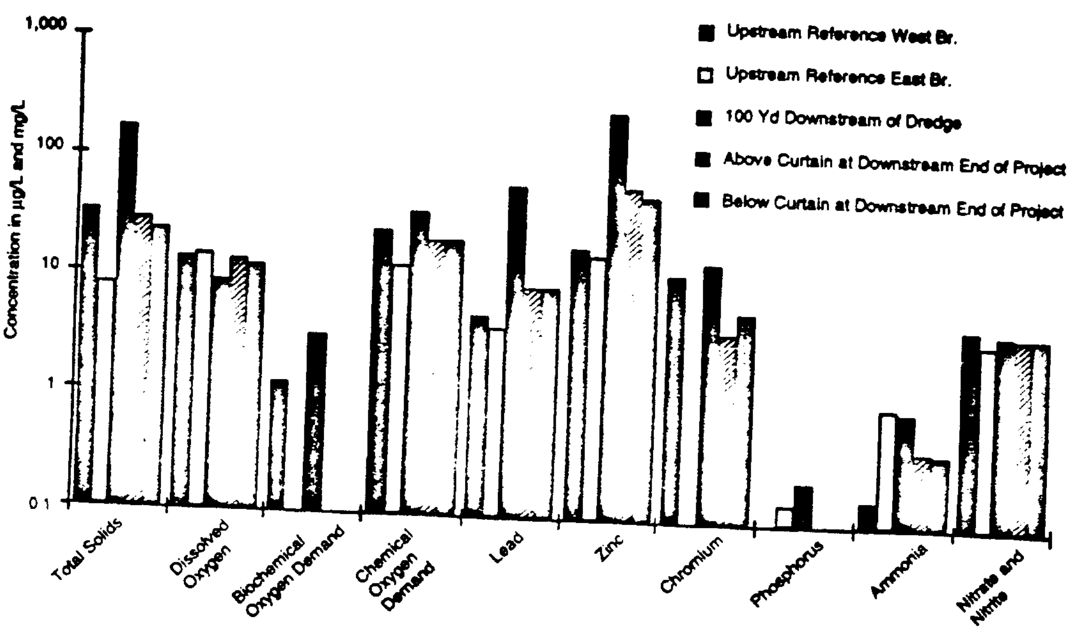
Dredging, bank shaping, and stabilization proceeded in a downstream direction on the west branch to the confluence with the east branch. When the west branch was finished, work moved to the upstream end of the east branch. Approximately 12 dump trucks were used to haul the dredged sediments to the retention facility. Trucks were loaded on average every 5 minutes. To prevent leakage from the trucks, the tailgates were fitted with neoprene seals, and chain binders were used to provide a backup to the tailgate lock. No sediment spills occurred during hauling. Dredging was completed on January 27, 1993. Bank shaping and stabilization work finished 2 weeks later.

Nearly 14,000 tons of riprap and 3,400 tons of crushed stone were used on the project. Bank shaping involved 3,200 yd^3 of soil.

Dredge Monitoring

Monitoring during dredging and other construction work was performed to track the impact of these activities on the creek and Lake Monona. Visual observations were made daily of the degree of turbidity changes caused by construction. Best management practices related to the work on site were used to minimize the instream and offsite impacts. Water sampling for chemical analyses was performed on a weekly basis at upstream reference sites, downstream of the dredging, and above and below the silt curtains. Creek water samples were analyzed for metals (arsenic, cadmium, calcium, copper, chromium, iron, lead, magnesium, nickel, zinc), nutrients (ammonia, nitrate and nitrite, total Kjeldahl nitrogen, total phosphorus), and general water quality parameters (suspended solids, chemical oxygen demand, BOD, conductivity, pH, alkalinity, hardness, temperature, dissolved oxygen).

Monitoring results indicate that there was no significant difference between the water quality parameters at the upstream reference sites and at the downstream end of the project on the dates of sampling. Figure 3 is a plot of selected water quality parameters measured on December 3, 1992, during the dredging activities. On this date, dredging was performed approximately 300 yd downstream of the upstream reference sampling site on the west branch. Sampling was also performed at the first bridge downstream of the dredging site. Other data shown in Figure 3 were obtained on the same date at a reference site on the east branch above the project and at two locations on the downstream end at the silt curtains. In can be seen in this figure that data from the dredging site show significantly higher values than at other sampling sites. The concentrations from the downstream end of the project (at the silt curtains), however, are equivalent to the undisturbed reference sites for most parameters, indicating that the resuspension of sediment and pollutants from the dredging had minimum offsite impacts. Lead and zinc values did exhibit an increase at the downstream site samples (Figure 3) compared with the upstream reference sites; however, the values at the downstream sites were within the



Metals values in µg/L, other values in mg/L
* Limit of quantification 1 mg/L BOD, 3 µg/L Cr

Figure 3. Selected water quality monitoring data, Starkweather Creek, December 3, 1992.

range of values measured over time at the undisturbed reference sites. Lead and zinc concentrations in water at the downstream end of the project were well below State Water Quality Criteria NR105 for acute and chronic toxicity in all water samples.

The silt curtains had little effect on the water quality of the stream—nearly all parameters were at the same levels above and below the curtains. Sediments and associated contaminants resuspended by the dredging work settled fairly quickly in the creek channel, and downstream loading to Lake Monona remained at background levels during the construction work. This project deployed the silt curtains normal to the streamflow (i.e., across the width of the channel) in an attempt to trap debris generated by the construction activity and to control resuspended sediments. The curtains were effective in trapping floating debris; however, they were not always effective in filtering solids from the streamflow. Figure 3 shows a slight drop in solids concentration across the silt curtain; however, the difference in concentration is fairly low and was not seen in most water sampling days. Field observations of the performance of the curtains showed that during all but the lowest base flow, the curtains would "billow out" to the downstream, allowing the streamflow to pass beneath the curtains.

Postremediation Monitoring

Routine water quality sampling will continue on a monthly basis for a least a year following the completion of construction work. Additional monitoring intended to document the restored conditions of the creek include fish shocking surveys, caged fish bioaccumulation, sediment bioassay, sediment chemistry, qualitative habitat assessment, and macroinvertebrate sampling (sediment and artificial substrate). These additional activities will be performed over the next 2 years to assess the success or failure of the restoration work, help to refine further work at other aquatic restoration projects, and guide the development of standard procedures for sediment assessment work.

Summary and Conclusion

Contaminated sediments can be managed to restore lost beneficial uses of a degraded waterway. The environmental restoration of Starkweather Creek has demonstrated that the knowledge and skills of various environmental programs can be successfully coordinated to accurately assess the degree of contamination, identify necessary sediment removal and disposal techniques, develop and implement a cross-program work plan, and carefully monitor the site disturbance and final restoration.

Some important aspects of this project that were critical to its successful implementation were cross-program coordination and communication, public communications and feedback, construction field supervision, and a significant investment in environmental monitoring to guide the development of the work plan and document the results of the restoration.

Wolf Lake Erosion Prevention

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Abstract

The U.S. Environmental Protection Agency (EPA), Region 5, in cooperation with the Lake County, Indiana, Soil and Water Conservation District, the City of Hammond, Board of Park Commissioners, and the U.S. Department of Agriculture, Soil Conservation Service, prevented bank erosion on over 300 m of the east shore of Wolf Lake. This project was funded through a $70,000 grant from EPA under Section 319(h) of the Clean Water Act. EPA had identified Wolf Lake as part of the Internal Joint Commission's Great Lakes Area of Concern, along with the Grand Calumet River Basin in northwest Indiana. Various sources of sediment were contaminating the lake, but the Park Board determined that the shoreline erosion was the highest priority. The bank was also one of the few remaining habitats of silverweed *(Potentilla anserina)*, a plant on the Indiana endangered species list. A member of the rose family *(Rosaceae)*, silverweed grows on wet, sandy shores in Canada south to Iowa, the Great Lakes, and coastal New England. When the Indiana Department of Natural Resources identified the plant at the site, the project was in jeopardy until a compromise was reached. Limestone riprap was chosen as the nonpoint source pollution/best management practice material to stabilize the 0.3- to 1.0-m bank. Wave action induced by wind was the cause of the bank erosion problem. Average fetch exposure, shore geometry, and shore orientation proved to be the significant factors in designing a successful shoreline protection system.

Introduction

The southern shoreline of Lake Michigan, in northwestern Indiana, is one of the major urban and industrial centers in the Great Lakes region and includes the cities of East Chicago, Gary, Hammond, and Whiting in Lake County, Indiana (1). The heavy industry in this area contains approximately 40 percent of the steel making capacity of the United States, and one of the largest petrochemical complexes in this country. This combination has created one of the most environmentally degraded areas within the entire Great Lakes basin.

Wolf Lake is located in the northwest corner of the region and is an important remnant of what once was a large Lake Michigan bay. As the Great Lakes' levels dropped from the Nipissing through the Algona to the present-day Lake Michigan, several coastal area lakes developed (2). Among these lakes were Calumet, Hyde, Wolf, Berry, and George. Today, only Calumet, Wolf, and small remnants of Lake George remain; the others were drained and filled to allow for development (3).

The present surface area of the lake is 156 ha in Indiana and 170 ha in Illinois. As would be expected because it was once a shallow bay, Wolf Lake is shallow, with a mean depth of only 1.5 m. The maximum depth is listed as 5.5 m in areas influenced by past sand mining (1). Wolf Lake is not protected by natural features such as hills or stands of trees. Therefore, strong winds frequently cause wave action to pound the eastern shoreline and create erosion and sediment.

Shoreline Erosion and Protection

Few things are a bigger eyesore and problem for lakeshore users than an eroding shoreline. A variety of lake shoreline protection practices are designed to stabilize and protect these areas against the forces of erosion, such as scour and erosion from wave action, ice action, seepage, and runoff from upland areas. These practices are both nonstructural (vegetation or beach sloping) and structural (flexible structures such as riprap and rigid structures such as seawalls).

Shoreline erosion is a significant problem in several areas along Wolf Lake's shoreline. The problem has been documented by historical photographs and personal accounts, but estimating the volume of shoreline eroded is difficult. Photographs indicate that the eastern shore has receded 15 m. Photographs from 1938, when compared with recent photographs, show that the area has receded at a rate of about 0.3 m/yr.

The lake's shallow water depth, long wind fetch, and motor boat use all contribute to the waves eroding the shoreline. The scarcity of rooted littoral vegetation and the sand, slag, and gravel texture of the scoured littoral sediment are further evidence of wave action. Fetch is defined as the distance a wind blows unobstructed over water, especially as a factor affecting the buildup of waves. The average fetch exposure, shore geometry, and shore orientation are significant factors in successful shoreline stabilization (4).

Vegetation effectively controls runoff erosion on slopes or banks leading down to the water's edge; however, vegetation is ineffective against direct wave action or seepage-caused bank slumping (5). Diverse, moderately dense stands of aquatic plants are desirable in a lake's littoral zone. Emergent aquatic plant communities protect the shoreline from erosion by damping the force of waves and stabilizing shoreline soils (6).

Riprap armoring is a flexible structure constructed of stone and gravel that is designed to protect steep shorelines from wave action, ice action, and slumping due to seepage. The riprap is flexible in that it will move slightly under certain conditions. This improves its ability to dissipate wave energy.

Seawalls, bulkheads, and retaining walls are rigid structures used where steep banks prohibit the sloping forms of protection. Seawalls do not primarily dissipate wave energy but rather redirect the wave energy away from the shore (7).

Site Evaluation

The Hammond Park Board had been in contact with the U.S. Environmental Protection Agency's (EPA's) Region 5 office in Chicago, Illinois, about an ongoing erosion problem at Wolf Lake in Hammond, Indiana. The site was actively eroding and endangering the east shoreline for 300 m. This was part of the Internal Joint Commission's Area of Concern and was identified in the area Remedial Action Plan (RAP) by the Indiana Department of Environmental Management (IDEM). The Park Board called on EPA for technical and financial assistance, and project development began.

In the fall of 1990, the eastern shoreline of Wolf Lake was surveyed by the Soil Conservation Service (SCS). The survey revealed a water depth ranging from 0.3 to 1.0 m, with a vertical dropoff. This area had been eroding for an undetermined amount of time and had reached a point where it would soon undercut a pedestrian trail connecting a picnic area with the beach. Over the years, the Park Board had allowed large pieces of broken concrete to be dumped along the shoreline to try to control the erosion. This had slowed the erosion process in some areas but accelerated it in others. Where the wave action could get between the concrete, the erosion continued to advance.

The undercutting of a fishing pier at the south end of the area demonstrated the strength of the wave action on the site. Although the average fetch at the site is about 1,000 m, the wave energy is funneled to the northeast and southeast shoreline by a manmade island located 200 m offshore. The maximum depth of the bay area created by this erosion is only 3 m, with the majority at no more than 1.5 m.

SCS recommended that the 300-m shoreline be stabilized with riprap. In the winter of 1990, the Lake County Soil and Water Conservation District applied to EPA for a Section 319 grant of $70,000 to stabilize the shoreline. SCS completed the designs, and the Park Board sought permit applications from IDEM, the Indiana Department of Natural Resources (IDNR), and the Army Corps of Engineers (COE). Several coordination meetings were held with the Park Board to keep them informed of the progress of the various activities. The Park Board approved the final plans in the spring of 1991, and permits were approved that summer.

During the permit review process, an IDNR biologist identified the presence of silverweed (Potentilla anserina) at the site. Silverweed, which is on the IDNR endangered species list, was growing in patches along the eastern shoreline. Silverweed is a prostrate species that sends up yellow flowers with leaves on a separate stalk. The leaves are strikingly silver beneath, divided into 7 to 25 paired, sharp-toothed leaflets that increase in size upward. The total plant length ranges from 0.3 to 1.0 m, and it flowers in June through August (8). This plant was also in danger of losing its habitat as the shoreline eroded back. The IDNR approved of the riprap project with the stipulation that care be taken to avoid main clusters of the plant.

Riprap Size and Placement

A stone revetment, riprap involves more than simply dumping rocks on the shoreline. The SCS area-office engineer developed a design, which was reviewed by the SCS state engineer. This design included the investigation of the average depth of the bay water, wave height, depth of dropoff, and the orientation of critical winds.

The largest wave that can reach shore is 0.8 times the depth of the water (9). This would generate a wave height of 1.2 m where the water depth is 1.5 m. A maximum wave height of 0.5 m would be reached for a 1,000-m fetch over 6-m deep water with a 16 m/sec wind speed (9). Therefore, NAS No. R-5 (46 cm maximum, D50 23 cm, minimum 13 cm) graded riprap was chosen for the armor stone (9). For the bedding or filter stone, NAS No. FS-2 (5 cm maximum, average No. 4, No. 100 minimum) would be used.

With the existing concrete in place, it was difficult to determine the amount of riprap needed. An estimate was made based on an average riprap thickness of 0.6 m and enough bedding stone to fill in the voids on a typical cross section 300 m long. The plans called for a 2:1 slope for the finished riprap, which meant 800 metric tons of bedding stone and 615 metric tons of riprap was needed.

The Park Board received bids for the work and awarded the contract in the late summer of 1992. The cost for actual purchase and placement of material was $133.00 per linear meter. Additional costs associated with the project were for design, administration, and construction supervision. The construction of the 300-m barrier took 7 working days, including hauling the stone from a quarry within 16 km. Stone was placed using a large hydraulic backhoe and a front-end loader.

Chapters 16 and 17 of the SCS *National Engineering Field Manual* (10) contain detailed discussions on the selection and placement of riprap for erosion control.

Discussion and Conclusion

The nonpoint source/best management practice (BMP) of limestone riprap was selected for the Wolf Lake project. Selection was based on the need for the practice to withstand wave energy, be cost effective, and be compatible with the endangered species plant found at the site. Revegetation was not selected as the BMP because the site was unstable and few plants could stand up to the wave action. The erosive force of wave action limits plants survival in open lakes. Aquatic macrophytes may not grow in areas where wind fetch exceeds 850 m (11). A seawall or other rigid BMPs were not selected because of their higher cost and the disturbance to the site that would be required for their installation. Another alternative not discussed here, because of the major site disturbance it would require, is regrading of the bank to a stable slope.

The design characteristics of the site taken into consideration were fetch exposure, shore geometry, and shore orientation. In addition, the resistance of dumped stone to displacement by waves depends on:

- Weight, size, shape, and composition of the stone.
- Gradation of the stone.
- Height of the wave.
- Steepness and stability of the protected area.
- Stability and effectiveness of the filter or bedding material (12).

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Incorporating Ecological Concepts and Biological Criteria in the Assessment and Management of Urban Nonpoint Source Pollution

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Abstract

The health and well-being of the aquatic biota in surface waters are important barometers of how effectively we are achieving the goals of the Clean Water Act (CWA); namely, the maintenance and restoration of biological integrity and the basic intent of water quality standards. Yet, these tangible products of the CWA regulatory and water quality planning and management efforts are frequently not linked nor equated with the more popularized notion of chemical-physical water quality criteria and other surrogate indicators and endpoints. Simply stated, biological integrity is the *combined* result of chemical, physical, and biological processes. Nowhere in water quality management and assessment is the interaction of these three factors more apparent than with nonpoint sources. Management efforts that rely solely on comparatively simple chemical-physical water quality criteria surrogates frequently do not result in the full restoration of ecological integrity. Therefore, ecological concepts, criteria, and assessment tools must be incorporated into the prioritization and evaluation of nonpoint source pollution abatement efforts.

Introduction

The monitoring of surface waters and evaluation of the biological integrity goal of the Clean Water Act (CWA) have historically been predominated by nonbiological measures such as chemical-physical water quality (1). While this approach may have fostered an impression of empirical validity and legal defensibility, it has not sufficiently measured the ecological health and well-being of aquatic resources. An illustration of this point was demonstrated in a comparison of the abilities of chemical water quality criteria and biological criteria to detect aquatic life impairment based on ambient monitoring in Ohio. Out of 645 water-body segments analyzed, biological impairment was evident in 49.8 percent of the cases where no impairments of chemical water quality criteria were observed (2). While this discrepancy may at first seem remarkable, the reasons for it are many and complex. Biological communities respond to and integrate a wide variety of chemical, physical, and biological factors in the environment whether they are of natural or anthropogenic origin. Simply stated, controlling chemical water quality criteria alone does not ensure the ecological integrity of water resources (1).

The health and well-being of surface water resources are the *combined* result of chemical, physical, and biological processes (Figure 1). To be truly successful in meeting these goals, monitoring and assessment tools are needed that measure both the interacting processes and the integrated result of these processes (3). This is especially true for nonpoint sources because many of the effects involve the interactions of these factors. Biological criteria offer a way to measure the end result of nonpoint source management efforts and successfully accomplish the protection of surface water resources. Biological communities respond to environmental impacts that chemical-physical water quality criteria alone cannot adequately discriminate or even detect. Habitat degradation and sedimentation are two prevalent impacts of nonpoint source origin that simply cannot be measured by chemical-physical criteria alone. As illustrated by Figure 1, the combination of chemical and physical factors results in surface water use impairments from nonpoint sources.

The Ohio Environmental Protection Agency (EPA) recently adopted biological criteria in its water quality standards (WQS) regulations. These criteria are based on measurable endpoints regarding the health and well-being of aquatic communities. They are further structured into the state's WQS regulations within a system of tiered aquatic life uses from which numerical biological criteria are derived using a regional reference site approach (4-7). These numerical expressions of biological goal attainment criteria are essentially the end

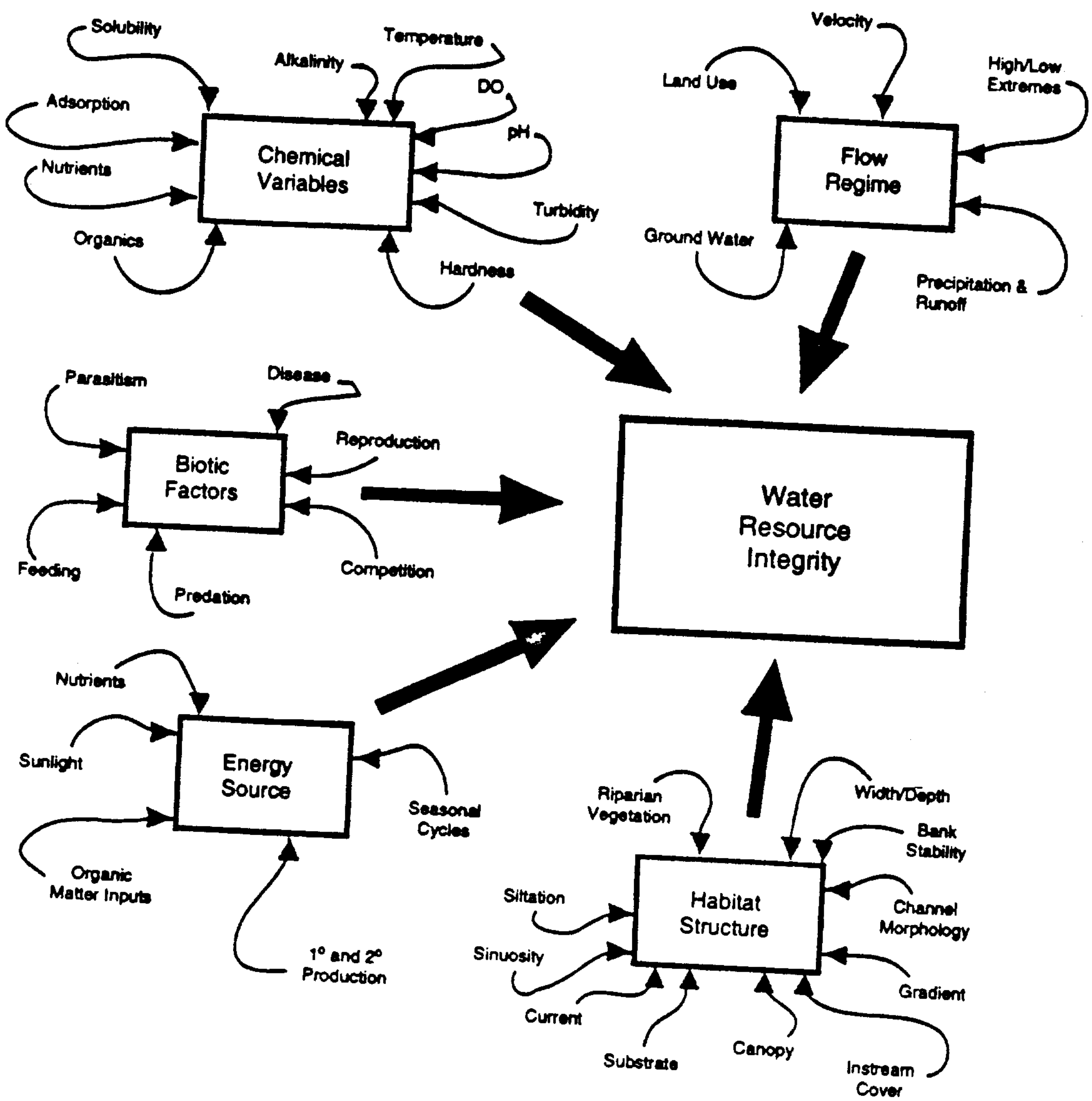

Figure 1. The five principal factors, with some of their important chemical, physical, and biological components, that influence and determine the integrity of surface water resources (modified from Karr et al. [1]).

product of an ecologically complex but structured derivation process. While numerical biological indices have been criticized for potentially oversimplifying complex ecological processes (8), distillation of such information to readily comprehendible expressions is both practical and necessary. The advent of new-generation evaluation mechanisms, such as the Index of Biotic Integrity (IBI) (1, 9, 10), the Index of Well-Being (Iwb) (11, 12), the Invertebrate Community Index (ICI) (5), and similar efforts (13-16), has filled important practical and theoretical gaps not always fulfilled by previously available single-dimension indices. Multimetric evaluation mechanisms, such as the IBI, extract ecologically relevant information from complex biological community data while preserving the opportunity to analyze such data on a multivariate basis. The problem of biological data variability is also addressed within this system. Variability is controlled by specifying standardized methods and procedures (17) that are then compressed through the application of multimetric evaluation mechanisms (e.g., IBI, ICI) and stratified by accounting for regional and physical variability and potential (e.g., ecoregions, tiered aquatic life uses). The results are evaluation mechanisms, such as the IBI and ICI, that have acceptably low replicate variability (18-20).

Ecoregional Biocriteria and Determination of Use Attainment

Biological criteria can play an especially important role in nonpoint source assessment and management because they directly represent an important environmental goal and regulatory endpoint (i.e., the biological integrity goal of the CWA). Numerous studies have documented this capability. Gammon et al. (21) documented a "gradient" of compositional and functional shifts in the fish and macroinvertebrate communities of small agricultural watersheds in central Indiana. Community responses ranged from an increase in biomass with mild enrichment to complete shifts in community function. Impacts from animal feedlots had the most pronounced effects. In the latter case, the condition of the immediate riparian zone was correlated with the degree of impairment.

Later work by Gammon et al. (22) suggests that nonpoint sources are impeding any further biological improvements observed in larger rivers due primarily to reduced point source impacts. This is similar to observations that Ohio EPA has made in the Scioto River downstream from Columbus. Urban nonpoint source impacts are well known and have also been documented by numerous investigators. Klein (23) documented a relationship between increasing urbanization and biological impairment, noting that the latter does not become severe until urbanization reaches 30 percent of the watershed area. Steedman (24) used a modification of the IBI to demonstrate the influence of urban land use and riparian zone integrity in Lake Ontario tributaries. Steedman developed a model relationship between the IBI and these two environmental factors.

Biological monitoring of nonpoint source impacts and pollution abatement efforts conducted in concert with the use of more traditional assessment tools (e.g., chemical-physical) can produce the type of evaluation needed to determine where nonpoint source management efforts should be focused, what some of the management goals should be, and what determines the eventual success (i.e., end result) of such efforts. At the same time, a well-conceived monitoring program can yield multipurpose information that can be applied to similar situations without the need to perform site-specific monitoring everywhere. This is best accomplished when a landscape-partitioning framework, such as ecoregions (25) and the subcomponents, is used as an initial step in accounting for natural landscape variability. Because of landscape variability, uniform and overly simplified approaches to nonpoint source management often fail to produce the desired results (26).

Biological criteria in Ohio are based on two principal organism groups: fish and macroinvertebrates. Numerical biological criteria for rivers and streams were derived from the results of sampling conducted at more than 350 reference sites that typify the "least impacted" condition within each ecoregion (5, 6). This information was used within the existing framework of tiered aquatic life uses in the Ohio WQS regulations to establish attainable, baseline biological community performance expectations on a regional basis. Biological criteria vary by ecoregion, aquatic life-use designation, site type, and biological index. The resulting criteria for two of the "fishable, swimmable" uses, Warmwater Habitat (WWH) and Exceptional Warmwater Habitat (EWH), are shown in Figure 2.

Procedures for determining the use attainment status of Ohio's lotic surface waters were also developed (5, 27). Using the numerical biocriteria as defined by the Ohio WQS regulations, use attainment status is determined as follows:

- *Full:* Use attainment is considered full if all of the applicable numeric indices exhibit attainment of the respective biological criteria; this means that the aquatic-life goals of the Ohio WQS regulations are being attained.
- *Partial:* At least one organism group exhibits nonattainment of the numeric biocriteria, but no lower than a narrative rating of "fair," and the other group exhibits attainment.
- *Non:* Neither organism group exhibits attainment of the ecoregional biocriteria, or one organism group reflects a narrative rating of "poor" or "very poor," even if the other group exhibits attainment.

Following these rules, a use attainment table is constructed on a longitudinal mainstem or watershed basis. Information included in the table includes sampling location (river mile index), biological index scores, the Qualitative Habitat Evaluation Index (QHEI) score, attainment status, and comments about important site-specific factors such as proximity to pollution sources. An example of how to construct a use attainment table is provided in Table 1.

Aquatic Ecosystems at Risk

Ecosystems that possess or reflect integrity (as envisioned by the biological integrity goal of the CWA) are characterized by the following attributes (1):

- The inherent potential of the system is realized.

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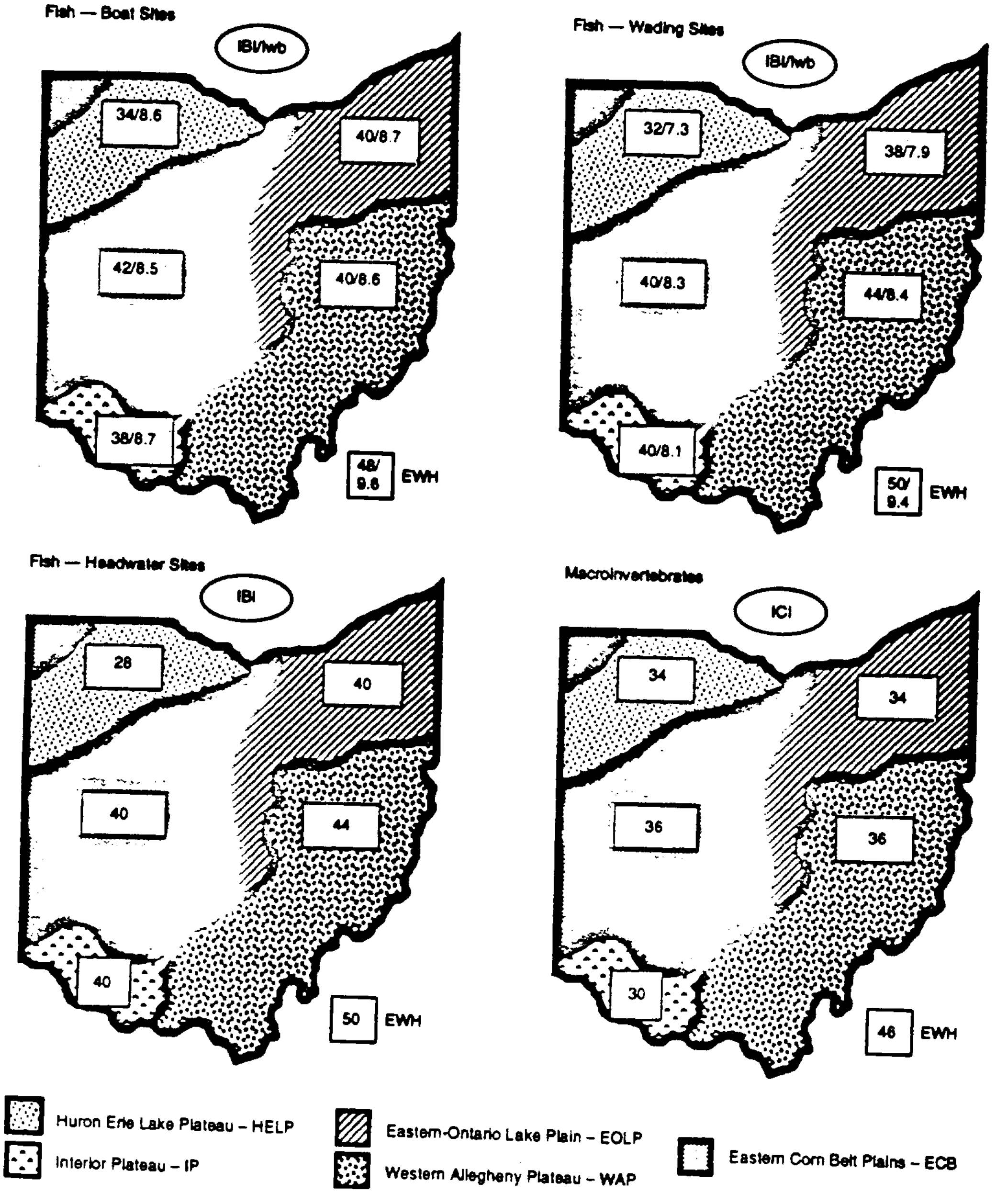

Figure 2. Biological criteria in the Ohio WQS for the Warmwater Habitat (WWH) and Exceptional Warmwater Habitat (EWH) use designations arranged by biological index, site type for fish, and ecoregion. The EWH criteria for each index and site type is located in the boxes located outside of each map.

- The system and its components are stable.
- The system retains a capacity for self-repair when perturbed or injured.
- Minimal or no external support for community maintenance is required.

Thus, ecosystems that are impaired and therefore lack integrity have had their capacity to withstand and rapidly recover from perturbations exceeded. Impaired ecosystems are likely to become even further degraded due to incremental increases in stress.

Many rivers and streams nationwide fail to exhibit the characteristics of healthy ecosystems. Recent estimates indicate that as many as 98 percent of lotic ecosystems are degraded to a detectable degree (29). Karr et al. (30) illustrated the extent to which the Illinois and Maumee River basin fish communities have declined during the past 50 years: two-thirds of the original fauna were lost from the former and more than 40 percent from the latter. Losses of naiad mollusks and crayfish have been even greater. In Ohio, long-term declines in fish communities have been extensively documented by Trautman (31). More recent information indicates that the fraction of the fish fauna that is imperiled or declining has increased from 30 to 40 percent since 1980 (32). This information indicates that lotic ecosystems are threatened in both Ohio and nationwide, an indication that existing frameworks for water resource protection and management have been essentially ineffective in preventing large-scale losses of ecological integrity. This is particularly true for ecosystems affected by habitat degradation, riparian encroachment, excess sedimentation, organic enrichment, and nutrient enrichment. All or most of these forms of degradation are evident in areas affected by urban nonpoint sources.

Urban Nonpoint Source Pollution in Ohio

Urban watersheds in Ohio have exhibited a familiar and well-known legacy of aquatic resource degradation. Few, if any, functionally healthy watersheds exist in the older, heavily urbanized parts of the Midwest. Good quantitative estimates of the proportion of surface waters that are degraded by urbanization are lacking, however, particularly for headwater streams. It is also widely perceived that the restoration of beneficial aquatic life uses in most heavily urbanized areas is not practically attainable. This in itself presents a barrier to any notion of attaining existing use designations or upgrading use designations for waters classified for less than fishable and swimmable uses. The assignment of appropriate aquatic life and recreational uses is a challenge that Ohio EPA has dealt with over the past 15 years.

Urban and suburban development activities that have the greatest impacts on aquatic life in Ohio include the wholesale modification of watershed hydrology, riparian vegetation degradation and removal, direct instream habitat degradation via channelization, construction and other drainage enhancement activities, sedimentation and siltation caused by stream-bank erosion (which is strongly linked to riparian encroachment), and contributions of chemical pollutants. Statewide, urban and suburban sources are responsible for impairment (major and moderate magnitude sources) in more than 927 miles of streams and rivers and more than 23,000 acres of lakes, ponds, and reservoirs (32). These activities also threaten existing use attainment in nearly 160 miles of streams and rivers and may be a potential problem in more than 4,380 miles of streams and rivers that have not yet been fully monitored and evaluated (33).

While much attention is generally given to toxic substances in urban nonpoint source runoff, evidence suggests that nontoxic effects are more widespread, at least in Ohio and the Midwest. The second leading cause of impairment identified by the 1992 Ohio Water Resource Inventory, sedimentation (or siltation) resulting from urban and other land-use activities is the most pervasive single cause of impairment from nonpoint sources in Ohio. Sedimentation is responsible for more impairment (over 1,400 miles of stream and rivers and 23,000 acres of lakes, ponds, and reservoirs) than any other cause except organic enrichment/dissolved oxygen, with which it is closely allied in urban and agricultural areas. Since Ohio conducted the Ohio Water Resource Inventory in 1988 (34), this cause category has surpassed ammonia and heavy metals in rank. If the statewide monitoring database were distributed more equally across the state, sedimentation would likely be found to be the leading cause of impairment.

Although sediment deposition in both lotic and lentic environments is a natural process, it becomes a problem when the capability of the ecosystem to "assimilate" any excess delivery is exceeded. Sediment deposited in streams and rivers comes primarily from stream bank erosion and in runoff from upland erosion. The effects are much more severe in streams and rivers with degraded riparian zones and low gradient. Given similar rates of erosion, the effects of sedimentation are much worse in channel-modified and riparian zone-degraded streams than in more natural, intact habitats. In channel-modified streams, incoming silt and sediment remain within and continue to degrade the stream channel, instead of being deposited in the immediate riparian "floodplain" during high flow periods (35). This also adds to and increases the sediment bedload that continues to affect the substrates long after the runoff events have ceased.

One of the more prevalent results is substrate embeddedness, which occurs when an excess of fine materials, particularly clayey silts and fine sand, fills the otherwise open interstitial spaces between larger substrates (Figure 3). In extreme cases, the coarser substrates may be "smothered"; in other cases, the substrate can be cemented together, or "armor plated." In either event, the principal ecological consequence is the loss of available benthic surface area for aquatic organisms (particularly macroinvertebrates) and as a location for the development of fish eggs and larvae. The soft substrates afforded by the increased accumulation of fine materials also provide an excellent habitat for the growth of undesirable algae. Thus, to successfully abate the adverse impacts of sediment, we need to be as concerned with what each event leaves behind as

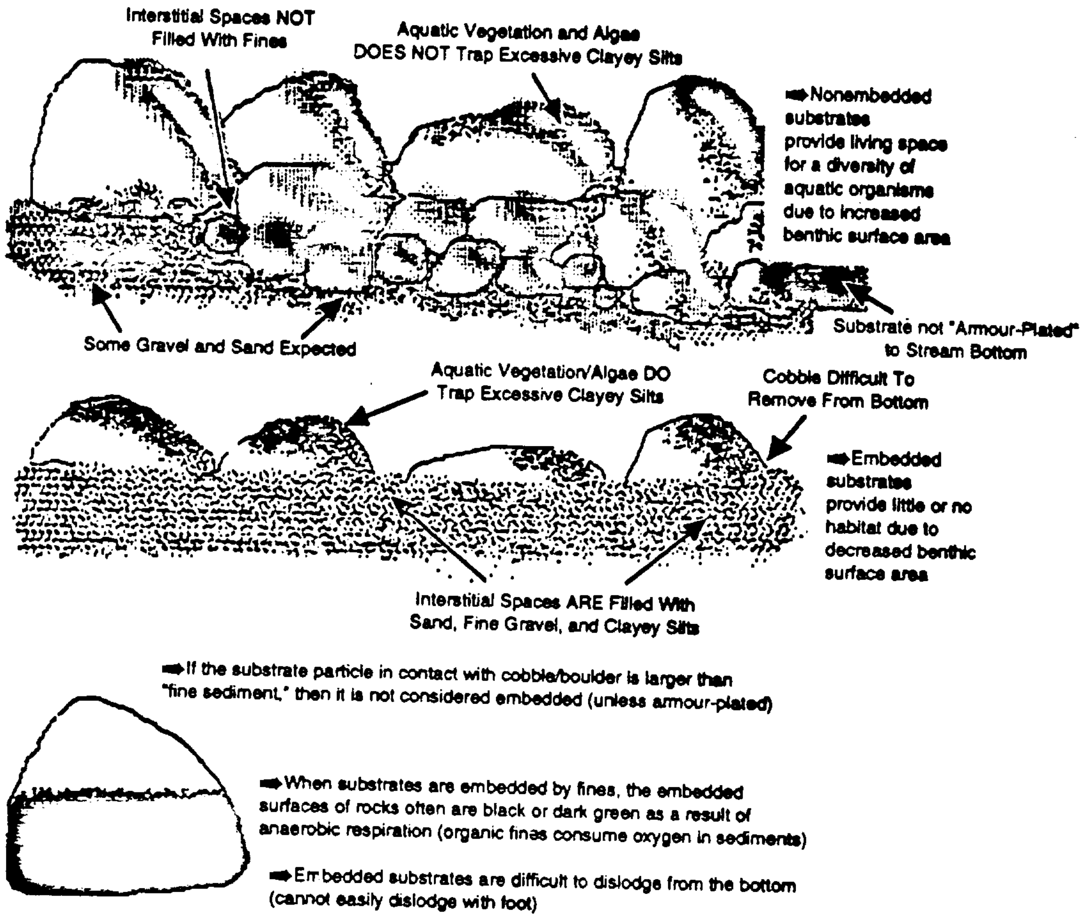

Figure 3. Characterization of substrate embeddedness with some of the key structural signatures and a summary of some of the ecological impacts of this form of stream substrate degradation.

much as with what takes place in the water column during each event.

The effects of sedimentation on aquatic life are the most severe in the ecoregions of Ohio where:

- Erosion and runoff are moderate to high.
- Clayey silts that attach to and fill the interstices between coarse substrates are predominant.
- Streams and rivers lack the ability to expel sediments from the low-flow channel, which results in a longer retention time and greater deposition of silt in the most critical habitats.

Estimates of gross erosion alone do not always correlate with adverse impacts to aquatic communities, although this is a frequently cited criterion for prioritizing nonpoint source management efforts. Some of the areas of Ohio that have the highest rates of gross erosion (e.g., East Corn Belt Plain, Interior Plateau, and Western Allegheny Plateau ecoregions) also have some of the most diverse and functionally healthy assemblages of aquatic life at the least affected reference and other sites (32). Many of the streams in these ecoregions have relatively intact riparian and instream habitat and thus are "buffered" against the naturally erosive conditions. The detrimental effects of sedimentation seem to be the worst in areas of the state where the proportion of clayey silts are highest, stream gradient is the lowest, and riparian encroachment and modification are extensive (i.e., Huron/Erie Lake Plain and portions of the East Corn Belt Plain and Erie/Ontario Lake Plain ecoregions).

The interaction between nonpoint source runoff and riparian and instream habitat must be appreciated and understood if impacts such as sedimentation are to be effectively dealt with. Figure 4 illustrates the interdependency of the rate of runoff, increased sediment delivery, in-channel habitat degradation, riparian zone condition, and substrate condition. An effect involving any one

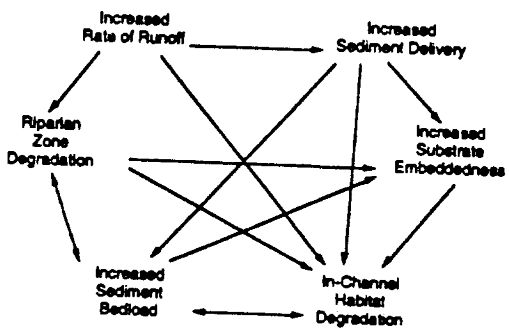

Figure 4. Illustration of the complex interaction of nonpoint source caused changes in hydrology and sediment delivery and how each singly and in combination can degrade instream and riparian habitat.

factor can set off a chain of events that results in cumulative changes reflected by most or even all of the interdependent factors. Two factors that are influenced in the conversion of watersheds by urban development are an increased rate of runoff and increased sediment delivery. These two factors then combine to influence other important aspects of stream habitat, such as riparian zone integrity and increased substrate embeddedness. In effect, a change in one of these factors can result in a cascading chain of events that eventually cause aquatic life use impairment or inhibit the ability of a degraded stream to be successfully rehabilitated. Thus, considerations of previously ignored aspects such as riparian and instream habitat and watershed dynamics must be included in urban nonpoint source assessment and abatement strategies.

The direct and indirect effects of sedimentation and the associated nutrient enrichment are becoming especially apparent in the larger mainstem rivers. Both sediment and nutrient enrichment impacts have largely been overlooked and will not only require a change in the status quo of water quality management but also in the interdisciplinary solutions and information gathering that demonstrates the character and magnitude of these impacts (36).

Bioassessment of Urban Watersheds

Biological criteria and bioassessment methods can and do play a key role in several areas of nonpoint source management. As a basis for determining use impairments, biocriteria have played a central role in the Ohio Nonpoint Source Assessments (33, 37), the biennial Ohio Water Resource Inventory (305b report) (32), and watershed-specific assessments of which Ohio EPA completes from 6 to 12 each year. Biological criteria represent a measurable and tangible goal against which the effectiveness of nonpoint source pollution abatement programs and individual projects can be judged. Biological assessments, however, must be accompanied by appropriate chemical-physical measures, land-use considerations, and source information necessary to establish linkages between the land-use activities and the instream responses.

A great deal of uncertainty exists about the link between steady-state water quality criteria and ecological indicators. While we have observed biocriteria attainment with chemical water quality criteria exceedences in only a fraction of the comparisons, the chemical data are largely from grab samples collected during summer-fall low flow situations. In many cases, we have failed to detect chemical criteria exceedences during low flows, yet biocriteria impairment is apparent. The correspondence of biocriteria attainment with water quality criteria exceedences measured under elevated flows has not been observed with any regularity. Nonetheless, we have surmised that much of the biocriteria nonattainment observed in affected urban watersheds is due to water quality criteria exceedences that have occurred during elevated flow events that preceded the biological sampling. Reaching such a conclusion, however, is made possible only by examining other evidence beyond water column data.

In many urban settings, sediment chemical concentrations frequently are highly or extremely elevated compared with concentrations measured at least-affected reference sites. Contaminated sediments enter the aquatic environment during episodic releases from point sources and during runoff events from nonpoint sources. The correspondence between increasingly elevated sediment concentrations and declining aquatic community performance is demonstrated by Figure 5. A sediment classification scheme derived by Kelly and Hite (38) for Illinois streams was used to classify results for sediment chemical analyses at sites with corresponding biological data. Sediment chemical concentrations are classified as nonelevated, slightly elevated, elevated, highly elevated, and extremely elevated as the concentrations increase beyond the mean concentration at background sites. The results for four heavy metal parameters (arsenic, cadmium, lead, and zinc) commonly encountered in urban settings show that the frequency

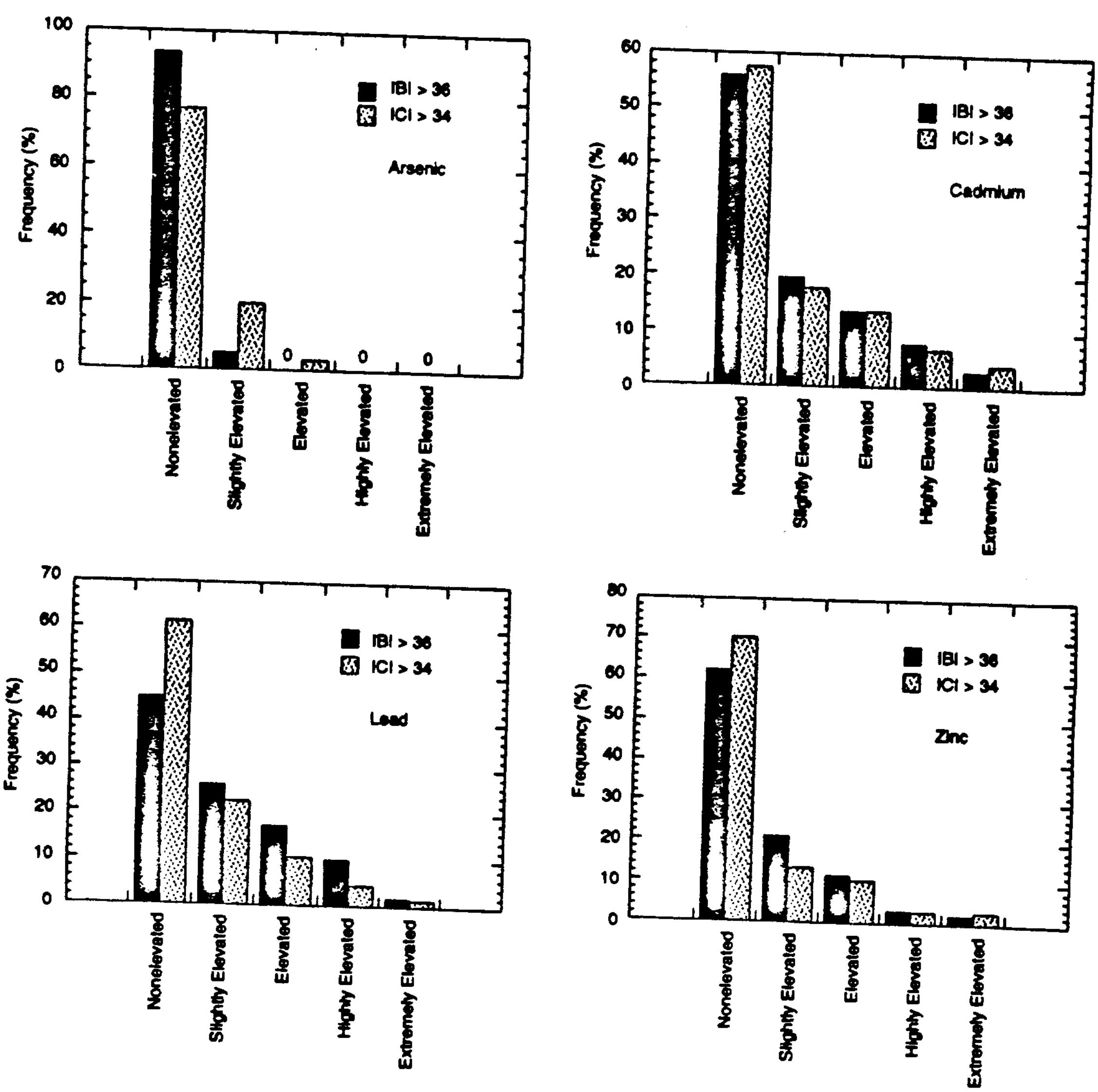

Figure 5. The frequency of occurrence of IBI and ICI scores which attain the warmwater habitat biocriteria under increasingly contaminated levels of four heavy metals in bottom sediments. Based on data collected by Ohio EPA throughout Ohio between 1981 and 1989.

of sites attaining the WWH use designation criteria for the IBI and ICI sharply decline as the sediment concentrations of these metals increase. For arsenic, no sites with highly or extremely elevated concentrations attain the biocriteria. For the remaining three parameters, in a few instances in each case, biocriteria attainment exists with highly elevated or extremely elevated sediment concentrations, but these are exceptions to the overall pattern.

For bioassessments to achieve their maximum effective use in the assessment of urban nonpoint sources, sampling and analysis should be based on a watershed design. An example of the use of biological criteria to evaluate aquatic life-use attainment/nonattainment in an urban watershed involves the Nimishillen Creek basin in northeastern Ohio (Table 1). This watershed is subject to a variety of point and nonpoint source impacts and is extensively affected by intensive urbanization in several

Table 1. Aquatic Life-Use Attainment Status for the Existing and Recommended Aquatic Life-Use Designations in the Nimishillen Creek and Selected Tributaries Based on Data Collected From June to September, 1985

Use Designation	RIVER MILE Fish/Invertebrate	IBI	Miwb	ICI[a]	QHEI[b]	Attainment Status[c]	Comment
Nimishillen Creek							
WWH	14.2/14.2	30[d]	6.7[d]	22[d]	60	Non	Dst. East and Middle Branches
	12.7/12.7	22[d]	6.0[d]	22[d]	71.5	Non	Cherry Ave.
	11.7/11.7	20[d]	4.8[d]	12[d]	81	Non	Dst. West Branch (Gregory Galvanizing)
	11.2/11.1	17[d]	3.3[d]	8[d]	81.5	Non	Dst. Hurford Run (Ashland Oil)
WWH	10.2/10.3	19[d]	3.1[d]	10[d]	72.5	Non	Ust. Canton WWTP
	8.8/8.8	19[d]	2.3[d]	8[d]	85	Non	Baum Rd.
	6.7/6.7	16[d]	3.6[d]	2[d]	80.5	Non	Howenstine Rd.
	3.2/3.2	24[d]	4.2[d]	6[d]	91	Non	Main St.
	0.6/0.6	20[d]	3.9[d]	0[d]	92	Non	Ust. at mouth
Sherrie (Sherrick) Run							
LRW	5.3/5.3	12[d]	N/A	P[d]	33.5	Non	
WWH	4.1/4.1	17[d]	N/A	P[d]	70 T	Non	
	0.1/—	22	N/A	P[d]	52	Non	Dst. Osnaburg Ditch
Osnaburg Ditch							
MWH	0.7/0.7	15[d]	N/A	P[d]	42 T	Non	Ust. East Canton WWTP
	0.1/0.1	12[d]	N/A	P[d]	39	Non	Dst. East Canton WWTP
Hurford Run							
LRW	2.0/—	12[d]	N/A	—	34.5	Non	Ust. Ashland Oil
	1.8/—	12[d]	N/A	—	27	Non	Dst. Ashland Oil
MWH	1.2/—	12[d]	N/A	—	52.5	Non	Dst. Domer Ditch
WWH	0.3/—	12[d]	N/A	—	66	Non	
	0.1/—	18[d]	N/A	—	50.5	Non	
Domer Ditch							
WWH	0.5/0.4	23[d]	N/A	MG	60	Non	Ust. Timken
	0.1/0.1	18[d]	N/A	P[d]	54.5	Non	Dst. Timken
West Branch Nimishillen Creek							
WWH	5.9/5.9	27[d]	N/A	18[d]	53	Non	At cemetery
	3.2/3.2	17[d]	4.8[d]	20[d]	59.5	Non	Dst. McDowell Ditch
	1.6/1.6	22[d]	5.5[d]	20[d]	43.5	Non	Ust. Tuscarawas St.
	0.8/—	24[d]	6.2[d]	—	34.5	(Non)	Ust. Gregory Galvanizing
	0.1/0.1	21[d]	3.1[d]	12[d]	65	Non	Dst. Gregory Galvanizing
McDowell Ditch							
MWH	1.8/1.8	21[d]	N/A	F	34	Partial	Ust. Everhard Rd.
	0.1/0.1	21[d]	N/A	F	41	Partial	At mouth
Zimber Ditch							
WWH	3.8/3.8	40[ns]	N/A	G	57	Full	Regional reference site
	1.8/2.4	29[d]	N/A	F	42	Non	Dst. Hoover Industrial Park
MWH	0.9/1.1	23[d]	N/A	F	31	Partial	Ust. North Canton Ditch
	0.6/0.6	23[d]	N/A	F	31.5	Partial	Dst. North Canton Ditch
Rettig Ditch							
Undesignated	0.9/0.9	29[d]	N/A	F	39	Non	Channel modified
North Canton Ditch							
LRW	0.1/0.1	32	N/A	P	46	Full	Partially culverted (80-m zone)

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Table 1. Aquatic Life-Use Attainment Status for the Existing and Recommended Aquatic Life-Use Designations in the Nimishillen Creek and Selected Tributaries Based on Data Collected From June to September, 1985 (Continued)

Use Designation	RIVER MILE Fish/ Invertebrate	IBI	MIwb	ICI[a]	QHEI[b]	Attainment Status[c]	Comment
Middle Branch Nimishillen Creek							
WWH	11.4/11.4	45	N/A	30^{ns}	50	Full	
	10.4/10.4	27^{d}	5.8^{d}	22^{d}	38	Non	Ust. State St.
	8.0/8.0	34^{ns}	7.7^{ns}	30^{ns}	74	Full	Dst. Werner-Church Rd.
	6.8/6.8	35^{ns}	8.0	40	47	Full	Regional reference site
	5.0/—	37^{ns}	7.6^{ns}	—	—	(Full)	Ust. 55th St.
	2.5/2.5	38	8.3	28^{d}	—	Partial	Ust. Martindale Rd.
	1.6/—	43	8.5	—	—	(Full)	Dst. State Route 62
	—/0.8	—	—	10^{d}	—	(Non)	
	0.2/0.1	28^{d}	7.2^{d}	14^{d}	60	Non	Cookes Park
Swartz Ditch							
MWH	2.6/2.6	26	N/A	F	34	Full	Ust. Smith-Kramer Rd.
	1.2/1.2	33	N/A	P^{d}	31	Non	Ust. Church Rd.
	0.2/0.3	34	N/A	F	45.5	Full	Dst. Hartville Ditch
Gulley (Hartville) Ditch							
MWH	—/4.1	—	—	P^{d}	—	(Non)	Ust. Teledyne
	3.4/—	26	N/A	—	27	(Full)	Ust. Hartville WWTP
	2.3/2.3	33	N/A	P^{d}	32	Partial	Dst. Smith-Kramer Rd.
	0.4/0.4	36	N/A	F	44	Full	Gans Rd.-Dst. Culvert
East Branch Nimishillen Creek							
WWH	8.6/8.6	39^{ns}	N/A	40	64.5	Full	Regional reference site
	6.4/6.3	33^{d}	6.8^{d}	26^{d}	51	Non	Ust. J&L Steel
WWH	4.7/4.7	29^{d}	6.4^{d}	4^{d}	80	Non	Dst. J&L Steel
	4.2/4.2	23^{d}	3.8^{d}	14^{d}	66	Non	Dst. Louisville South WWTP
	3.4/2.8	24^{d}	4.5^{d}	20^{d}	66	Non	Dst. Louisville North WWTP
	1.9/1.9	24^{d}	5.1^{d}	20^{d}	67.5	Non	Ust. LTV Steel
	0.1/0.1	31^{d}	8.2^{d}	14^{d}	60.5	Partial	At mouth

Ecoregion Biocriteria: Erie/Ontario Lake Plain

INDEX - Site Type	WWH	EWH	MWH[e]
IBI - Headwaters	40	50	24
IBI - Wading	38	50	24
MIwb - Wading	7.9	9.4	5.6
ICI	34	46	22

[a] Narrative criteria used in lieu of ICI: E = exceptional, G = good, MG = marginally good, F = fair, P = poor.
[b] All QHEI values are based on the most recent version of the index (28).
[c] Use attainment is parenthetically expressed when based on one organism group.
[d] Significant departure from ecoregion biocriteria; poor and very poor results are underlined.
[e] For channel modified areas.
Dst. = downstream
LRW = Limited Resource Waters
MIwb = modified Iwb
MWH = Modified Warmwater Habitat
ns = nonsignificant departure from WWH and EWH biocriteria (4 IBI or ICI units; 0.5 MIwb units).
Ust. = upstream
WWTP = wastewater treatment plant

areas. As with many of the Ohio watersheds that are more heavily affected by point and nonpoint sources, the majority of sampling sites either fail to attain the applicable biological criteria or are only in partial attainment. Out of 57 sampling sites in the entire watershed, only 11 (19 percent) fully attained the applicable biological criteria. These results demonstrate the degree of degradation that exists in most urban watersheds and the multiple source causes.

Another issue of critical importance to the management of urban watersheds is also apparent in Table 1, use attainability. Many of the use designations listed for the various streams of the Nimishillen Creek basin are recommended uses, meaning that a different aquatic life use applied at the time of the sampling. An important objective of the biological sampling conducted by Ohio EPA is to determine the appropriate aquatic life-use designation. If the results of the sampling and data analysis suggest that the existing use designation is inappropriate (or the stream is presently unclassified), the appropriate use is recommended. These recommendations are then proposed in a WQS rulemaking procedure and adopted after consideration of public input.

Figure 6 illustrates the relative distribution of IBI scores based on biological monitoring conducted by Ohio EPA in several urban and suburban watersheds throughout Ohio. These range in size from relatively small headwater streams (less than a 20-square-mile watershed area) to increasingly larger streams and rivers. For the smaller watersheds, there is a pattern of lower IBI scores and a subsequent loss of biological integrity with an increasing degree of urbanization. The baseline biological criterion for the WWH use designation is not attained by any (or only a few) sampling sites in the older urban watersheds, such as the Cuyahoga River and Little Cuyahoga River of northeastern Ohio and Mill Creek in Cincinnati. The IBI scores in these watersheds are indicative of poor and very poor water resource quality. The Rocky River basin is largely a suburban area of Cleveland upon which municipal wastewater discharges have had an extensive impact, but despite this the basin exhibits higher IBI scores. The highest IBI scores were observed in Rocky Fork (Columbus area), Taylor Creek (Cincinnati area), and Little Miami River (southwest Ohio) tributaries, which have only recently begun to be suburbanized. These three watersheds also lack some of the companion impacts of the older urban areas, namely, combined sewer overflows and industrial discharges.

For the larger streams and rivers, the pattern was similar, with the older urban areas exhibiting the lowest IBI scores and the less urbanized and suburban watersheds exhibiting higher scores, some of which attain the WWH criteria. The major exceptions, however, involve the two large mainstem rivers (Great Miami River and Scioto River) which exhibit higher IBI scores despite flowing within urban settings. This illustrates the influence of river and upstream watershed size on the ability of a river or stream to withstand increased urbanization. Both the Great Miami River and Scioto River mainstems originate in rural areas and are quite large when they enter the Dayton and Columbus urban areas. Thus, stream size relative to the watershed and the influence of land-use patterns are important to understanding and managing local nonpoint source impacts.

Applications to Nonpoint Source Management

Steedman (24) observed the IBI to be negatively correlated with urban land use. The land use within the 10 to 100 km^2 area upstream from a site was the most important in predicting the IBI, which suggests that "extraneous" information was likely included if whole watershed land-use area was used. Steedman (24) also determined that the condition of the riparian zone was an important covariate (a measure of independent variation) with urban land use in addition to other factors, such as sedimentation and nutrient enrichment. A model relationship between these factors and the IBI was developed and provided the basis to predict when the IBI would decline below a certain threshold level with certain combinations of riparian zone width and percent of urbanization. In the Steedman (24) study, the domain of degradation for Toronto area streams ranged from 75-percent riparian removal at 0-percent urbanization to 0-percent riparian removal at 55-percent urbanization. These results indicate that it is possible to establish the bounds within which the combination of watershed land use and riparian zone condition must be maintained for a target level of biological community performance to persist. It seems plausible that such relationships could be established for many other watersheds, provided the database is sufficiently developed not only for biological communities but also for land-use composition and riparian corridor condition. Additionally including the concept of ecoregions and subecoregions should lead to the development of criteria for land use and riparian zones that would ensure the maintenance of biocriteria performance levels in streams and rivers over fairly broad areas without the need to develop a site-specific database everywhere.

Well-designed biological surveys can fit well into the watershed approach to nonpoint source management. Because the biota respond to and integrate all of the various factors that affect a particular water body, they are essentially the end product of what happens within watersheds. The important issue is that ambient monitoring be conducted as part of the nonpoint source assessment and management process, and that it be performed correctly in terms of timing, methods, and design. Monitoring alone is not enough, however. Federal, state, local, and private efforts to remediate nonpoint source impairments must include an interdisciplinary approach that goes beyond water column chemistry impacts to include the cumulative range of factors responsible for ecosystem degradation that has been documented over the past century. Existing regulations and standards have only been locally successful in reducing water resource declines attributable to watershed and riparian zone degradation. Effective protection and rehabilitation strategies require the targeting of large areas and individual sites (39) as well as the

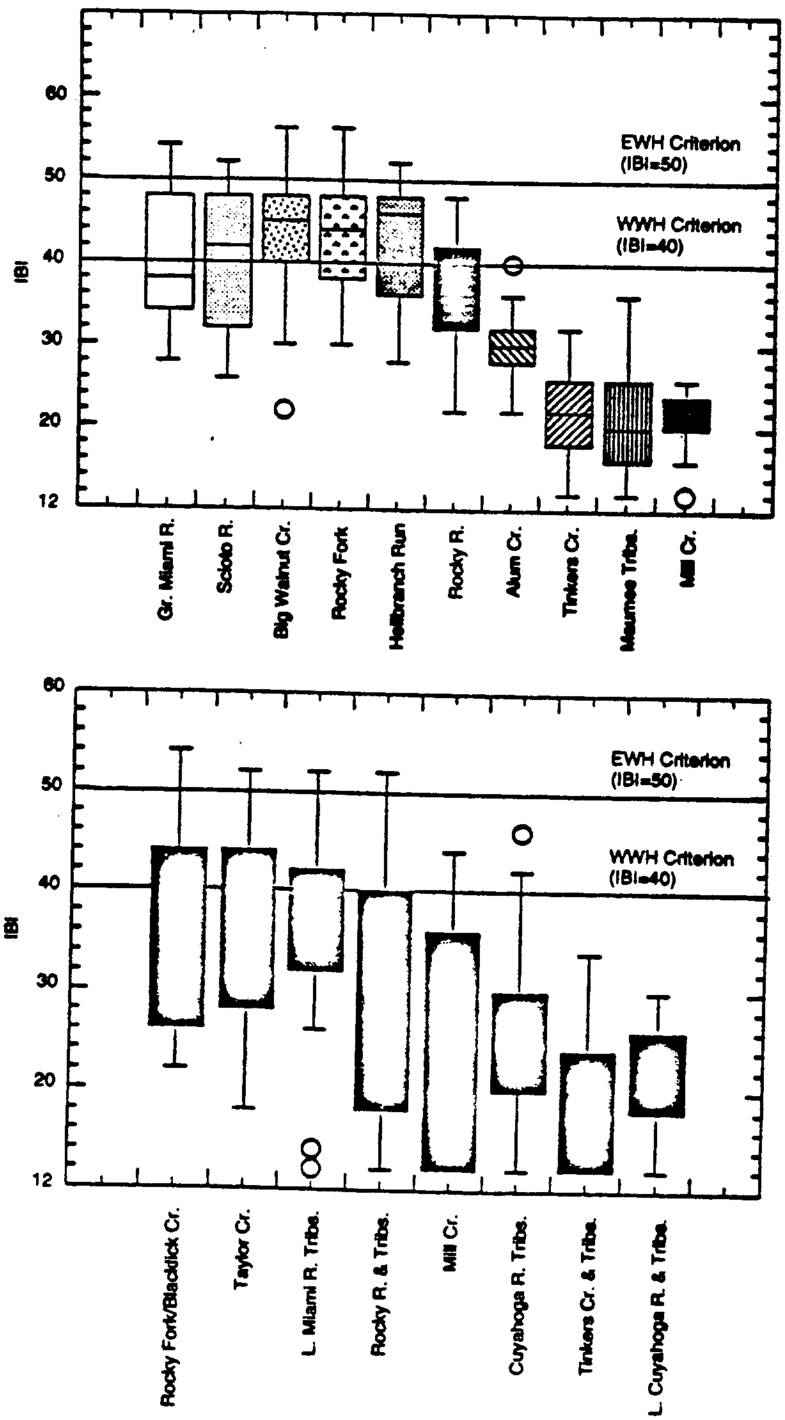


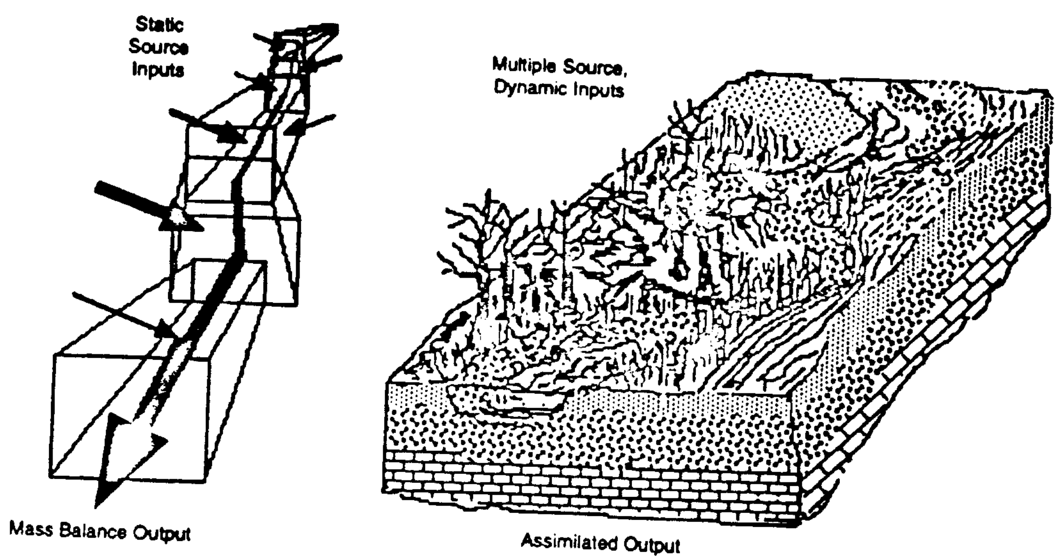
Figure 6. IBI values observed in selected Ohio headwaters streams (drainage area <20 mi.^{2}; upper) and larger Ohio streams and rivers between 1981 and 1992. Box and whisker plots include all values recorded in each stream or stream/river assemblage.

incorporation of ecological concepts in the status quo of land-use management practices and policies.

Ohio EPA has initiated the development of policies that will ensure a holistic approach to nonpoint source management. For example, we have specified a minimum width of two to three times the bank full channel width as necessary to protect riparian zones and ensure the integrity of instream habitat. This also ensures that the ability of the stream to assimilate nonpoint source runoff will be maintained. To be completely successful, however, this measure must be accompanied by the application of best management practices in the uplands. Such an approach goes well beyond a singular concern for the concentration of pollutants in the water column and must be incorporated into the total maximum daily load approach envisioned by the U.S. Environmental Protection Agency as an integral part of urban nonpoint source runoff management.

Thus, it seems that we have a choice in the management of urban nonpoint sources, as portrayed by Figure 7. Extending the traditional process by which we have managed chemical pollutants discharged by point sources during the past 15 to 20 years to nonpoint sources is exemplified by treating streams as once-through flow conduits that are essentially isolated from interactions with the landscape. This is commonly exemplified by simplified mass-balance approaches to establishing water quality-based effluent limitations for point sources using steady-state assumptions. While this approach has been successful in reducing point source loadings of commonly discharged substances, it holds much less promise for highly dynamic inputs from diffuse sources. For nonpoint source management to truly result in the restoration and preservation of biological integrity, we must regard streams as an interactive component of the landscape where multiple inputs and influences act together to determine the health of the aquatic resource.

Urban watershed management and protection issues will continue to develop as new information is revealed and relationships between instream biological community performance and watershed factors are better developed. Nonetheless, some of what we know now should be included in current management strategies. Urban and suburban development must become proactive; that is, developments must be designed to accommodate the features of the natural landscape and include common sense features such as setbacks from riparian zones. Regulatory agencies also share responsibility, particularly in resolving use attainability issues. Watersheds that exhibit the attainment of aquatic life-use biocriteria should be protected to maintain the current conditions. Frequently our attention seems to emphasize high quality or unique habitats; however,



A. Stream as an isolated, once-through flow conduit (steady-state, mechanical system)

B. Stream as an interactive component of the landscape (dynamic, living system)

Figure 7. Two views of a stream ecosystem: A. The stream is viewed as an isolated conveyance for static source wastes and runoff with the net water column output as a mass balance function of flow and concentration. B. The stream as an interactive component of the landscape with dynamic and multiple source inputs and assimilated output as affected by the surrounding land use, habitat, geology, soils, and other biotic and abiotic factors.

water quality standards must be maintained where they are presently attained, if even minimally so. Strategies should also include the restoration of degraded watersheds where that potential exists. In systems where the degree of degradation is so severe that the damage is essentially irreparable, minimal enhancement measures should still be required, even though full use attainment is not expected. Biocriteria and bioassessments have an important and central role to play in this process.

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Overview of Contaminated Sediment Assessment Methods

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Urban runoff has significantly contributed to the contamination of lakes, rivers, and streams. After years of accumulation in the water, toxic chemicals have found their way to the bottom sediments. These contaminants can be directly toxic to fish and other aquatic organisms as well as significant sources of contaminants to wildlife. Human health effect concerns arise primarily from consumption of contaminated fish and water fowl. Assessing contaminated sediments is a difficult task due to the complex nature of the sediment matrix, contaminant mixtures, and the physical dynamics of the waterways. To determine the scope and extent of the sediment contamination at a particular site, a comprehensive sediment assessment program must be developed.

In recognition of the significance of the problem, the Assessment and Remediation of Contaminated Sediments (ARCS) program was authorized for 6 years—by Congress under Section 118(c)(3) of the Water Quality Act of 1987 and the Great Lakes Critical Program Act of 1990—to develop and demonstrate new and innovative methods both to assess and to treat contaminated sediments. The ARCS program developed an "Integrated Contaminated Sediments Assessment Approach" for use in the Great Lakes Areas of Concern (1). This approach includes:

- Sampling design and quality assurance
- Sample collection
- Chemical analysis
- Toxicity testing
- Benthic community structure survey
- Tumors and abnormalities

These six topics are the focus of this paper.

Assessment Components

Sample Design and Collection

The ultimate goal of assessment is to determine the scope and extent of contamination, including the magnitude and spatial bounds of the problem. Assessment needs direct sample design. Sediment sampling programs are most often undertaken to achieve one or more of the following objectives: to fulfill a regulatory testing requirement, to determine characteristic ambient levels, to monitor trends in contamination levels, to identify hot spots of contamination, and to screen for potential problems. These different objectives lead to different sampling designs. For example, a study for a dredging project may have a specific set of guidelines on sampling frequency, sample site selection methodology, and other parameters already determined by existing, specific guidance. The design for a study to track sediment contamination trends would expend its resources to sample fewer sites more frequently. A study to identify hot spots would concentrate efforts on fewer sites within zones known to be mostly contaminated, while an initial screening study might take few randomly distributed samples for analysis together with some "observation" samples to supplement the analytical results.

The most appropriate sample collection device for a specific study depends on the study objectives, sampling conditions, parameters to be analyzed, and cost. Three general types of devices are used to collect sediment samples: dredges, grab samplers, and corers. Core samples give by far the most complete information; thus, corers should be the sampler of choice whenever possible. Deep core sampling gives a three-dimensional picture of the situation. This allows characterization of the depth of contamination. Before a river or lake bottom is dredged in an effort to remove contamination, knowing whether more serious contamination will be uncovered is vital. All of this information guides remediation decisions.

The ARCS program concentrated on three levels of sampling data:

- *Historical data* can give some preliminary clues to what may be present at a site. Consideration of historical data can help to move the sample design process in the proper direction. Historical data have some limitations, however, that bear consideration. Often data are only available for surface sediments, and quality assurance may be in question.
- *Reconnaissance sampling data* involve characterizing a large area with "quick and dirty" screening tests on fewer samples. This data can help eliminate some of the parameters of concern, thus allowing more extensive testing of toxic substances present at the site.
- *Detailed assessment data* involve the more extensive chemistry and biological testing to fully characterize a hot spot.

Chemical and Physical Analysis

Sampling efforts are performed with a variety of objectives in mind. Therefore, minimal chemical and physical parameter testing requirements vary between studies or programs. Some chemical and physical parameters, however, should be common to most programs unless evidence precludes their consideration:

- *Particle or grain size* is a physical parameter that determines the distribution of particles. Size is important because finer grained sediments tend to bind contaminants more than coarse sediments do.
- *Total organic carbon (TOC)* is an important indicator of bioavailability for nonionic hydrophobic organic pollutants.
- *Acid volatile sulfides (AVS)* have been found to be closely related to the toxicity of sediment-related associated metals.
- *Polyaromatic hydrocarbons (PAHs)* are semivolatile organic pollutants, several of which are potential carcinogens and are linked to tumors in fish.
- *Polychlorinated biphenyls (PCBs)* are chlorinated organic compounds once used for numerous purposes, including as a dielectric fluid in electrical transformers.
- *Pesticides* are synthetic compounds predominantly used in agriculture to control crop-damaging insects.
- *Other semivolatiles* include acid/base neutral compounds (ABNs) such as phenols, naphthenes, and toluenes.
- *Heavy metals* are naturally occurring in the environment, but an excess of metals can be an indication of anthropogenic contamination; heavy metals can be toxic to benthic organisms.

For a typical Great Lakes site, grain size, TOC, and AVS analyses should be done; the other five analyses should be performed accordingly. For example, if heavy metals in a particular area are not a problem, they could be omitted from the scheme. Also, if certain other contaminants are suspected in an area, they should be included as test parameters (e.g., tributyl tin and methyl mercury).

Toxicity Testing

Although chemical analysis is an illuminating part of the assessment process, chemical analysis alone does not determine impacts. Bioavailability is key to determining whether or not toxic contaminants will cause effects. For example, it is possible to find a situation where high concentrations of contaminants are present but no toxic effects are manifested in the benthic community; in such a situation, the contaminants may not be bioavailable to the benthic community. In any case, further toxicity testing would be required. One way to evaluate bioavailability is by performing toxicity tests. Toxicity tests measure the effects of sediment contamination test organisms. Test organisms can be exposed directly to sediments (solid phase) or to sediment slurries called elutriates.

The ARCS program evaluated over 40 toxicity tests during the assessment program at three priority areas of concern. Based on the results of the ARCS program, a battery of tests should include Microtox and *Daphnia magna* (7-day, three-brood survival reproduction solid phase assay) because they are good screening assays, relatively sensitive, discriminatory, and well correlated with other assay responses. In addition, one or two of the following tests should be included in the assay battery: *Pimephales promelas* (larval growth solid phase), *Hyalella azteca* (7-day survival solid phase), *Ceriodaphnia dubia* (three-brood survival and reproduction, solid or elutriate phase), and *Hexagenia bilineata* (10-day survival and molting, solid or elutriate phase).

Benthic Community Survey

Benthic communities are communities of organisms that live in or on sediment. In most benthic community structure assessments, primary emphasis is placed on determining the species that are present and the distribution of individuals among those species. Information on benthic community composition and abundance is typically used in conjunction with information in the scientific literature to infer the distribution of species and individuals. Because sediment quality affects all major structural and functional attributes of benthic communities in generally predictable ways, benthic community structure assessment is a valuable tool for evaluating sediment quality and its effects on a major biological component of freshwater ecosystems. Specific assessment methods are available to complement the chemical and toxicological portions of the sediment quality assessment.

Freshwater benthic macroinvertebrate communities are used in the following ways to assess the quality of the water resource:

- Identification of the quality of ambient sites through a knowledge of the pollution tolerances and life history requirements of benthic macroinvertebrates.
- Establishment of standards based on community performance at multiple reference sites throughout an ecoregion or other regionalization categories.
- Comparison of the quality of reference sites with test sites.
- Comparison of the quality of ambient sites with historical data to identify temporal trends.
- Determination of spatial gradients of contamination for source characterization.

Tumors and Abnormalities

Tumors and other abnormalities are another useful assessment tool. These abnormalities are believed to be caused by contaminants present in the sediments, specifically PAHs. A typical use of this type of study would be to analyze for tumors and abnormalities before and after cleanup to see if a change in the incidence rate occurred. In the ARCS program, investigation of tumors and abnormalities helped to characterize the different areas of concern. For example, in the Ashtabula and Buffalo Rivers we found numerous liver and external abnormalities in Brown Bullhead, such as lip papillomas, preneoplastic lesions, and neoplastic lesions.

Interpretation and Use of Data

All data are useless without an interpretation scheme. Using or looking at data in isolation can lead to false conclusions. Therefore, it is important to look at all aspects of data using some type of integrated process to aid decision-making.

Data Depiction

Data cannot be easily interpreted from tables. Data need to be depicted in a visual manner, such that hot spots, gradient depth information, and trends are evident. One way to accomplish this goal is to make a map of the site and plot data results on the map. A three-dimensional map can be most useful in data depiction.

Sediment Quality Values

As stated before, the numbers obtained from chemical testing are not very significant by themselves. If you have a gray-area situation, in which the chemistry numbers are high but toxicity or biological alteration is not necessarily evident, deciding whether this is or will become a problem may be difficult. In such a case, comparison of one's particular program numbers with existing numbers could give information on how to proceed. There are three general types of sediment quality values (2):

- *Equilibrium partitioning* is a theoretical approach that focuses on predicting the chemical interactions between sediments, interstitial water (i.e., the water between sediment particles), and contaminants. Chemically contaminated sediments are expected to cause adverse biological effects if the predicted interstitial water concentration for a given contaminant exceeds the chronic water quality criterion for that contaminant.
- *The empirical effects-based approach* (e.g., sediment quality triad or apparent effects threshold) combines measures of sediment chemistry, sediment toxicity, and/or benthic infauna communities to determine the overall sediment quality.
- *National status and trends* is a statistical approach that uses chemical data assembled from modeling laboratory and field studies to determine the ranges in chemical concentration that are rarely, sometimes, and usually associated with toxicity.

Each approach has advantages and disadvantages. The best approach is selected based on each programs' particular needs.

Risk Assessment

After studying the data received from the chemistry, toxicity, and environmental impact analysis, the final assessment step is an evaluation of associated risk to human, aquatic, and wildlife. What is the risk now, and what is it potentially? This involves evaluating exposure to and impacts resulting from contact with contaminated sediments and media contaminated by sediment contaminants. If several sites are involved, a prioritization system may be needed as a decision-making tool for remedial actions.

The ARCS program used two levels of evaluation: baseline and comprehensive hazard evaluations. Baseline human health hazard evaluations were performed for all five priority demonstration areas and were developed from available site-specific information. The baseline hazard evaluations described the hazards to receptors under present site conditions. This baseline assessment also examined all potential pathways for human exposure to sediments for each given location. Comprehensive hazard evaluations were performed for the Buffalo River and Saginaw Bay areas. Results from ARCS studies showed that consumption of contaminated fish provided the greatest risk to human health.

Conclusions

There are a number of approaches to the assessment process. The main components are sample design, chemical and physical analysis, biological testing and data interpretation. Within that framework, choices are made as to what course to follow. Regardless of which assessment path one takes, each phase of the assessment process should be carefully considered and tailored to the needs and goals of that particular program. All data must be integrated for decisions to be based on a preponderance of evidence and to yield the most definitive of results.

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Linked Watershed/Water-Body Model

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Abstract

With passage of the state's Surface Water Improvement and Management (SWIM) Act of 1987, the Southwest Florida Water Management District realized a need for an integrated eutrophication model incorporating both a watershed loading model and a water-body response model. In addition, because many watershed models depend on land use and soils mapping data, a modeling system that could take advantage of data already stored in the district's geographical information system (GIS) would be useful.

This paper describes the desirable attributes of such a modeling system, the means used to select the appropriate model components, the actual modeling system developed, and an application of the model. The modeling system is constructed around two U.S. Environmental Protection Agency supported models—Storm Water Management Model (SWMM) and Water Quality Analysis Simulation Program Model (WASP4)—and is linked to the ARC/INFO GIS. Rather than the details of SWMM or WASP4, the paper focuses on the SWMM/WASP Interactive Support Program (SWISP), the interactive, menu-driven user environment that allows for the easy execution of the linked watershed/water-body modeling system of programs. With SWISP, the user can view and edit input data sets as well as execute and graphically postprocess the results.

The modeling system is being tested and refined sequentially on three test sites. The paper presents the results of testing to date on a specific case study: Lake Thonotosassa, a hypereutrophic, 800-acre lake in Hillsborough County, Florida. The objective of the modeling is to allow for the assessment of various restoration strategies for improving in-lake water quality. The modeling system, which is PC based and in the public domain, will be available for public release in the fall of 1993, along with a user's manual.

Introduction

With passage of the state's Surface Water Improvement and Management (SWIM) Act of 1987, the Southwest Florida Water Management District (SWFWMD) realized a need for an integrated eutrophication model incorporating both a watershed pollutant loading model and a water-body response model. In addition, because many watershed models depend on land use and soils mapping data, a modeling system that could take advantage of data already stored in the district's geographical information system (GIS) would be useful. The stated objective of the watershed/water-body modeling project was "to select and/or link a watershed(s) and water-body eutrophication model for use in prioritizing land-use management and pollution control strategies and evaluating the effects of implementation of best management practices (BMPs) on in-lake water quality and natural systems."

A variety of watershed models exist that make it possible, within limited degrees of certainty, to evaluate the effects of land-use practices on receiving waters. These models are used to prioritize watersheds that contribute the greatest loading to a water body. When coupled with an appropriate model of the receiving water body, the model system can be used to predict how changes in land use will affect the receiving body, both in terms of water quantity and quality.

A watershed model is an important planning tool for evaluating the contributions from existing conditions and projecting contributions under different scenarios. A watershed/water-body model system allows those using them to make decisions regarding alternative land use, zoning, treatment, and BMP options, thus altering constituent loadings to a receiving water body.

Water quality/ecological models are designed to mimic in-waterbody dynamics as the result of inputs and to predict trophic state or other conditions of interest. These models allow the modeler to predict lake conditions based on known or projected inputs, and thus evaluate how changes in loading will affect the overall health of a water body. Decisions with regard to how much of a load reduction is required to produce desired in-lake effects can be made, and the benefits of implementing a particular corrective strategy can be assessed.

From a water-body management perspective, it is desirable to have as a decision tool a linked model that couples the attributes of both watershed and water-body models. With such a model, it would be possible to evaluate how changes in land use will, for example, affect the trophic state (and other states) of a surface water body.

Model Attributes

Prior to selecting a consultant, district staff developed a list of 13 desirable attributes of a linked watershed/water-body model (LWWM):

- Data can be input directly into the linked model from the district's GIS (ARC/INFO) database.
- The model system should consist of "off the shelf" watershed and water-body models, although some customizing may be required. (Proprietary software is not acceptable.)
- Calibration and validation data requirements should not be excessive.
- The model can be applied to most Florida aquatic systems with the watershed component suitable for estuarine systems.
- The model has a storm event or seasonally based watershed component, yet it is capable of yielding annualized values.
- The output of the watershed model component should be fully compatible with the input of the water-body model component.
- The model should be user-friendly, menu-driven, interactive, and fully documented.
- The water-body model considers the physical, chemical, and biological parameters and processes necessary to simulate the eutrophication process and attendant water quality conditions.
- The model is sensitive to eolian, sediment, and ground-water inputs.
- The water-body model should consider the temporal and spatial variation as required to simulate critical water quality conditions and processes.
- The model should be sensitive to trophic dynamics and exchanges between trophic levels.
- The water-body model should predict the trophic state using existing empirical relationships already developed for Florida lakes.

Model Selection

Dames and Moore, Inc., was selected to develop the district's LWWM. The district also established a modeling technical advisory committee (TAC) composed of various recognized modeling and GIS experts from other agencies, academia, and private consulting firms. The primary goal of the TAC was to aid the district and its consultant in finalizing modeling goals and the list of desirable model attributes to be used in an evaluation of existing candidate models. One of the initial tasks accomplished by Dames and Moore was a literature and model comparison report (1) with recommended models to be used in the proposed LWWM. This review focused on model capabilities with regard to the overall LWWM project objectives and did not include a rigorous investigation of the background and theory behind each model.

Dames and Moore, following the examples of Basta and Bower (2) and Donigian and Huber (3), developed specific evaluation criteria to objectively review candidate models consistent with district objectives. Dames and Moore, with the aid of the TAC and before identifying available models, developed four criteria to be used on a preselection basis to identify candidate models for further consideration:

- The models must have written documentation.
- The models must be maintained, either formally (i.e., funded model caretaker) or informally (through active use and application).
- The models must be PC based or have the capability of being easily transportable to the PC environment.
- The models must be nonproprietary.

Based on the above criteria and considering district requirements for review of certain specifically named models, a first-cut list of candidate models was developed followed by a final list of candidate models (Table 1).

The modeling TAC was relied on heavily to eliminate models from further consideration and ultimately arrived at the two selected models, SWMM and WASP4. The rationale for eliminating certain models is detailed by Dames and Moore (1); it was decided that the modeling system should rely on a single watershed model. After considerable discussion, certain models were

Table 1. List of Final Candidate Models Evaluated by Dames and Moore, Inc., for Possible Incorporation in the SWFWMD's Linked Watershed/Water-Body Model System (1)

Watershed Models	Water-Body Models
AGNPS	BATHTUB
ANSWERS	BETTER
CREAMS	CE-QUAL-R1
DR3M-QUAL	CE-QUAL-W2
EPA-FHWA	HSPF
EUTROMOD	NUTRIENT LOADING/TROPHIC STATE (EUTROMOD)
GLEAMS	QUAL2EU
HSPF	WASP4
NPSLAM	WORRS
STORM	
SWMM	
SWRRB	

eliminated because of their primarily rural or agricultural applicability, other models were eliminated on the basis of limited maintenance, and considerable in-house debate and discussion centered on the advantages and disadvantages of "mechanistic" versus "empirical" type models. Despite its selection, there was concern that SWMM was too complicated to use without extensive training and experience and that this would affect the desirable attribute of being user friendly and easy to apply (or misapply); this was considered a disadvantage common to all "mechanistic" models considered. SWMM is primarily an urban model, and although it has been applied in nonurban areas successfully, the erosion and sedimentation capabilities are not as detailed as most rural or agricultural models. Another disadvantage of SWMM is that subbasins must be defined homogeneously with respect to land use for the water quality routines, and this restriction would limit to some extent the enhancement that could be easily afforded by a GIS linkage (1). Similar type considerations as those mentioned above were used to eliminate candidate water-body models from further consideration.

Eventually, WASP4 was selected as the appropriate "mechanistic" model to complement the watershed loading model. The TAC noted that the model was well maintained, tested, and documented. Although identified as the most complex of the selected water-body models, it was also the most flexible because of its ability to simulate processes, which allows it to be used at either a screening or predictive level depending on the availability of data, the experience of the user, and the objective of the application. Although flexible, the TAC indicated that WASP4 was still perceived as being extremely data intensive (1).

Ultimately, SWMM and WASP4 were selected because these models were determined to be "sufficiently complex to be usable for the most data intensive studies, but have the capability of 'turning off' or 'zeroing out' components such that the model can be made simple. The models are public domain, and both are supported by the EPA. In addition, full documentation is available for both models, and they have each been well tested, including several applications in the southwest Florida area" (1). The models selected were not the best for every application; however, they were considered to be those that best met the objectives of the SWFWMD.

Linked Watershed/Water-Body Modeling System Development

The LWWM incorporates three major environmental modeling components:

- Runoff (point and nonpoint)
- Hydrodynamic/Hydraulic routing
- Time variable water quality modeling

In essence, the LWWM operates as follows:

- It obtains land-use and soil-type information from ARC/INFO coded output.
- It incorporates this information into the runoff component of SWMM.
- SWMM calculates event-driven runoff loads of both point and nonpoint sources.
- The LWWM uses the hydrodynamic model, RIVMOD, to describe the longitudinal distributions of flow in the investigated water body.
- WASP4 incorporates these loads, flow distributions, and water quality information and simulates water-body interactions.

A schematic of the above program linkage is shown in Figure 1.

The LWWM was developed to allow engineers and scientists to rapidly evaluate the effects of both point and nonpoint source loads on receiving waters. The LWWM model obtains land-use information from a GIS that can be used to swiftly generate land-use and soil-type data for the runoff component of the LWWM system, SWMM. The SWMM model calculates event-driven runoff loads for both nonpoint and point sources. This time series of loads and water quantity runoff is then used as input for the receiving water model, WASP4 (EUTRO4). The information generated by the models will be accessible to users via interactive graphs and other user-friendly interfaces.

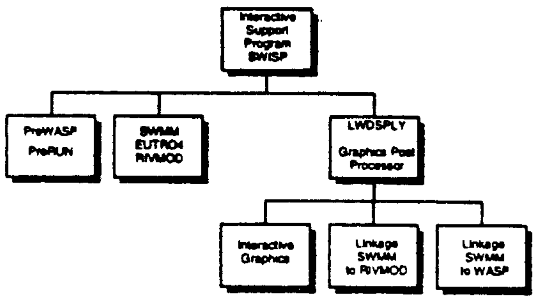


Figure 1. Linked watershed/water-body model (LWWM).

Geographical Information System Interface

A GIS is a computer program used for the entry, management, analysis, and display of geographic or mappable information. GIS systems typically include all of the functions of a computer-aided design (CAD) system, as well as the powerful analytical and modeling capabilities of a full-featured relational database. The power of a GIS lies in its ability to derive problem-solving information from existing data through such techniques as map overlays and modeling, and to store this information in an organized, usable form.

GIS analytical techniques are applied to generate automatically the input data sets for the SWMM watershed model. The software used for development of these data sets is ARC/INFO, an industry-standard GIS from Environmental Systems Research Institute (ESRI). This software is the primary GIS platform in use at the SWFWMD and at all other water management districts throughout the state. Several other federal, state, regional, and local agencies have also adopted ARC/INFO as a standard and are preparing comprehensive geographic databases in this format. The SWFWMD has compiled an extensive geographic database of the entire district in an ARC/INFO format, including detailed coverages for the U.S. Department of Agriculture Soil Conservation Service (SCS) soils, land use and cover, and basin boundaries. These data are compiled using automated ARC/INFO techniques to generate an input data file for the LWWM.

SWMM

SWMM (4) is a comprehensive mathematical model for the simulation of urban water quantity and quality in storm and combined sewer system. All aspects of urban hydrologic and water quality cycles are simulated. SWMM was developed between 1969 and 1971 by a consulting team under contract with the U.S. Environmental Protection Agency (EPA). It was one of the first such models and has been continually maintained and updated. The SWMM model is perhaps the best known and most widely used urban quantity/quality models in existence today.

SWMM simulates real storm events on the basis of rainfall hyetographs, land use, topography and system characterization to predict outcomes in the form of quality and quantity values. SWMM is composed of various computational blocks that can be run as stand-alone programs. The LWWM simplifies this process by selecting the appropriate blocks to run. The blocks used by LWWM and their function are as follows:

- *Runoff block:* Performs hydrologic and water quality modeling with elementary hydraulic routines.
- *Combine block:* Combines interface files to aggregate results of multiple runs.
- *Rain block:* Processes National Weather Service (NWS) precipitation data from magnetic tape or disk.

All other computational blocks within SWMM are either not applicable to the LWWM model or their function is already incorporated within the LWWM (i.e., graphic and tabular processing of output).

The LWWM model uses SWMM Version 4.2 but has been tested successfully with older versions.

RIVMOD Implementation

RIVMOD is a dynamic numerical, hydrodynamic riverine model that describes the longitudinal distributions of flows in a one-dimensional water body through time. The primary criteria for selecting RIVMOD is the need to describe spatially varying flows in a water body through time. The model is applicable to rivers, streams, tidal estuaries, reservoirs, and other water bodies where the one-dimensional assumption is appropriate. RIVMOD solves the governing flow equations in a manner that allows prediction of gradually or highly varying flows through time and space. The model has the capability of handling flow or head as boundary conditions. The specification of head as a boundary condition allows use of the model where an open boundary is required (e.g., an estuary or a river flowing into a lake). Algorithms are employed in RIVMOD to allow it to provide WASP4 with flows, volumes, and water velocities.

WASP Implementation

The WASP4 modeling system (5) was designed to provide the generality and flexibility necessary for analyzing a variety of water quality problems in a diverse set of water bodies. The model considers the hydrodynamics of large branching rivers, reservoirs, and estuaries; the mass transport in ponds, streams, lakes, reservoirs, rivers, estuaries, and coastal waters; and the kinetic interactions of eutrophication-dissolved oxygen and sediment-toxic chemicals.

WASP4 is a dynamic compartment modeling program for aquatic systems, including both the water column and the underlying benthos. The time-varying processes of advection, dispersion, point and diffuse mass loading, and boundary exchange are represented in the basic program. The flexibility afforded by the Water Quality Analysis Simulation Program is unique. WASP4 permits the modeler to structure one-, two-, and three-dimensional models; allows the specification of time-variable exchange coefficients, advective flows, waste loads, and water quality boundary conditions; and permits tailored structuring of the kinetic processes, all within the larger modeling framework, without having to write or rewrite large sections of computer code.

WASP4 simulates the movement and interaction of pollutants within the water using two programs to simulate two of the major classes of water quality problems: conventional pollution (involving dissolved oxygen, biochemical oxygen demand, nitrogen, phosphorus, and eutrophication) and toxic pollution (involving organic chemicals, metals, and sediment).

Because of WASP4's generalized framework and dynamic structure, it is relatively easy to link it to other simulation models. WASP4 was modified to read loads from an external file created by SWMM. This allows WASP4 to update its point and nonpoint source loading information daily.

SWMM/WASP Interactive Support Program (SWISP)

SWISP (Figure 2) is an interactive, menu-driven user environment that allows for the easy execution of the LWWM system of programs. SWISP allows you to view and edit WASP/RIVMOD/SWMM input datasets as well as execute and postprocess the results. SWISP is the Windows of the LWWMs; once the user executes SWISP, the user can perform all functions related to all the simulation models. SWISP provides file management, which allows the user to select a file or a set of files to activate for manipulation and/or execution. SWISP automatically loads the correct simulation model based on the type of input dataset selected; upon execution of the model, SWISP provides the input data file names that will be executed. When the simulation is completed, SWISP is automatically reloaded so that the results may be postprocessed.

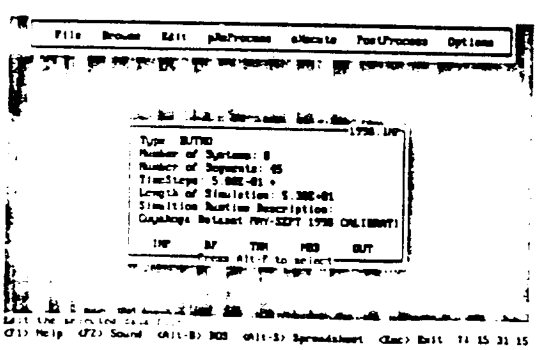
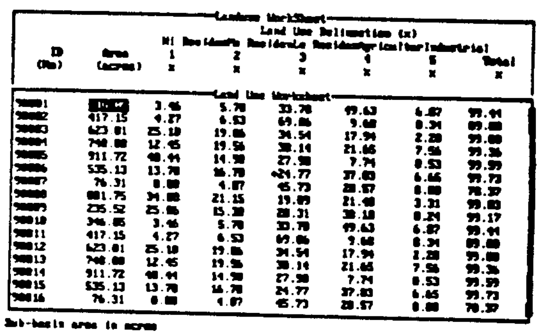


Figure 2. SWMM/WASP Interactive Support Program (SWISP).

SWMM Runoff Preprocessor (PreRUN)

The PreRUN program (Figure 3) was developed to aid the user in the development of SWMM RUNOFF block input datasets (SWMM Version 4.2x and higher). PreRUN provides intuitive data entry forms that successful guide the user through the development of syntactically correct datasets. Additionally, the PreRUN program can import a GIS file that is created before executing the preprocessor. The GIS interface file provides soil-type and land-use classifications to the PreRUN program so that the user can quickly give parameters to the SWMM Runoff block. PreRUN is designed to work with or without the GIS interface file.



ID (No)	Area (acres)	1 %	2 %	3 %	4 %	5 %	Total %
[illegible]	[illegible]	3.46	5.70	33.70	49.63	6.87	99.41
[illegible]	417.15	4.27	6.53	69.86	9.68	0.34	89.88
[illegible]	623.01	25.10	19.86	34.54	17.94	2.20	99.00
[illegible]	740.00	12.45	19.56	30.14	21.66	7.56	99.36
[illegible]	911.72	40.44	14.58	27.58	7.74	0.53	99.99
[illegible]	535.13	13.70	16.70	24.77	37.03	6.66	99.73
[illegible]	76.31	0.00	4.07	45.73	28.57	0.00	78.37
[illegible]	881.75	34.00	21.15	19.89	21.48	3.31	99.03
[illegible]	235.52	25.86	15.30	28.31	38.18	0.24	99.17
[illegible]	346.85	3.46	5.70	33.70	49.63	6.87	99.41
[illegible]	417.15	4.27	6.53	69.06	9.68	0.34	89.88
[illegible]	623.01	25.10	19.86	34.54	17.94	2.20	99.00
[illegible]	740.00	12.45	19.56	30.14	21.65	7.56	99.36
[illegible]	911.72	40.44	14.58	27.58	7.74	0.53	99.59
[illegible]	535.13	13.70	16.70	24.77	37.83	6.65	99.73
[illegible]	76.31	0.00	4.07	45.73	28.57	0.00	78.37

Sub-basin area in acres

Figure 3. SWMM Runoff Preprocessor (PreRun).

The power of the PreRUN preprocessor lies in its ability to import a GIS interface file. The GIS file contains land-use and soil classification data for user-delineated watershed subbasins; this information is used by PreRUN to develop area weighted calculations for the SWMM model.

PreWASP Interactive Preprocessor (PreWASP)

The PreWASP program (Figure 4) aids the user in the development of a WASP4 eutrophication input dataset. The preprocessor provides predefined environments (ponds, lakes, rivers, estuaries) that can be modified to match site-specific geometries, or the user may elect to build one from scratch. The PreWASP program allows the user to rapidly develop an input dataset by providing forms that can be filled out quickly using several "Quick Fill" edit functions. The PreWASP program allows the user to select the level of complexity at which to apply

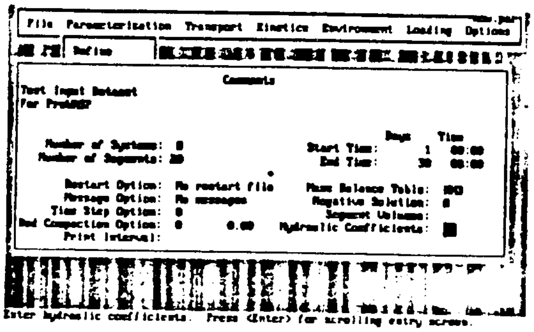


Figure 4. PreWASP Interactive Processor (PreWASP).

the model and provides data forms that are needed to accomplish that level of complexity.

Linked Water-Body/Watershed Postprocessor (LWDSPLY)

The interactive graphical postprocessor LWDSPLY allows the user to rapidly visualize the results of WASP, RIVMOD, DYNHYD, and SWMM simulations. LWDSPLY and SWISP are the only software needed to process the large array of result files that can be produced from simulations of the models contained in the LWWM. LWDSPLY allows the user to view the results both graphically and tabularly and has options for exporting data to spreadsheets. LWDSPLY has the capabilities to process more than one simulation result file at a time (the files must be from the same model), and allows the plotting of up to four graphs on the screen simultaneously. These four plots (view ports) can be manipulated individually to show different results. As with all the programs, context-sensitive help is available at any time within the program by simply pressing F1 for help or ALT-H for a listing of the keyboard map (Figure 5).

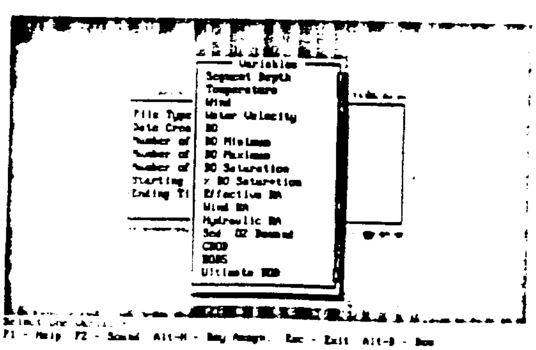


Figure 5. Linked Water-Body/Watershed Postprocessor (LWDSPLY).

The LWDSPLY program allows the user to view (Figure 6), plot, and export information very rapidly. All simulation results can be plotted or written to an ASCII text table or exported to a spreadsheet file. LWDSPLY also provides the algorithms for formatting the output of one model into the input of another.

Linking SWMM to WASP4

SWMM and WASP4 are linked using the LWDSPLY program. The linkage is generic and allows the user to link SWMM results to either the WASP organic or eutrophication model. This linkage is accomplished by creating a SWMM combine block interface using the ASCII combine block option. PreRUN is set to create this file by default. The user must select the WASP4 (TOXI or EUTRO) model with which the SWMM file is to be linked; this allows LWDSPLY to configure itself for the correct output.

Once the appropriate linkage type has been selected, the user is then required to map the appropriate SWMM conduit IDs to WASP segments (Figure 7). Note that you can map more than one conduit's ID to a WASP segment; LWDSPLY will combine the output. LWDSPLY will not check any errors regarding the mapping, so the burden is on the user to fill this table out correctly. The figure below shows the data entry screen for the basin to segment mapping. Note that all the conduit IDs do not need to be mapped out to WASP segments; the user only needs to be concerned with the conduits that affect the water body.

Once the conduit to segment mapping has been completed, the SWMM runoff constituents must be mapped to the WASP4 state variables. The user must map the SWMM state variables to the WASP state variables. The linkage allows the user to fractionate a SWMM state variable to several WASP state variables. The example given below shows the mapping of total nitrogen (calculated by SWMM) into three state variables of WASP's EUTRO4 (NH_3, NO_3, and organic nitrogen). To accomplish this, the user must specify the percentage of the total SWMM constituent runoff mass that will go into each WASP system. This option is presented to the user because SWMM typically calculates mass runoff for total nitrogen and total phosphorus, while WASP needs nitrogen loaded as ammonia, nitrate, and organic nitrogen, as well as phosphorus loaded as orthophosphate and organic phosphorus. There is no error checking done here. The percentages converted can be less than or greater than 100 percent.

When the user is completed with the mapping functions, LWDSPLY will prompt the user for a filename to which to write the nonpoint source interface file. WASP expects the nonpoint source files to have the extension .NPS.

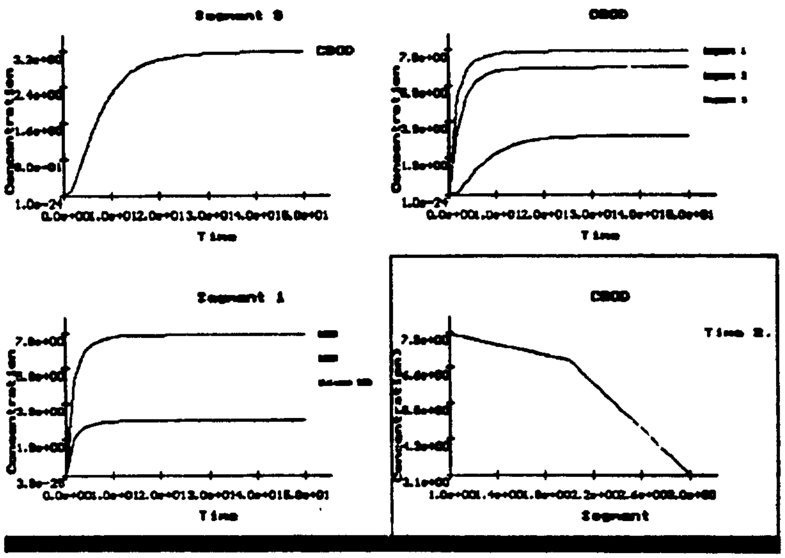


Figure 6. Viewing data in the LWDSPLY.

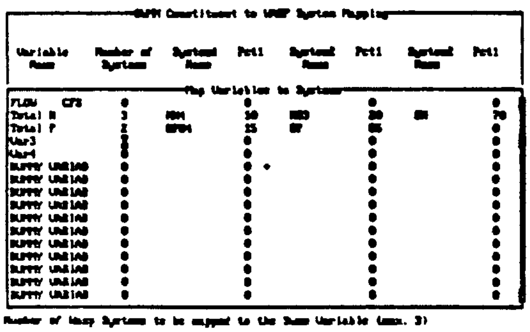


Figure 7. Mapping SWMM conduit IDs to WASP segments.

Model System Application—Lake Thonotosassa, Florida

Study Area Description

Lake Thonotosassa is located in northeast Hillsborough County, Florida (Figure 8). The lake has a surface area of 813 acres, with a maximum depth of approximately 16 feet. It is tributary to the Hillsborough river system, a source of water supply for Tampa, and a part of the Tampa Bay ecosystem providing freshwater to the estuary.

The watershed is approximately 55 square miles and extends east to Plant City and south to Sydney (Figure 8). Elevation in the watershed ranges from 35 ft National Geodetic Vertical Datum (NGVD) along the shoreline of the lake to 145 ft in the eastern section of the catchment. The area in general has relatively mild slopes but is steeper on the eastern section when compared with the southern and western sections. This lake was chosen in part due to the relatively large database available as a result of recently completed diagnostic/feasibility studies (6).

Modeling

Available data included topographic maps, land use, soils, rainfall, wind, solar radiation, water levels, and water quality. These data were utilized in the model setup and calibration processes. Modeling consisted of developing a database linkage from the GIS, watershed modeling with the SWMM model, and water-body modeling with RIVMOD and WASP4. The modeling scenarios are described below.

Digitized land use and soils data were obtained from the SWFWMD on magnetic tapes and downloaded to the Dames and Moore ARC/INFO system. Drainage divides that define subbasins were digitized as an additional overlay. These data provided the basis for developing the *.GDF file, which was linked with the SWMM model via the PRESWMM program package. These maps were directly output from the GIS. In addition, the GIS was used to provide aggregate maps for soils and land use.

The GIS identified 42 land uses at up to Level III for the watershed. SWMM is capable of utilizing five land uses in its watershed modeling. A decision was therefore made to aggregate land uses to provide five classes with similar characteristics. The classes selected were urban, agriculture, open, wetlands, and uplands. To maintain flexibility in redefining aggregates during the

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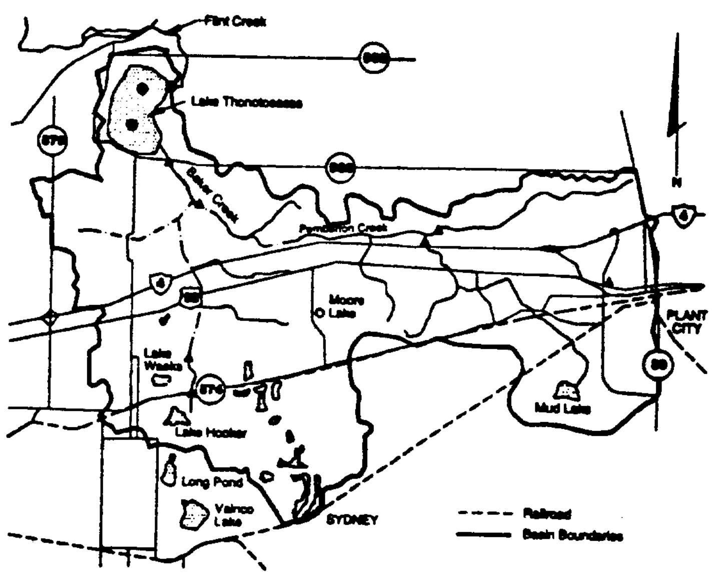

Figure 8. Lake Thonotosassa location map.

modeling process, the unaggregated GIS database served as model input to PRESWMM. PRESWMM then provided the aggregated land-use data for modeling purposes.

SCS soils data on the GIS are more detailed than required for modeling purposes. These data were aggregated in the GIS to provide mapping of hydrologic soil groups A, B, C, or D, as provided by the Hillsborough County soils map and document (7).

The SWMM model (RUNOFF block) was used to simulate both water quantity and water quality inflows to the lake. Before the input file was set up, the watershed was segmented into 34 subbasins. The subbasins were defined by examining topographic, land-use, and soils maps.

To set up SWMM, PRESWMM was used to create an input file consisting of information from the GIS system and user control input (UCI). The GIS system provided land-use and soils information, as previously discussed. These data served as input to PRESWMM, which created the input file for SWMM. In addition, UCIs were input into the PRESWMM interactive program. These UCIs include data on catchment slopes, overland Mannings roughness coefficient (n), evaporation, infiltration rates, basin widths, percent of directly connecting impervious area (DCIA), depression storage, channel slopes, channel lengths, channel geometry, and channel Mannings roughness coefficient (n). Channel basin linkages are also defined so that the model can route flows from the land segment to channels, and from channels to other channels.

After the model was set up, a data period was selected for calibration. The period was from June 11, 1991, to April 24, 1992, and was selected to coincide with available discharge measurement records. The model was calibrated by conducting a series of model runs, comparing simulated and measured data, and adjusting parameters.

The calibration was based primarily on data collected at two stations, LT-4 and LT-5. Station LT-5 is located on Pemberton Creek just upstream of the Baker Creek confluence, which represents 40 percent of the total watershed. The other calibration point is station LT-4, which covers 98 percent of the lake's watershed. The difference in flows between these stations is that contributed by Baker Creek draining the southern portion of the catchment. The final calibration plot for LT-4 is shown in Figure 9.

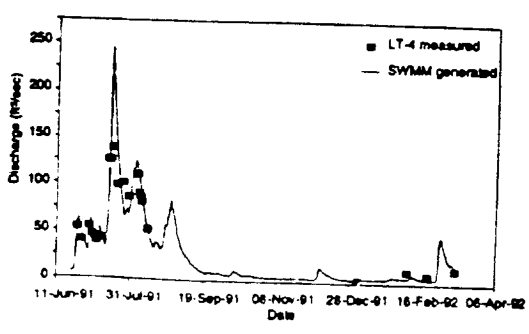

Figure 9. Lake inflow calibration.

The SWMM water quality setup used the same setup as for the water quantity except that coefficients that define buildup/washoff rates and rating curves were added to the routine. The calibration was performed by comparing water quality concentrations for measured and simulated total nitrogen and total phosphorus. The procedure was a sequence of model runs, comparing results, and adjusting parameters.

Water-Body Modeling

Water and pollutant loading inflows generated by SWMM were used as input to the lake, and the lake water quality was simulated. The following two models were used: 1) RIVMOD was used to simulate the dynamics of the inflows, outflows, and change storage in the lake, and 2) EUTRO4 used the simulated hydrodynamics and relevant quality parameters to simulate the lake's water quality.

Sources of pollutants to the lake were identified, with emphasis on nutrient loading. An in-lake model was applied by utilizing ambient water quality data and flows and pollutant loadings from the watershed to model current in-lake processes. The model was calibrated for nitrogen, phosphorus, and chlorophyll-*a*. WASP4 was the lake model used in simulating the in-lake processes.

The lake and inlet channel was subdivided into 10 segments. Four of the segments were in the inlet channel (Baker Creek). These segments were included to allow some flexibility in modification, if necessary, of the nutrient input to the lake during the lake water quality calibration process. The lake had six segments; this was believed to be adequate considering that there were only two water quality data collection stations. The final segment represents the lake outflow point. The segmentation is shown in Figure 10.

The eutrophication water quality model (EUTRO4) was set up as a system of 10 water column segments (Figure 10) to coincide with the hydrodynamic setup. Model time step was one day, with simulation for all eight systems of the WASP4 Intermediate Eutrophication Kinetics package. The eight systems are ammonia, nitrate+nitrate, orthophosphate, chlorophyll-*a*, biochemical oxygen demand, dissolved oxygen, organic nitrogen, and organic phosphorus. Water column segments interact with each other both by advective flows and diffusive exchange.

The SWMM model generated loads of total nitrogen, total phosphorus, and biochemical oxygen demand (BOD). For water quality modeling, data on nitrate-nitrate nitrogen, organic nitrogen, ammonia nitrogen, orthophosphate, and organic phosphorus were required. These constituents were estimated by applying stoichiometric ratios obtained from the data collected during the extensive data collection period. Loads of

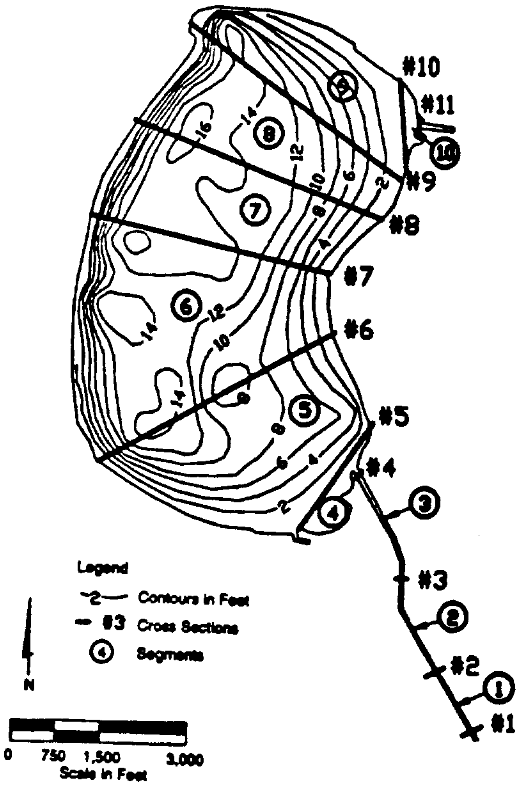

Figure 10. Lake Thonotosassa modeling segmentation and bathymetric map.

dissolved oxygen were also included in the model. These were obtained by applying monthly dissolved oxygen data to SWMM simulated flows.

Seven environmental parameters were included in the setup. The parameters defined values for salinity, segment temperature, ammonia flux, phosphate flux, and sediment oxygen demand. Salinity and temperature were derived from field measurements. Some of the constants associated with the environmental parameters were pointers used in combination with various time functions to define time series of water temperature, solar radiation, fraction daylight hours, and wind velocity. Time series of water temperature, solar radiation, and wind velocity were derived from the available data discussed above. Fraction of daylight hours was obtained from latitude-dependent information presented in Chow (8).

Initial constituent concentration was based on the measurements of June 26, 1991, and initial model time. Organic phosphorus was assumed to be the difference between total phosphorus and orthophosphate. It is recognized, however, that organic phosphorus may be overestimated because of particulate forms of inorganic

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phosphorus. Organic nitrogen was calculated from total Kjeldahl nitrogen and ammonia.

The model was set up with the constants required for eutrophication simulation. Values for these constants were derived primarily from the literature (9), although some field measurements were used as guidance to determine constants. These constants were primarily calibration factors.

Calibration was accomplished by adjusting constants within reasonable limits until a satisfactory fit between measured and simulated data was obtained (Figures 11 to 13). In some instances, although the model fit was by no means perfect, the model was considered calibrated within the constraints of the various estimates of inflows and environmental parameters. Constraints were associated with each of the eight systems in the eutrophication package: ammonia, nitrate-nitrate, orthophosphate, phytoplankton, BOD, dissolved oxygen, organic nitrogen, and organic phosphorus. Ammonia, nitrate-nitrate, and organic nitrogen are subsystems of the nitrogen cycle; orthophosphate and organic phosphorus are subsystems of the phosphorus cycle; and BOD and dissolved oxygen are subsystems of the dissolved oxygen balance. All systems interact.

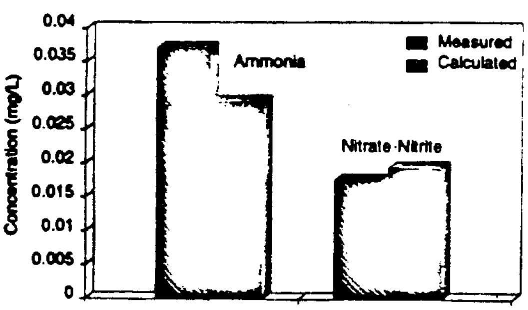

Figure 11. Ammonia and nitrate-nitrite calibration, Lake Thonotosassa.

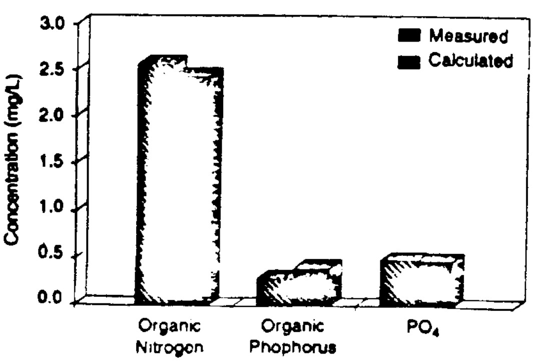

Figure 12. Organic nitrogen, organic phosphorus, and PO_4 calibration, Lake Thonotosassa.

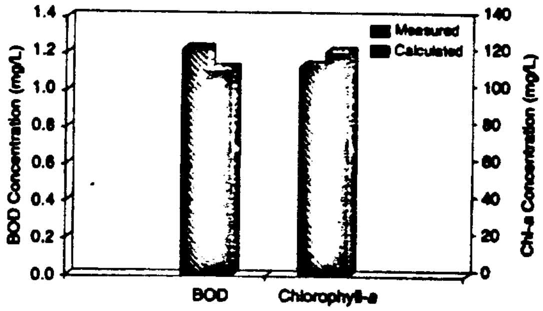

Figure 13. BOD and chlorophyll-a calibration, Lake Thonotosassa.

Summary

The development and model components of the LWWM system and its user environment, SWISP, have been described. The LWWM has been applied to Lake Thonotosassa and its watershed. Water quantity and quality originating from the watershed were modeled as pollutant loading to the lake. In-lake processes were then simulated. Refinements are being made to the LWWM system in anticipation of project completion in September 1993. The resultant modeling system will be tested on two other systems, one a river flowing into an estuary (i.e., Little Manatee) and one a series of 19 interconnected lakes (i.e., the Winter Haven chain of lakes). It is anticipated that the resultant modeling system will become the district standard for eutrophication modeling of its surface water bodies. The final code and user's manual for SWISP will be public domain, and it is hoped that this modeling system will be used by other water resource managers in developing pollutant load reduction strategies for their water bodies.

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AUTO_QI: An Urban Runoff Quality/Quantity Model With a GIS Interface

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Abstract

This paper describes the development and application of the AUTO_QI model, which the authors developed at the Illinois State Water Survey in Champaign, Illinois. The paper includes background information on the Illinois Urban Drainage Area Simulator (ILLUDAS), on which AUTO_QI is hydrologically based. AUTO_QI stands for AUTOmated Quality-ILLUDAS. The model is automated in the sense that it includes an optional geographic information system (GIS) interface using ARC/INFO software. The Quality-ILLUDAS portion of the name indicates that the model simulates quality as well as quantity of runoff from an urban area.

AUTO_QI uses a continuous simulation of soil moisture to provide reliable estimates of antecedent moisture conditions for the simulation of selected runoff events. The soil moisture simulation requires a continuous precipitation record for the period of interest. The user may then specify some base rainfall above which the runoff volume and pollutant loading are then simulated for each event in the record. The resulting series of runoff volumes or pollutant loadings may then undergo statistical analysis. For each catchment in the study area, the user must provide soils and land cover information as well as buildup and washoff factors for each pollutant of interest. The model can simulate multiple drainage outfall points for a given rainfall record and group the results for different receiving waters. The user may incorporate specific best management practices (BMPs) into the simulation for comparison of loadings with and without BMPs. The paper also discusses use of the GIS interface including processing of remotely sensed data.

Introduction

Models for simulation of urban runoff hydrographs such as the Illinois Urban Drainage Area Simulator (ILLUDAS) (1), Stormwater Management Model (SWMM) (2, 3), and Storage, Treatment, Overflow, Runoff Model (STORM) (4) have been used for some time. Their wide usage reflects their reliability for stormwater drainage design. Models that incorporate urban runoff water quality are available but are less common. The main reasons for this are:

- The water quality component is less reliable.
- The models require extensive input data.
- The models lack verification.

The relatively infrequent use of a water quality component is unfortunate because urban water quality modeling is a convenient tool for assessing pollutant loadings. Considering the high cost of monitoring and the lack of extensive data for using a statistical approach, the proper model with field data verification is a logical and feasible method for water quality assessments.

The principal investigators have developed an approach (5) that greatly reduces the cost of applying a deterministic model Q-ILLUDAS (6) to a relatively large area. This approach incorporates the ARC/INFO geographic information system (GIS) for data management. The savings comes from automation of input files. Readily available automated data include the U.S. Geological Survey (USGS) LUDA Level II land use data and the U.S. Census Bureau's DIME or TIGER/LINE file for population, housing, and street density. The streams, soils, and other data are also available in the Illinois and other state and federal GIS databases. This method is very effective for simulating regional urban runoff loadings that involve large databases and multiple outfalls. The model and GIS interface are known as AUTO_QI.

Literature Review

Shaw (7) describes the special hydrologic problems of urban runoff as follows. The problem of estimating runoff from storm rainfall depends on the character of the catchment surface. The degree of urbanization (extent of impervious area) greatly affects the volume of runoff obtained from a given rainfall. Retention of rainfall by initial wetting of surfaces and absorption by vegetation and pervious areas reduces the amount of storm runoff. These surface conditions also affect the time distribution of the runoff. Computational methods used to obtain runoff from the rainfall should allow for the characteristics of the surface area to be drained. Thus, the first efforts in urban runoff modeling were to relate runoff from storm rainfall to the catchment characteristics.

The first stormwater sewer design method was the rational method by Kuchling (8). Sherman (9) introduced the unit hydrograph method. After the development of digital computers, early urban hydrologic models were developed, such as those by James (10), Papadakis and Preul (11), Terstriep and Stall (1), and McPherson and Schneider (12). One characteristic of urban runoff is that during the early minutes of a storm, urban runoff mainly derives from the impervious surfaces. Contributions from the pervious portion of the basin are highly variable and more difficult to define. Other research results may be found in Novotny and Chesters (13), Hann et al. (14), and Shaw (7).

Many conducted early urban runoff water quality modeling research, including Sartor and Boyd (15), Hydrologic Engineering Center (4), McPherson (16), Sutherland and McCuen (17), U.S. EPA (18-20), and Noel and Terstriep (6). Donigian and Huber (21) prepared a comprehensive review of modeling of nonpoint source water quality in urban and nonurban areas. Other reviews that consider surface runoff quality models include Feldman (22), Huber and Heaney (23), Kibler (24), Whipple et al. (25), Barnwel (26, 27), Huber (28, 29), Bedient and Huber (30), and Viessman et al. (31).

Table 1. Urban Runoff Quality Model

Model	Authors	Year
QUAL-II	Hydrologic Engineering Center	1975
SWMM	Huber et al.	1975
STORM	Hydrologic Engineering Center	1977
MUNP	Sutherland and McCuen	1978
Q-ILLUDAS	Noel and Terstriep	1982
QQS	Geiger and Dorsh	1980
HSPF	Johanason et al.	1980

Table 1 shows a partial list of urban water quality models.

For a detailed description of each of the models, the reader may review the respective references. This section will limit its discussion to the deposition and accumulation of pollutants on impervious surfaces and removal of solids from the street surface.

As reported by Sonnen (32), the state of the mathematical urban water quality model was fairly dismal a decade ago. Little has changed since then because the physical processes are so complex that they defy efforts to reduce them to mathematical statements. Consequently, semiempirical methods are often used.

Deposition and Accumulation of Pollutants on Impervious Surfaces

As described by Novotny and Chesters (13), the primary sources of pollutants are wet and dry atmospheric deposition, litter, and traffic. Pollutants deposited on the surface during a dry period can be carried by wind and traffic and accumulate near the curb or median barrier. Thus, many studies report the street pollutant loading by unit length of curb.

The street refuse that runoff washes to storm sewers contains many contaminants. Significant amounts of organics, heavy metals, pesticides, and bacteria are commonly associated with street refuse. Factors that affect the pollutant accumulation rates are atmospheric fallout, wind, traffic, litter deposition, vegetation, and particle size distribution.

Pollutant accumulation in an urban area has a significant random component; thus, no mathematical model yields totally reliable results. Consequently, one common concept used is the storage-input-output schematic approach, which assumes that the amount of accumulated pollutants on a surface can be described as a simple mass balance formula:

$$dP/dt = A - r \qquad \text{(Eq. 1)}$$

where

A = pollutant accumulation rate (lb/day)
r = pollutant removal rate (lb/day)
P = amount of street refuse or dust/dirt present on the street (lb)
t = time in days

Integrating Equation 1, then:

$$P = A/r\ [1 - \exp(-rt)] + C \qquad \text{(Eq. 2)}$$

where

exp = exponential function
C = undefined constant

Using the empirical data from U.S. EPA (33), the parameters were defined for the Washington, DC, area as follows:

$$A = (ATMFL + LIT)\ (SW/2) + 1.15\ TD$$

$$r = 0.00116 \exp [0.0884 (TS + WS)]$$
$$C = 0$$

where

ATMFL = atmospheric fallout rate (g/m^2/day)
LIT = litter deposition rate (g/m^2/day)
SW = street width (m)
TD = traffic density (thousand axles/day)
TS = traffic speed (km/hr)
WS = wind speed (km/hr)

Sutherland and McCuen (17) made another attempt by developing a set of refuse accumulation functions using average daily traffic volume and pavement condition expressed by the present serviceability index (PSI). The results are a set of accumulation equations in terms of these input factors.

The accumulation of street refuse is the main pollution source in urban areas. Novotny and Chesters (13) reported on typical urban street refuse. Table 2 also presents findings from research on this topic.

The Chicago results indicate that multiple-family areas generate about three times more street dirt than single-family areas. The commercial and industrial areas generate about five and seven times more than the single-family areas.

The street refuse accumulation rate based on the eight American cities (15, 35) is two to four times higher than the Chicago dust/dirt accumulation rate. This reflects the wide variations in pollutant accumulation rates in existing measured field data for different cities.

Refuse Washoff by Surface Runoff

When surface runoff occurs on impervious surfaces, the splashing effect of rain droplets and the drag forces of the flow put particles in motion. Sedimentation literature includes many hydraulic models that are potentially applicable to the problem of particle suspension and transport. Two models used frequently in urban runoff modeling are described below.

Yalin Equation

Of numerous equations published in the literature, the Yalin equation (36) is probably one of the best for describing suspension and transport of particles by shallow flow typical for rills and street gutters. The equation has been reported in the following form:

$$p = 0.635\, s\, [1 - \ln (1 + as) / (as)] \qquad \text{(Eq. 3)}$$

where

p = particle transport per unit width of flow (g/m/sec)
$s = (Y/Ycr) - 1$
$a = 2.45 r_s^{-0.4} \sqrt{Ycr}$
ln = natural log function

The variables are defined as follows:

$$Y = \text{particle bed load tractive force} = \frac{\mu^*}{[(\rho_s - 1)gD]}$$

ρ_s = particle density (g/c-cm^3)
Ycr = the critical tractive force at which sediment movement begins (newton/m^2)
D = particle diameter (m)
μ^* = sheer velocity (m/sec)
g = gravity acceleration (m/sec^2)

Based on Yalin's equation, Sutherland and McCuen (17) developed a washoff model. The model is based on the relationship between percentage removal of total solids in a particle range (0.001 to 1.0 mm) due to a total rainfall volume of 1/2 in. and correlation factor Kj such that

$$TSj = Kj\ (TSi) \qquad \text{(Eq. 4)}$$

where

TSj = percentage removal of total solids in a particle range due to total rainfall volume j, measured in mm

Table 2. Street Refuse Accumulation

	Solids Accumulation			
	Chicago (34) Dust and Dirt		Eight American Cities (15, 35) Total Solids	
Land Use	g/curb miles/day	lb/acre/day	g/curb miles/day	lb/acre/day
Single family	10.4	2.1[a]	48	9.5[a]
Multiple family	34.2	6.8[a]	66	13.1[a]
Commercial	49.1	9.7[a]	69	13.7[a]
Industrial	68.4	13.5[a]	127	25.1[a]

[a]The curb density in Chicago and eight American cities was assumed by the authors to be 90 m/acre.

Kj = factor relating TSj and TSi
TS = percentage removal of total solids in the particle range due to a total rainfall of 1/2 in.

Sartor et al. Washoff Function

The Sartor et al. washoff function is based on the first-order washoff function (15, 35):

$$dP/dt = - Ku\ r\ P \qquad \text{(Eq. 5)}$$

where

P = amount of solids remaining in pounds
t = time in days
Ku = constant depending on street surface characteristics (called urban washoff coefficient)
r = rainfall intensity (in./hr)

The constant Ku was found independent of particle size within the studied range of 10 to 1,000 µm. The integrated form of the equation can be expressed as:

$$P_t = P_o\ [1 - \exp(-Ku\ r\ t)] \qquad \text{(Eq. 6)}$$

where

P_o = initial mass of solids in the curb storage
P_t = mass of material removed by rain with duration t
exp = exponential function

In spite of the Sartor concept's highly empirical nature and arbitrarily chosen constants, many urban runoff models such as SWMM (2, 3) and STORM (4) have incorporated it.

AUTO_QI Model

Model Overview

AUTO_QI actually comprises three programs known as HYDRO, LOAD, and BMP. These programs run in series, each using output from the previous program as input along with additional information from the user. HYDRO performs a continuous simulation of soil moisture based on a daily and hourly rainfall record that the user provides. It also computes runoff volume for each event above some user-specified rainfall amount. LOAD uses these runoff volumes along with additional pollutant accumulation and washoff information to calculate pollutant loadings for each runoff event. The BMP program then reduces these loadings in accordance with user-specified best management practices (BMPs) and reports the results both with and without BMP conditions. The simulation process may be examined by looking at wet and dry periods.

Runoff

Runoff may only occur during a "wet period," a day during which rainfall occurs. During these potential runoff periods, the model requires hourly rainfall amounts. The basin is assumed to have three types of area: directly connected paved area, supplemental paved area, and contributing grassed area. As the name implies, runoff from the directly connected paved area flows directly to the storm system. Runoff from the supplemental paved area flows first across the grassed area and is thus subjected to infiltration losses. The remainder of the basin is assumed to be grassed area, so all rain falling on this surface is also subjected to infiltration losses.

Paved Area Runoff

The model distinguishes between directly connected paved area and supplemental paved area. The losses from directly connected paved area consist of initial wetting and depression storage. These losses are combined and treated as an initial loss; they are subtracted from the beginning of the rainfall pattern. After subtracting these losses from the rainfall pattern, the remainder of the rainfall appears as effective rainfall and thereby as runoff from the paved area.

Grassed Area Runoff

Computation of grassed area runoff includes runoff from the supplemental paved area because both are subjected to infiltration. As in the case of paved area runoff, rainfall is the primary input for grassed area runoff calculations. The modifications that must change the rainfall pattern to grassed area runoff are much more complex than in the paved area case. The procedure followed here first adds in supplemental paved area runoff, then subtracts initial and infiltration losses.

In this model, rainfall on the supplemental paved area is simply distributed by linear weighting over the entire grassed area, thereby modifying the actual rainfall for grassed areas such that:

$$R' = R\ (1.0 + SPA/CGA) \qquad \text{(Eq. 7)}$$

where

R′ = effective rainfall on the grassed area
R = actual rainfall
SPA = supplemental paved area
CGA = contributing grassed area

In an urban basin, bluegrass turf most often covers the area that is not paved. When rain falls on this turf, there are two principal losses. The first is associated with depression storage and the second with infiltration into the soil. In this model, depression storage fills and maintains, and infiltration is satisfied before any runoff takes place. Depression storage is normally considered to be 0.20 in., but the model provides for this to be varied.

The dominant and far more complex loss of rainfall on grassed areas is caused by infiltration. The theoretical approach to evaluating infiltration rates uses the physical properties of the soil to estimate the water storage available in the soil mantle, and evaluates the role of this water storage as rain water infiltrates into and through the soil mantle. The original ILLUDAS manual provides details of water storage in soil and infiltration rates through soil. The following text offers only brief descriptions.

Water Storage in Soil

The amount of water that the soil mantle can store depends on the total pore space available in the soil between the soil particles. This model divides the total water stored in the soil mantle into two principal parts. The first of these is gravitational water. This is the water that will drain out of soil by gravity. The second is evapotranspiration (ET) water. This is the water that plants can remove through evapotranspiration.

Soil moisture storage capacity varies with soil type and may be classed by hydrologic soil group. This model considers seven hydrologic soil groups. The U.S. Soil Conservation Service describes the hydrologic soil groups as follows:

- A = low runoff potential and high infiltration rate (consists of sand and gravel)
- AB = soil having properties between soil types A and B
- B = moderate infiltration rate and moderately well drained
- BC = soil having properties between soil types B and C
- C = slow infiltration rate (may have a layer that impedes downward movement of water)
- CD = soil having properties between soil types C and D
- D = high runoff potential and very slow infiltration rate (consists of clays with a permanent high water table and high swelling potential)

Appendix B supplies default values of soil moisture storage capacity for different soil types. Users can change these values to suit their own experience. For further references, see Eagleson (37) and Richey (38).

Infiltration Rate

Knowing the water storage available for infiltration within a soil mantle makes it possible to compute the infiltration rate at any time from the Horton equation, as given by Chow (39):

$$f = f_c + (f_0 - f_c)\exp(-kt) \qquad \text{(Eq. 8)}$$

where

f_c = final infiltration rate (in./hr)
f_0 = initial infiltration rate (in./hr)
k = shape factor
t = time from start of rainfall (hr)
exp = exponential function

This equation is solved by the Newton-Raphson technique for given f_c and f_0 values that depend on soil properties supplied by the user. A shape factor (k) of 2 was used to provide the shape best reflecting natural conditions.

The total amount of infiltration during a storm event depends on the total amount of soil moisture (ET water and gravitational water) in storage. The higher the amount of available soil moisture, the lower the amount of infiltration, and vice versa. This model distributes the total amount of infiltration among ET storage and gravitational storage in a preassigned 60:40 ratio. AUTO_QI continuously simulates soil moisture so that a reliable soil moisture is available at the beginning of any event.

During dry periods, the model operates on two different time steps: daily if there is no rainfall on the current day and hourly if there is rainfall at some time during the current day. During dry periods, depression storage and soil moisture depend on:

- Evaporation, at a user supplied rate, from depression storage.
- Infiltration from depression storage, with the infiltration volume separated in a 60:40 ratio into ET water and gravitational water.
- Evapotranspiration, at a user specified rate, from ET water storage.
- Percolation, at a constant rate f_c, from gravitational water storage.

Spatial Distribution of Runoff Processes

The model assumes all of the wet period and dry period processes are spatially distributed, and simulates by the use of a triangular distribution. Figure 1(a) shows a distribution assumed to vary linearly from zero to twice

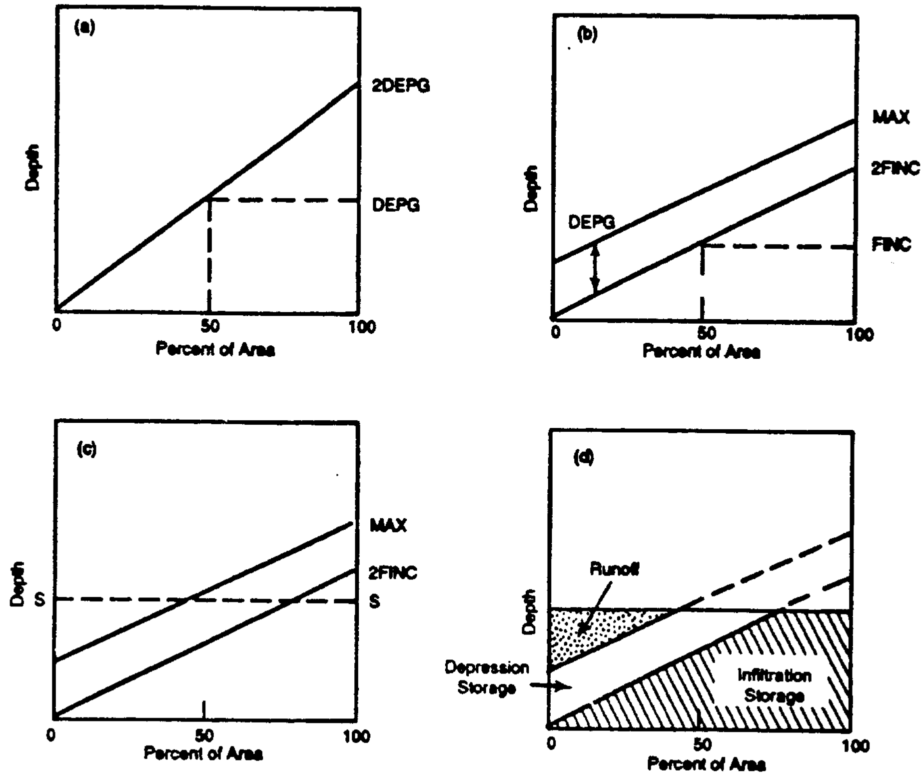

Figure 1. Triangular spatial distribution of runoff.

the user-specified mean value over the subcatchment area. DEPG, as an example, is the mean pervious depression storage. Figure 1(b) shows the concurrent processing of depression storage and infiltration potential. Although both filling of depression storage and infiltration are assumed to be spatially distributed, they are also assumed to be totally independent of one another physically. Depression storage may therefore have a uniform distribution with respect to infiltration potential.

The concurrent processing of infiltration and depression storage, Figures 1(c) and 1(d), assumes that infiltration potential varying from zero to 2FINC is satisfied for a particular level of supply, S, before considering depression storage. The supply rate S is defined as the sum of the rainfall and the uniformly distributed volume of depression storage at the start of the interval. The volume below S and between curves 2FINC and MAX represents the moisture supply to depression storage in the interval and is processed according to the above discussion of Figures 1(a) and 1(b). The volume remaining below S and above the curve bounded by MAX is the surface runoff volume for the hour.

Pollutant Generation

After generating an effective hyetograph for both pervious and impervious areas, these rainfall depths are supplied as input to the program LOAD. LOAD then generates the washoff of different pollutants from the storm event. LOAD uses linear accumulation and exponential washoff equations. The user supplies the number of pollutants and associated characteristics such as daily accumulation rate and daily removal rate.

Dry Periods

One form of mass balance formula in discrete form is the linear accumulation equation, which generates the antecedent pollutant load at the beginning of an event as follows:

$$P_t = P_{t-1} (1-r) + A \qquad \text{(Eq. 9)}$$

where

P_{t-1} = initial load at time t-1

P_t = load at time t
r = background removal rate
A = daily accumulation rate

Wet Periods

At the start of rainfall, the amount of a particular pollutant on a surface that produces runoff will be Po, in lb/acre. Assuming that the pounds of pollutant washed off in any time interval, dt, are proportional to the pounds remaining on the ground, P, the first order differential equation is:

$$-dP/dt = kP \quad \text{(Eq. 10)}$$

When integrated, this converts into the exponential washoff function for the removal of the surface loads as follows:

$$P_0 - P = P_0(1 - \exp(-kt)) \quad \text{(Eq. 11)}$$

where

$P_0 - P$ = washoff load (lb/acre)
k = proportionality constant
t = storm duration in hours

To determine k, the model uses the same assumption as the SWMM model. Therefore, k varies in direct proportion to the rate of runoff such that:

$$k = iB$$

where

i = runoff (in./hr)
B = constant

To determine B, it was assumed that a uniform runoff of 1/2 in./hr would wash away 90 percent of the pollutant from paved areas and 50 percent of the pollutant from grassed areas in 1 hour. That leads to a value for B of 4.6 for paved areas and 1.4 for grassed areas. These are default values that the user can modify.

To find the washoff load, apply each constituent's loading parameters to the buildup function to determine the initial load (by land use). Then apply the exponential washoff equation for impervious and pervious areas. The event mean concentration (EMC) is determined by dividing the total washoff loads by the runoff volume for each land use.

Best Management Practices

BMPs are the measures implemented to reduce pollutants from source areas, or in streams and receiving waters. Many factors govern BMP pollutant removal ability. Schueler (40) outlined three primary interrelated factors:

- The removal mechanisms used.
- The fraction of the annual runoff volume that is efficiently treated.
- The nature of urban pollutants being removed.

The AUTO_QI model does not model specific BMP processes but represents the effectiveness of BMPs by a removal efficiency factor. The model can handle one or more BMPs in a catchment or portion of a catchment. The pollutant removal factor may be inferred from field performance monitoring, laboratory experiments, modeling analyses, or theoretical considerations. Most model users, however, must rely on literature values as a starting point.

The particulate related pollutants, such as sediment and lead, are relatively easy to remove by common removal mechanisms, such as settling. Soluble pollutants, such as nutrients, are much more difficult to remove. The settling mechanism has little or no effect on these pollutants. Therefore, biological mechanisms, such as uptake by bacteria, algae, rooted aquatic plants, or terrestrial vegetation, are often used. A detailed description of individual BMPs can be found in Schueler (40) and Novotny and Chesters (13).

The model allows users to test the potential enhancement of water quality by implementing one or more BMPs in a catchment or group of catchments. The user specifies what portion, in percent, of a catchment the desired BMPs will affect and the removal efficiency of the BMPs. The model output lists the load and EMC without BMPs, followed by the load and EMC expected with BMPs. The user may apply this same procedure to reflect existing conditions if one or more BMPs are already in place.

Data Preparation

Interfacing the GIS Database and AUTO_QI

Urban runoff quantity and quality are highly dependent on the land use and hydrologic soil type. To tabulate the land use/soil complex for a large basin is a time-consuming process. To simplify the data collecting process, an optional ARC Macro Language (AML) program was developed to retrieve the land use/soil layers in a format suitable for model input.

The AML includes a menu-driven data review feature with two windows on the screen. The right window displays an index map of the whole drainage basin and the subbasin boundaries. The user can select a subbasin and display the land use, soil layers, streets, and storm sewers. If the user wants the land-use input file of a specific subbasin, the AML retrieves the attribute data and generates an ASCII file for the model input.

AML Programs

The AML programs link and provide the user interface between the GIS, which runs on a PRIME, and the AUTO_QI program, which runs on a PC. These programs process the data that AUTO_QI uses and also enable the user to view the graphic data at the subbasin level via a menu. The programs should be used with ESRI's ARC/INFO software on a PRIME computer and are grouped into two functions: the preprocessor programs and the menu system programs. PREPROCESSORLANDSOIL.AML, PREPROCESSORBMP.AML, and RUNIT.AML are the names of the three main programs.

PREPROCESSORLANDSOIL.AML uses the soil, land use, and BMP coverages to create a soil/land-use file for input to the AUTO_QI model. PREPROCESSORBMP.AML uses land-use and BMP coverages to create BMP application files for the AUTO_QI model. RUNIT.AML accesses the ARC/INFO menu system to view the coverages and INFO data. This menu also allows the user to choose and view individual subbasins and their data layers.

GIS Database Layers

Soil Layer

In 1985, funding from the Illinois Department of Mines and Minerals (IDMM) allowed for the digitization of the statewide "General Soil Map of Illinois" for the Illinois GIS system. This map contains 57 general soil associations in Illinois. The attribute data include the soil surface color, surface code, and the hydrologic class (well drained, moderately well drained, somewhat well drained, and poorly drained). The AUTO_QI model needs this hydrologic soil classification for hydrologic modeling. The source map scale for the soil associations is 1:500,000.

Land Use Layer

The statewide land-use maps are available from the U.S. Geographical Survey LUDA digital database (41). The land uses are classified based on LUDA Level II, which contains 37 land-use categories (Appendix D). Digital Landsat image data or scanning aerial photographs have updated land-use/cover information (42-44). The Illinois State Water Survey has developed image analysis capability using the ERDAS image processing package (45). The results of a classified land use can easily be transferred to the ARC/INFO system.

Street Layer (DIME file/TIGER/LINE file)

Either the 1980 DIME file or the 1990 TIGER/LINE file, which were created by the U.S. Census Bureau, can provide the street coverage. The DIME and TIGER/LINE files comprise street segment records. A segment is defined as the length of a street feature between two distinct vertices or nodes. Other features are political boundaries and topologic features (e.g., rivers, shorelines, canals, railroads, airports). Additional demographic information is also available in the attribute data. This includes state, county, and standard metropolitan statistical area codes, aggregate family income, aggregate rental cost for occupied dwelling units, and numerous other demographic statistics. The data can be plotted by census tract. The source map scale is 1:100,000. The street layer is valuable for estimating the pollutant accumulation rate and the imperviousness of the drainage basin.

Sewer Network

The database may also include an automated storm sewer network. The AML menu system provides for this coverage. The coverage is not required by the AML, however, and is not needed by AUTO_QI.

Model Verification

Overview

Due to the lack of observed data in the Lake Calumet area, the AUTO_QI model was verified by using the Boneyard Creek Basin in Champaign-Urbana, Illinois. The USGS has continuously gauged this station since 1948. The watershed area was reduced from 4.7 to 3.6 square miles in 1960 by a diversion. The basin contains a portion of Urbana, the commercial center of Champaign, and the University of Illinois campus. The central business district of Champaign makes up 7.5 percent of the drainage area and is nearly 100 percent impervious. Other city properties, including predominantly residential along with some commercial and light industrial, constitute an additional 81.2 percent of the basin. The remaining 11.3 percent of the basin is in parks, open space, and other land-use classes. Measurements have found the basin to be approximately 44 percent total paved area, which includes approximately 24 percent of direct connected paved area, 13 percent of supplemental paved area, and 7 percent of nonconnected paved area. The soils of the basin are predominantly Flanigan silt loam of hydrologic class B (8).

Runoff Simulation

For runoff simulation, rainfall data for 3 years were chosen. These years represent low (25 percent), average (50 percent), and high (75 percent) annual exceedence of rainfall. Table 3 displays these data.

Land uses in the basin were simplified into two categories. Table 4 lists the land-use parameters for these categories which were used to verify the model.

Table 3. Selected Years and Total Annual Rainfall

Year	Total Rainfall (in.)	Chance of Exceedence (percent)	Comments
1959	35.94	50	Average year
1976	32.63	75	Dry year
1977	42.44	25	Wet year

Table 4. Land-Use Parameters

Land Use	USGS Land Use Level 2 Code	% PA	% SPA	DEPI (in.)	DEPG (in.)
Residential	11	15	20	0.1	0.1
Commercial	12	90	5	0.1	0.1

% PA = paved area in percent
% SPA = supplemental paved area in percent
DEPI = impervious depression storage depth
DEPG = pervious depression storage depth

Results of Runoff Simulation

The events selected allowed the actual event runoff volume to be distinguished with reasonable confidence from the continuous runoff data. Table 5 presents the actual events for the "average year" of 1959.

Figure 2 shows that AUTO-QI does an acceptable job of reproducing runoff volumes for dry, average, and wet years. The simulated runoff/rainfall ratio for these 3 years is approximately 20 percent, which is consistent with the observed data and with what has been found previously (1).

Water Quality Simulation

Water quality data for Boneyard Creek were available for eight events in 1982 from a study by Bender et al. (46). Simulated water quality data were compared with those 1982 data.

Water Quality Parameters

Table 6 tabulates the pollutant accumulation/decay parameters required by the model and used in this study.

The accumulation rate and removal rate were selected based on typical Midwest urban runoff basins. No attempt was made to adjust these parameters to fit the observed data.

Table 7 tabulates the comparisons between simulated washoff and actual washoff of total suspended solids (TSS), phosphorus (P), and lead (Pb). The results of this verification are disappointing. They demonstrate, however, the problems of water quality simulation without verification and calibration data. The buildup and washoff factors in the model could be adjusted to "calibrate" the model to this data set and produce better results, but that was not the intent here.

Table 6. Water Quality Parameters

	ARi (lb/acre/day)	ARp (lb/acre/day)	RRi (%)	RRp (%)
For residential land use:				
Suspended solids	7.6300	3.9900	4.50	4.50
Phosphorus	0.0138	0.0070	6.00	5.00
Lead	0.0100	0.0053	6.00	5.00
For commercial land use:				
Suspended solids	9.5500	5.5500	3.00	4.50
Phosphorus	0.0100	0.0053	4.50	4.50
Lead	0.0110	0.0060	6.00	5.00

ARi = Accumulation rate for impervious area
ARp = Accumulation rate for pervious area
RRi = Removal rate for impervious area
RR = Removal rate for pervious area

Table 5. Summary of Runoff Simulation for Selected Events in 1959

Date	Dry Days	Rainfall (in.)	Event Duration (hr)	Observed Runoff (in.)	Simulated Runoff (in.)	Simulated Grass Runoff (%)
7/23/59	3.21	0.51	6.00	0.07	0.08	3
7/27/59	3.17	0.80	5.00	0.15	0.16	4
8/29/59	6.00	0.23	5.00	0.02	0.03	3
9/01/59	2.63	0.39	6.00	0.035	0.07	1
9/09/59	8.00	0.18	2.00	0.024	0.02	2
10/10/59	3.63	2.52	9.00	0.51	0.60	7
11/04/59	0.08	0.82	8.00	0.185	0.19	4
11/13/59	0.13	1.39	23.00	0.32	0.31	2
12/10/59	5.67	0.68	15.00	0.106	0.11	1

Summary

A new comprehensive computer package was developed on the basis of two proven models for urban water quantity/quality assessment, ILLUDAS and Q-ILLUDAS. The package consists of three main parts:

- Water quantity/quality model, called AUTO_QI.
- A convenient menu system called QIMENU for preparing and editing inputs, viewing the outputs, running the model, and assisting users.
- A GIS interface called RUNIT, and other GIS processing programs.

The AUTO_QI model, which provides continuous simulation, consists of three main components: HYDRO, LOAD, and BMP. HYDRO uses a runoff/soil moisture accounting procedure, pervious and impervious depression storage, interception, Horton infiltration curves, and water storage in the soils to generate runoff volumes for each event in the record. LOAD is the water quality simulator that uses the output from HYDRO along with the pollutant accumulation and exponent washoff functions to generate loads and EMCs. BMP is the best management practices simulator that handles numerous separate or overlapping BMPs and produces the model output. The user may simulate the impacts of pollution reduction at multiple stormwater outfall points. The results can be viewed at one outfall point or multiple outfall points.

QIMENU aids users with preparation of input files, selection of parameters, running the model, testing the BMPs, and viewing the output.

The GIS interface uses the AML and automates the generation of the major input files for AUTO_QI. It also provides the user with a menu-driven program to review GIS coverages on the screen.

The model was verified by using data from the Boneyard Creek drainage basin in Urbana, Illinois. The three sets of rainfall data selected represent wet, average, and dry years. The input data consist of daily and hourly rainfalls, percent impervious and supplemental paved areas, depression storage, initial and final infiltration rates, gravitational and evapotranspiration soil storage, pollution accumulation and removal rate, and washoff factor. When comparing the outputs with the observed data for the Boneyard Creek basin, the results indicated that the model performed well for runoff volume. The simulations of pollutant loadings using the uncalibrated model were poor and indicate the need for further testing and calibration.

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The principal investigators of this report were Michael L. Terstriep and Ming T. Lee. Thomas Davenport, EPA Regional Nonpoint Source Coordinator, reviewed the early versions of this report and provided a number of helpful comments and suggestions. Douglas Noel developed the program for the original Q-ILLUDAS model, consulted on this project, and provided a general outline for the revised computer program. M. Razeur Rahman wrote the LOAD and BMP portion of the model. Evan P. Mills wrote the menu-driven program QIMENU for handling the inputs and outputs. Amelia V. Greene wrote the AML program for the GIS interface. John Brother prepared the graphical work.

Table 7. Washoff Load Simulation for Selected Events of 1982

			TSS		Phosphorus		Lead	
Date	Rainfall (in.)	Runoff (in.)	Sim. (lb)	Obs. (lb)	Sim. (lb)	Obs. (lb)	Sim. (lb)	Obs. (lb)
3/19/82	0.52	0.08	12,312	18,777	18	18	15	11
4/02/82	0.66	0.11	6,954	89,179	10	75	8	77
4/15/82	0.12	0.01	2,388	3,332	10	7	3	4
4/16/82	0.60	0.10	19,549	52,087	28	46	23	48
5/15/82	0.43	0.07	25,409	25,857	36	29	29	15
6/15/82	1.17	0.21	3,302	30,969	5	48	5	35
6/28/82	0.98	0.16	29,808	22,931	43	31	35	5
7/18/82	1.14	0.30	5,070	19,001	8	26	6	11

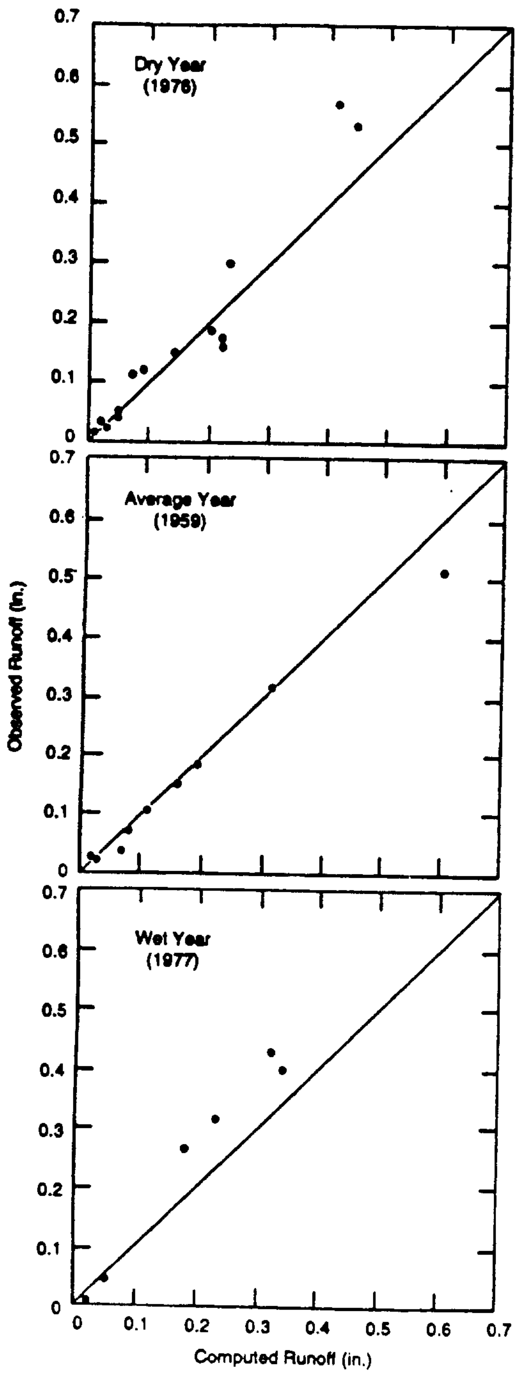

Figure 2. Comparison of observed and computed event runoff volumes in Boneyard Creek basin, Champaign-Urbana, Illinois.

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Source Loading and Management Model (SLAMM)

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Introduction

The Source Loading and Management Model (SLAMM) was developed to more efficiently evaluate stormwater control practices. It soon became evident that to accurately evaluate the effectiveness of stormwater controls at an outfall, the sources of the pollutants, or problem water flows, must be known. SLAMM has evolved to include a variety of source area and end-of-pipe controls and the ability to predict the concentrations and loadings of many different pollutants from many potential source areas. SLAMM calculates mass balances for both particulate and dissolved pollutants and runoff flow volumes for different development characteristics and rainfalls. It was designed to give relatively simple estimates (pollutant mass discharges and control measure effects) for a very large variety of potential conditions.

SLAMM was developed primarily as a planning level tool, for example, to generate information needed to make planning level decisions while not generating or requiring superfluous information. Its primary capabilities include predicting flow and pollutant discharges that reflect a broad variety of development conditions and the use of many combinations of common urban runoff control practices. Control practices evaluated by SLAMM include detention ponds, infiltration devices, porous pavements, grass swales, catchbasin cleaning, and street cleaning. These controls can be evaluated in many combinations and at many source areas as well as the outfall location. SLAMM also predicts the relative contributions of different source areas (e.g., roofs, streets, parking areas, landscaped areas, undeveloped areas) for each land use investigated. As an aid in designing urban drainage systems, SLAMM also calculates U.S. Department of Agriculture Soil Conservation Service (SCS) curve numbers (CNs) that reflect specific development and control characteristics. These CNs can then be used in conjunction with available urban drainage procedures to reflect the water quantity reduction benefits of stormwater quality controls.

SLAMM is normally used to predict source area contributions and outfall discharges, but SLAMM (1) has also been used in conjunction with a receiving water model (HSPF) to examine the ultimate effects of urban runoff.

The development of SLAMM began in the mid-1970s, primarily as a data reduction tool for use in early street cleaning and pollutant source identification projects sponsored by the U.S. Environmental Protection Agency's (EPA's) Storm and Combined Sewer Pollution Control Program (2-4). Much of the information contained in SLAMM was obtained during EPA's Nationwide Urban Runoff Program (NURP) (5), especially the early Alameda County, California (6), and the Bellevue, Washington (7) projects. The completion of the model was made possible by the remainder of the NURP projects and additional field studies and programming support sponsored by the Ontario Ministry of the Environment (8), the Wisconsin Department of Natural Resources (9), and EPA Region 5 (this report). Early users of SLAMM included the Ontario Ministry of the Environment's Toronto Area Watershed Management Strategy (TAWMS) study (8) and the Wisconsin Department of Natural Resources' Priority Watershed Program (9). SLAMM can now be effectively used as a tool to enable watershed planners to obtain a better understanding of the effectiveness of different control practice programs.

A logical approach to stormwater management requires knowledge of the problems that are to be solved, the sources of the problem pollutants, and the effectiveness of stormwater management practices that can control the problem pollutants at their sources and at outfalls. SLAMM is designed to provide information on the last two aspects of this approach.

Stormwater Problems

Before stormwater control programs can be selected and evaluated, it is necessary to understand the stormwater problems in local receiving waters. Table 1 lists typical receiving water problems associated with both the long-term accumulation of pollutants and the short-term (event-related) buildup of pollutants. Many of these problems have been commonly found in urban receiving waters in many areas of the United States (10). Because these problems are so diverse, an equally wide variety of individual stormwater controls must usually be used together. Unfortunately, combinations of controls are difficult to analyze using conventional stormwater models or the results of monitoring activities. SLAMM was developed to effectively examine control practices and land uses that may affect these receiving water problems.

Table 1. Typical Receiving Water Problems

Long-Term Problems Associated With Accumulations of Pollutants	• Sedimentation in stormwater conveyance systems and in receiving waters. • Nuisance algae growths from nutrient discharges. • Inedible fish, undrinkable water, and shifts to less sensitive aquatic organisms caused by toxic heavy metals and organics.
Short-Term Problems Associated With High Pollutant Concentrations or Frequent High Flows (Event Related)	• Swimming beach closures from pathogenic microorganisms. • Water quality violations. • Property damage from increased flooding and drainage system failures. • Habitat destruction caused by frequent high flow rates (e.g., bed scour, bank erosion, flushing of organisms downstream).

SLAMM Computational Processes

Figure 1 illustrates the development characteristics that affect stormwater quality and quantity. This figure shows a variety of drainage systems, from concrete curb and gutters to grass swales, along with directly connected roof drainage systems and drainage systems that drain to pervious areas. "Development characteristics" define the magnitude of these drainage efficiency attributes, along with the areas associated with each surface type (e.g., road surfaces, roofs, landscaped areas). The use of SLAMM shows that these characteristics greatly affect runoff quality and quantity. Land use alone is usually not sufficient to describe these characteristics. Drainage type (curbs and gutters or grass swales) and roof connections are probably the most important attributes affecting runoff quantity and quality. These attributes are not directly related to land use, but some trends are obvious; most roofs in strip commercial and shopping center areas are directly connected, and the roadside is most likely drained by curbs and gutters, for example. Different land uses, of course, are also associated with different levels of pollutant generation. For example, industrial areas usually have the greatest pollutant accumulations.

Figure 2 shows how SLAMM considers a variety of pollutant and flow routings that may occur in urban areas. SLAMM routes material from unconnected sources directly to the drainage system or to adjacent directly connected or pervious areas, which in turn drain to the collection system Each of these areas has pollutant deposition mechanisms in addition to removal mechanisms associated with them. As an example, unconnected sources, which may include rooftops draining to pervious areas or bare ground and landscaped areas, are affected by regional air pollutant deposition (from point source emissions or from fugitive dust) and other sources that would affect all surfaces. Pollutant losses from these unconnected sources are caused by wind removal and rain runoff washoff, which flows directly to the drainage system or to adjacent areas. The drainage system may include curbs and gutters, where there is limited deposition, and catch basins and grass swales, which may remove substantial participates that are transported in the drainage system. Directly connected impervious areas include paved surfaces that drain directly to the drainage system. These source areas are also affected by regional pollutant deposition, in addition to wind removal and controlled removal processes, such as street cleaning. Onsite storage is also important on paved surfaces because of the large amount of participate pollutants that are not washed off, blown off, or removed by direct cleaning (2, 4, 6).

Figure 3 shows how SLAMM proceeds through the major calculations. There is a double set of nested loops in the analyses where runoff volume and suspended solids (particulate residue) are calculated for each source area and then for each rain. These calculations consider the effects of each source area control, in addition to the runoff pattern between areas. Suspended solids washoff and runoff volume from each individual area for each rain are summed for the entire drainage system. The effects of the drainage system controls (catch basins or grass swales, for example) are then calculated. Finally, the effects of the outfall controls are calculated.

SLAMM uses the water volume and suspended solids concentrations at the outfall to calculate the other pollutant concentrations and loadings. SLAMM keeps track of the portion of the total outfall suspended solids loading and runoff volume that originated from each source area. The suspended solids fractions are then used to develop weighted loading factors associated with each pollutant. In a similar manner, dissolved pollutant concentrations and loadings are calculated based on the

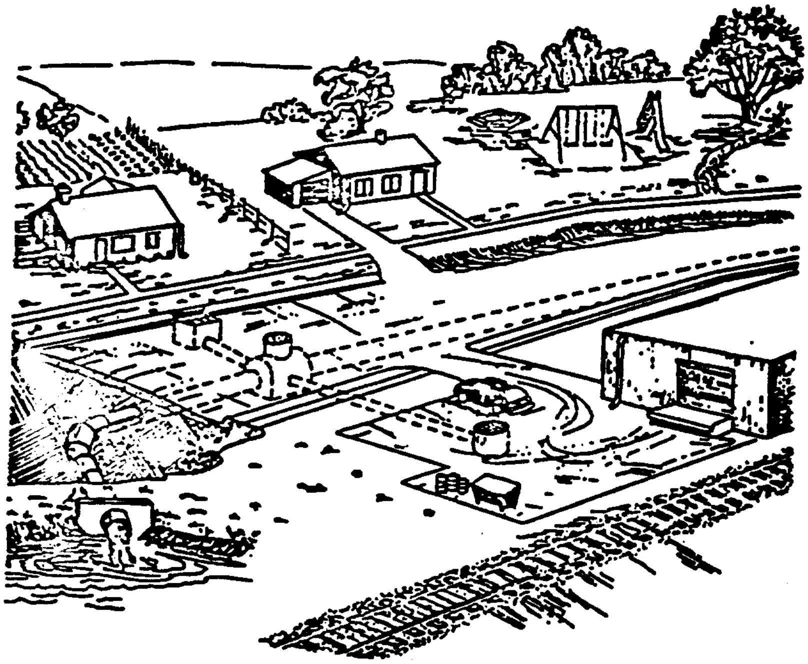

Figure 1. Urban runoff source areas and drainage alternatives (9).

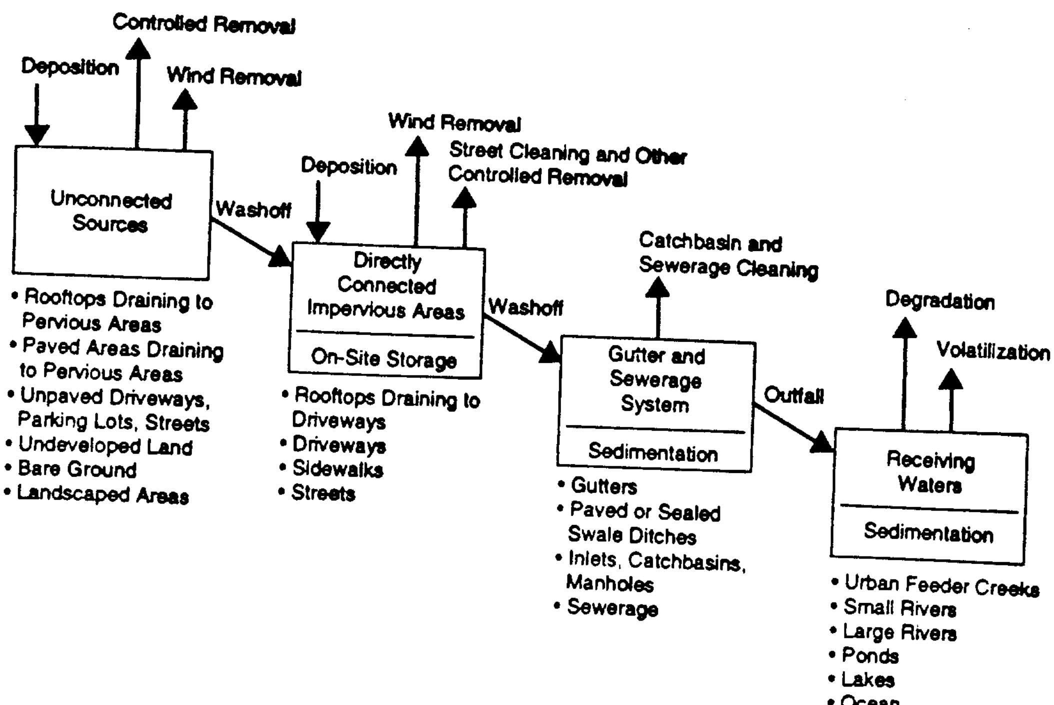

Figure 2. Pollutant deposition and removal at source areas (9).

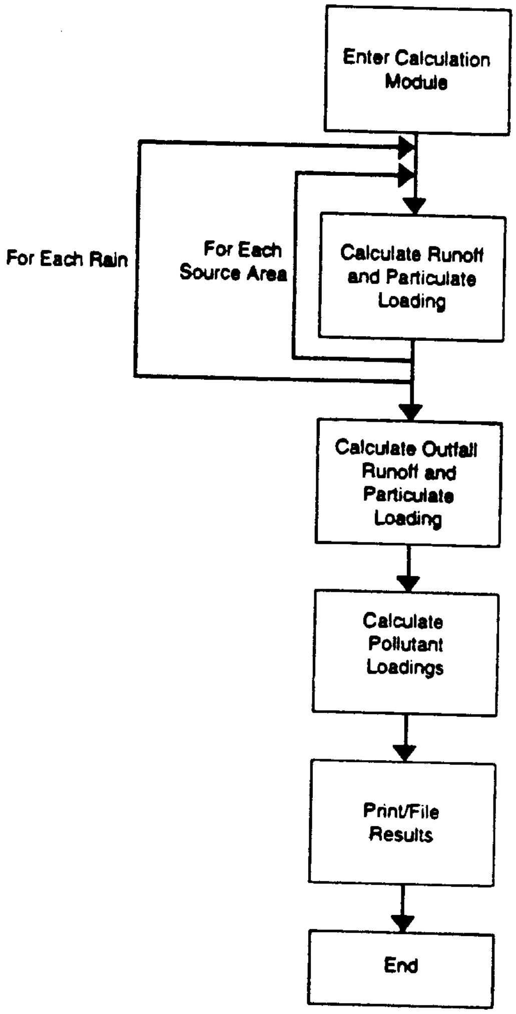

Figure 3. SLAMM calculation flow chart.

percentage of water volume that originates from each of the source areas within the drainage system.

SLAMM predicts urban runoff discharge parameters (total storm runoff flow volume, flow-weighted pollutant concentrations, and total storm pollutant yields) for many individual storms and for the complete study period. It has built-in Monte Carlo sampling procedures to consider many of the uncertainties common in model input values. This enables the model output to be expressed in probabilistic terms that represent the likely range of results expected.

Unique Aspects of SLAMM

SLAMM is unique in many aspects. One of the most important aspects is its ability to consider many stormwater controls (affecting source areas, drainage systems, and outfalls) together, for a long series of rains. Another is its ability to accurately describe a drainage area in sufficient detail for water quality investigations without requiring a great deal of superfluous information that field studies have shown to be of little value in accurately predicting discharge results. SLAMM also applies stochastic analysis procedures to represent actual uncertainty in model input parameters to better predict the actual range of outfall conditions (especially pollutant concentrations). The main reason SLAMM was developed, however, was because of problem areas in many existing urban runoff models. The following paragraphs briefly describe small storm hydrology and particulate washoff, the most significant of these problem areas.

Small Storm Hydrology

One of the major problems with conventional stormwater models concerns runoff volume estimates associated with small storms. Figures 4 and 5 show the importance of common small storms when considering total annual pollutant discharges. Figure 4 shows the accumulative rain count and the associated accumulative runoff volume for a medium density residential area in Milwaukee, Wisconsin, based on 1983 monitored data (11). This figure shows that the median rain, by count, was about 0.3 in., while the rain associated with the median runoff quantity is about 0.75 in. Therefore, more than half of the runoff from this common medium density residential area was associated with rain events that were smaller that 0.75 in. The 1983 rains (which were monitored during the Milwaukee NURP project) included several very large storms, which are also shown on Figure 4. These

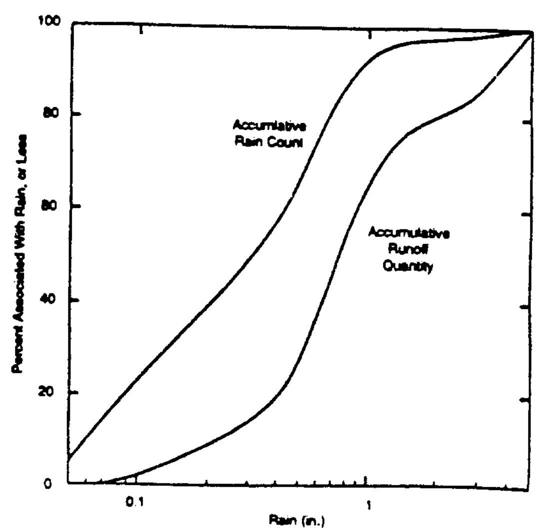

Figure 4. Milwaukee rain and runoff distributions (medium-density residential area).

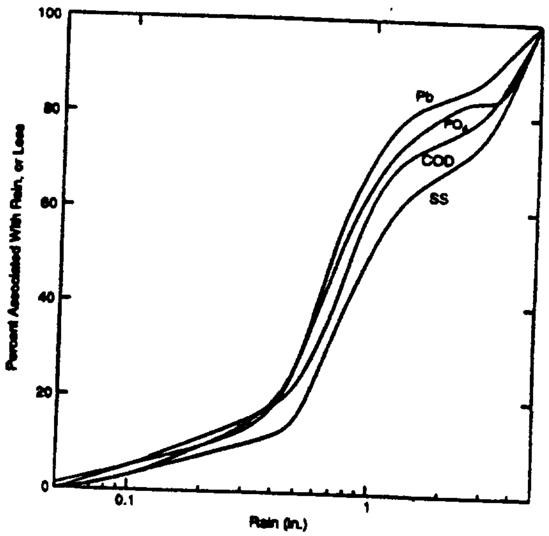

Figure 5. Milwaukee pollutant discharge distributions (medium-density residential area).

large storms (3 to 5 in. in depth) distort Figure 4 because, on average, the Milwaukee area only can expect one 3.5-in. storm every 5 years. If these large rains did not occur in most years, then the significance of the small rains would be even greater.

Figure 5 shows the accumulative loadings of different pollutants (suspended solids, chemical oxygen demand, phosphates, and lead) monitored during 1983 in Milwaukee at the same site as the rain and runoff data shown in Figure 4 (11). When Figure 5 is compared with Figure 4, runoff and discharge distributions appear very similar. This is a simple way of indicating that no significant trends of stormwater concentrations were observed for different size events. Substantial variations in pollutant concentrations were observed, but these were random and not related to storm size. Similar conclusions were noted when all of the NURP data were evaluated (5). Therefore, accurately knowing the runoff volume is very important when studying pollutant discharges. By better understanding the significance and runoff generation potential of these small rains, runoff problems will be better understood.

Figure 6 illustrates the concept of variable contributing areas as applied to urban watersheds. This figure indicates the relative significance of three major source areas (street surfaces, other impervious surfaces, and pervious surfaces) in an urban area. The individual flow rates associated with each of these source areas increase until their time of concentrations are met. The flow rate then remains constant for each source area until the rain event ends. When the rain stops, runoff recession curves occur, draining the individual source areas. The three component hydrographs are then added together to form the complete hydrograph for the

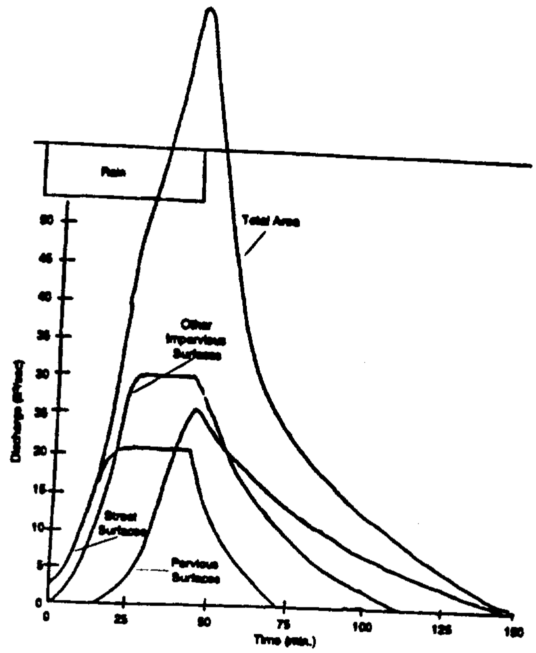

Figure 6. Variable contributing areas in urban watersheds.

area. Calculating the percentage of the total hydrograph associated with each individual source area enables estimates of the relative importance of each source area to be quantified. The relative pollutant discharges from each area can then be calculated from the runoff pollutant strengths associated with each area.

When the time of concentration and the rain duration are equal for an area, the maximum runoff rate for that rain intensity is reached (12). The time of concentration occurs when the complete drainage area is contributing runoff to the point of concern. If the rain duration exceeds the time of concentration, then the maximum runoff rate is maintained until the rain ends. When the rain ends, the runoff rate decreases according to a recession curve for that surface. The example shown in Figure 6 is for a rain duration greater than the times of concentrations for the street surfaces and other impervious areas, but shorter than the time of concentration for the pervious areas. Similar runoff quantities originated from each of the three source areas for this example. If the same rain intensity occurs but lasts for twice the duration (a less frequent storm), the runoff rates for the street surfaces and other impervious surfaces will be the same until the end of the rain, when their recession curves would begin. The pervious surface contribution would increase substantially, however, because its time of concentration may be exceeded by the longer rain duration. If the same rain intensity occurs but only for half of the original duration, the street surfaces time of concentration is barely met, and the other impervious surfaces would not have reached their time of concentration. In this last example, the pervious surfaces would barely begin to cause runoff. In this last case, the street surfaces are the dominant source of runoff water. By knowing the relative contributions of water and pollutants from each source area, it is possible to evaluate potential source area runoff controls for different rains.

Figure 7 shows monitored rainfall-runoff results from one of a series of tests conducted to investigate runoff losses associated with common small rains on pavement (13). This figure indicates that initial abstractions (detention storage plus evaporation losses) for this pavement totaled about 1 mm, while the total rainfall losses were about 6 mm. These maximum losses occurred after about 20 mm of rain. For a relatively small rain of about 7 mm, almost one-half of the rain falling on this pavement did not contribute to runoff. During smaller storms, the majority of the rainfall did not contribute to runoff. These rainfall losses for pavement are substantially greater than commonly considered in stormwater models. Most stormwater models use rainfall-runoff relationships that have been developed and used for many years for drainage design. Drainage design is concerned with rain depths of at least several inches. When these same procedures are used to estimate the runoff associated with common small storms (which are the most important in water quality investigations), the runoff predictions can be highly inaccurate. As an example, Figure 8 is a plot of

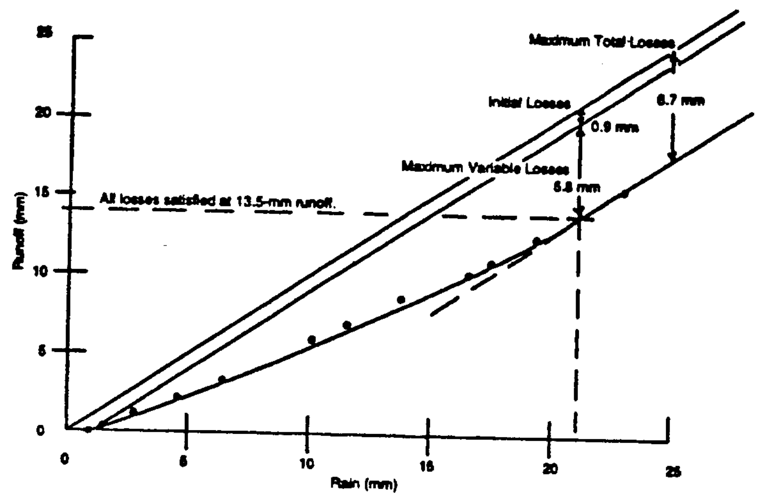

Figure 7. Rainfall-Runoff plot (example for high-intensity rains, clean and rough streets) (13).

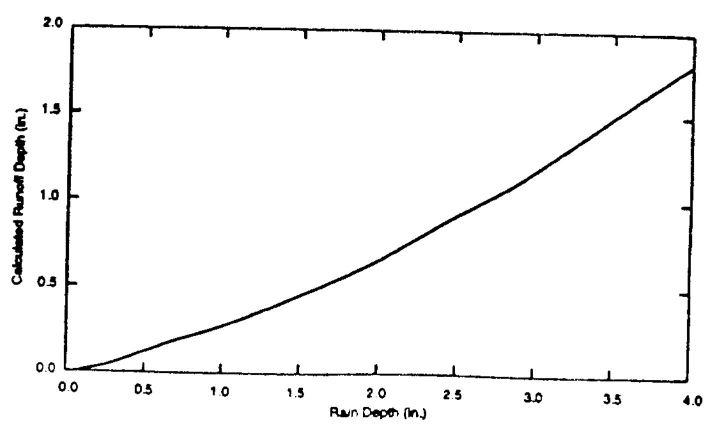

Figure 8. Rainfall-Runoff plot (medium-density area with clayey soils).

the observed runoff for different rain depths in Milwaukee during the 1983 NURP investigations. It was noted previously that several storms were monitored during this period that were very large. The volumetric runoff coefficient (the ratio of runoff to rain depth) observed varies for each rain depth. This ratio can be about 0.1 for storms of about 0.5 in. but may approach 0.4 for a moderate size storm of 2.5 in. or greater which is typically associated with drainage events. The NURP study (5), however, recommended the use of constant (average) volumetric runoff coefficients for the stormwater permit process. Therefore, the runoff volumes of common small storms would most likely be overpredicted.

Figure 9 shows the calculated SCS (14) CNs associated with different storms at a medium density residential site in Milwaukee. This figure shows that the CN values vary dramatically for the different rain depths that actually occurred at this site. The CN values approach the CN values that would be selected for this type of site only for rains greater than several inches in depth. The CN values are substantially greater for the smaller common storms, especially for rains less than the 1-in. minimum rain criteria given by SCS (14) for the use of this procedure. These results are similar to those obtained at many other sites. In almost all cases, the CN values for storms of less than 0.5 in. are 90 or greater. Therefore, the smaller storms contribute much more runoff than would typically be assumed if using SCS procedures. The CN method was initially developed, and is most appropriate, for use in the design of drainage systems associated with storms of much greater size than those of interest in stormwater quality investigations.

SLAMM makes runoff predictions using the small storm hydrology methods developed by Pitt (13). Figure 10

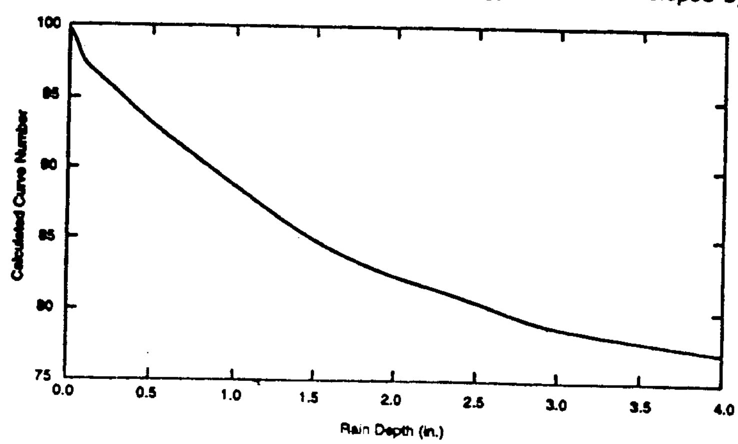

Figure 9. Curve number changes for different rain depths (medium-density area with clayey soils).

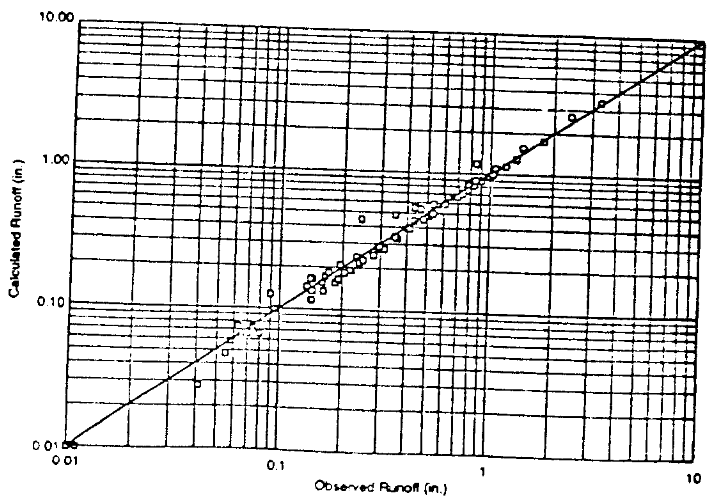

Figure 10. Commercial shopping center runoff verification.

shows the verification of the small storm hydrology method used in SLAMM for storms from a commercial area in Milwaukee. This figure shows that the calculated runoff for many storms over a wide range of conditions was very close to the actual observed runoff. Figure 11 shows a similar plot of the predicted versus observed runoff for a Milwaukee medium density residential area. These two sites were substantially different from each other in the amount of impervious surfaces and in the way these areas were connected to the drainage system. Similar satisfactory comparisons using these small storm hydrology models for a wide range of rain events have been made for other locations, including Portland, Oregon (15), and Toronto, Canada (8).

Particulate Washoff

Another unique feature of SLAMM is its use of a washoff model to predict the losses of suspended solids from different surfaces. Figure 12 is a plot of the suspended solids concentrations for different rain depths for sheetflow runoff from paved surfaces during controlled tests in Toronto (13). This figure shows local "first-flush" effects, with a trend of decreasing suspended solids concentration with increasing rain depth. During the smallest rains, these concentrations are shown to be about several hundred milligrams per liter, and as high as 4,000 mg/L. The suspended solids concentrations during the largest events (about 1 in. in depth) decreased

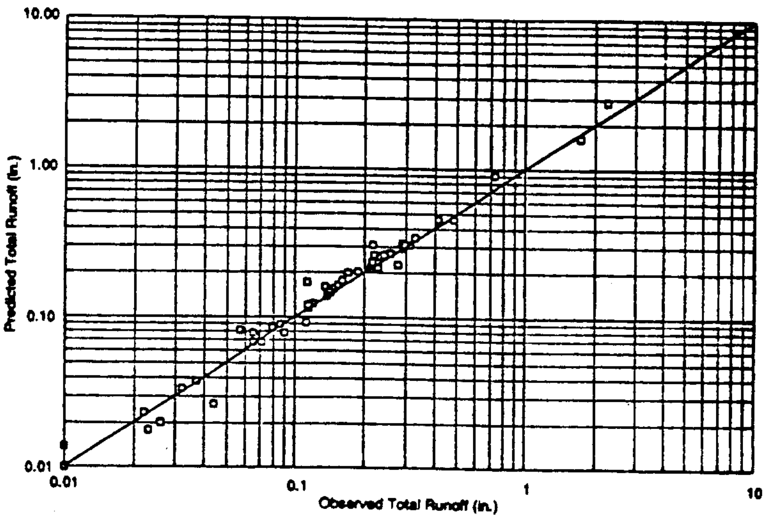

Figure 11. Medium-density residential area runoff verification.

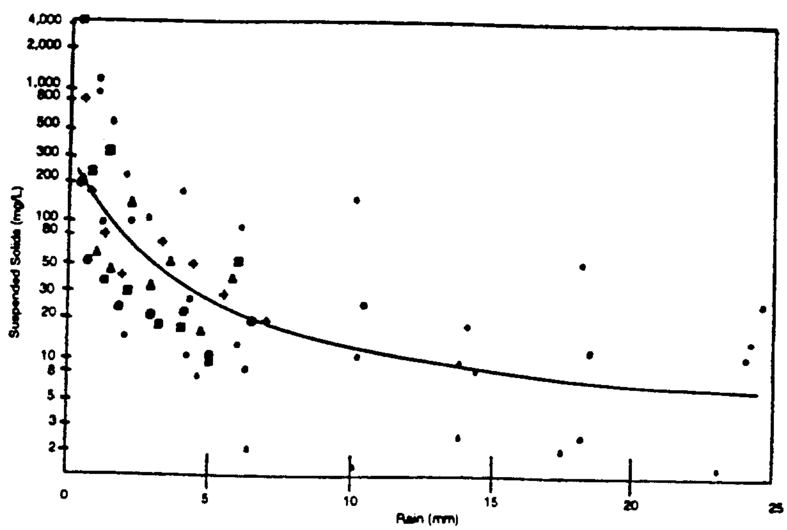

Figure 12. Pavement "first-flush" suspended solids concentrations (13).

dramatically to about 10 mg/L. These data were obtained during controlled small storm hydrology and particulate washoff tests using carefully controlled and constant rain intensities. A first flush of pollutants, as seen in this figure, is likely only to occur for relatively small homogeneous surfaces subjected to relatively constant rain intensities. First flushes at storm drain outfalls may not be commonly observed because of the routing of many different individual first-flush flows that are mixed. Because the highest concentrations associated with these individual flows reach the outfall at different times, these individual first flushes are mixed and lost. More significantly, later times during a rain may have much higher periods of peak rain intensities, resulting in peak washoff late in a storm. Intermittent periods of high rain intensities later in rains likely cause localized periods of high runoff pollutant concentrations that may occur long after the beginning of the rain. Therefore, first-flush situations are most likely to occur for homogeneous drainage areas (such as for large paved areas or roofs) during relatively constant rain intensities.

SLAMM calculates suspended solids washoff based on individual first-flush (exponential) plots for each surface. These plots are derived from observations during rains and during controlled tests (8). The use of individual surface washoff plots has been verified using runoff observations from large and complex drainages (13). Figures 13 through 15 show washoff plots for total solids, suspended solids (>0.45 μm), and dissolved solids (<0.45 μm) during an example controlled street surface washoff test (13). These plots indicate the accumulative gram per square meter washoff as a function of rain

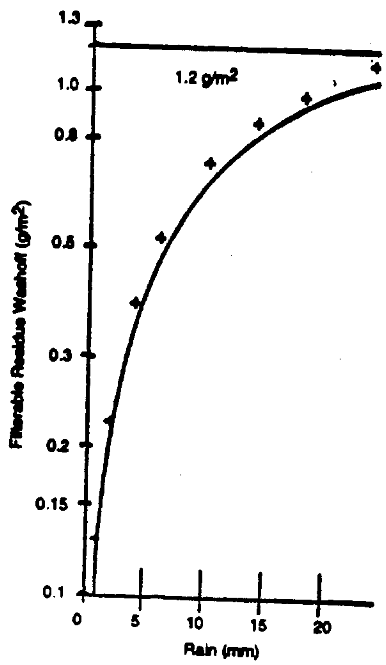

Figure 14. Dissolved solids washoff test results (13).

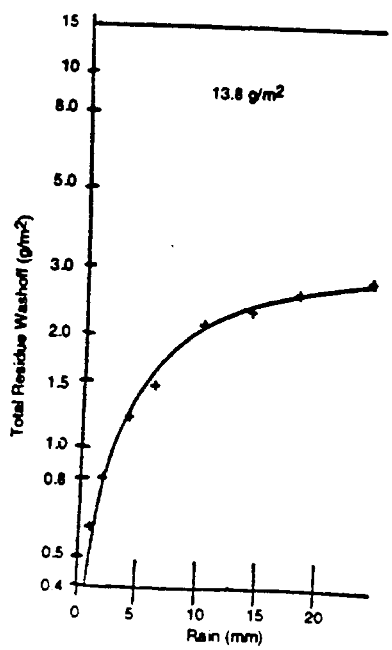

Figure 13. Total solids washoff test results (13).

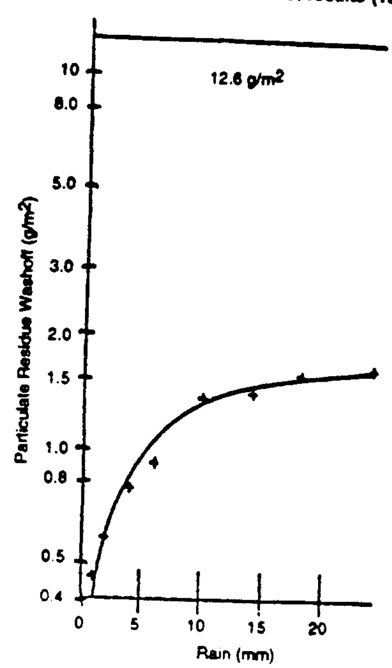

Figure 15. Suspended solids washoff test results (13).

depth. Also shown on these figures are the total street dirt loadings. As an example, Figure 13 shows that 13.8 g/m^2 of total solids were on the street surfaces before the controlled rain event. After about 15 mm of rain fell on the test sites, almost 90 percent of the particulates that would wash off (about 3 g/m^2) did, similar to the rain depth needed for "complete" washoff as reported by earlier studies by Sartor and Boyd (16). The total quantity of material that could possibly wash off (about 3 g/m^2), however, is a small fraction of the total loading that was on the street (13.8 g/m^2). If the relationship between total available loading and total loading of particulates is not considered (as in many stormwater models), then the predicted washoff would be greatly in error.

Figure 14 is similar to Figure 13 but shows the smallest particle sizes ("dissolved solids," < 0.45 μm) as a function of washoff. Here, the total loading of the filterable solids on the streets was only about 1 g/m^2, and almost all of these small particles were available for washoff during these rains. Figure 15 shows the washoff of largest particles ("suspended solids," > 0.45 μm) on the street. Here, the street loading was 12.6 g/m^2, with only about 1.8 g/m^2 available for washoff. The predicted washoff of suspended solids could be in error by 700 percent if the total loading on the street was assumed to be removable by rains. SLAMM uses test results from Pitt (13) that measured the washoff and street dirt loading availability relationships for many street surfaces, rain intensities, and street dirt loadings to more accurately predict the amount of washoff.

Another common problem with stormwater models is the use of incorrect particulate accumulation rates for different surfaces. Figure 16 shows an example of the accumulation and deposition of street surface particulates for two residential areas monitored in San Jose, California (2). The two areas were very similar in land use but the street textures were quite different. The good condition asphalt streets were quite smooth, while the oil and screens overlaid streets were very rough. Immediately after intensive street cleaning, the rough streets still had substantial particulate loadings, while the smooth streets had substantially less. The accumulation of debris on the streets also increased the street dirt loadings over time.

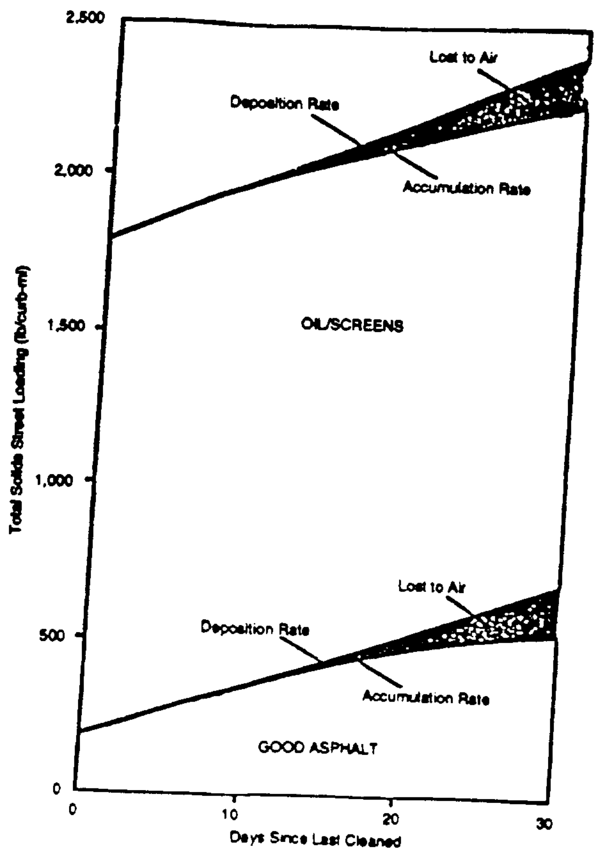

Figure 16. Deposition and accumulation rates of street dirt (13).

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The accumulation rates were very similar for these two different streets having the same land uses. The loadings on the streets at any given time, however, were quite different because of the greatly different initial loading values (permanent storage loadings). If infrequent street dirt loading observations are made, the true shape of the accumulation rate curve may not be accurately known. As an example, the early Sartor and Boyd (16) test results that have been used in many stormwater models assumed that the initial loading values after rains were close to zero, instead of the actual substantial initial loadings. The accumulation rates were calculated by using the slope between each individual loading value and the origin (zero time and zero loading), rather than between loadings from adjacent sampling times, which can easily result in accumulation rates many times greater than actually occurred.

The street dirt deposition rates were found to be only a function of the land uses, but the street dirt loadings were a function of the land use and street texture. The accumulation rates slowly decreased as a function of time and eventually became zero, with the loading remaining constant after a period of about 1 month of either no street cleaning or no rains. Figure 16 shows that the deposition and accumulation rates on the streets were about the same until about 1 or 2 weeks after a rain. If the streets were not cleaned for longer periods, then the accumulation rate decreased because of fugitive dust losses of street dirt to surrounding areas by winds or vehicle turbulence. In most areas of the United States (having rains at least every week or two), the actual accumulation of material on street surfaces is likely constant, with little fugitive dust losses (2).

SLAMM includes a large number of street dirt accumulation and deposition rate relationships that have been obtained for many monitoring sites throughout the United States and Canada. The accumulation rates are a function of the land uses, while the initial loadings on the streets are a function of street texture. The decreasing accumulation rate is also a function of the time after a street cleaning or large rain event.

Monte Carlo Simulation of Pollutants Strengths Associated With Runoff From Various Urban Source Areas

Initial versions of SLAMM only used average concentration factors for different land-use areas and source areas. This was satisfactory for predicting the event mean concentrations (EMC, as used by NURP [5]) for an extended period and for calculating the unit area loadings for different land uses. Figure 17 is a plot of the event mean concentrations at a Toronto test site (8). The observed concentrations are compared with the SLAMM predicted concentrations for a long-term simulation. All of the predicted EMC values are close to the observed EMC values. To predict the probability distributions of the concentrations, however, it was necessary to include probability information for the concentrations found in the different source areas. Statistical analyses of concentration data (attempting to relate concentration trends to rain depths and season, for example) from these different source areas have not been able to explain all of the observed variations in concentration. The statistical analyses also indicate that pollutant concentration values from individual source areas are distributed log normally. Therefore, log-normally distributed random concentration values are used in SLAMM

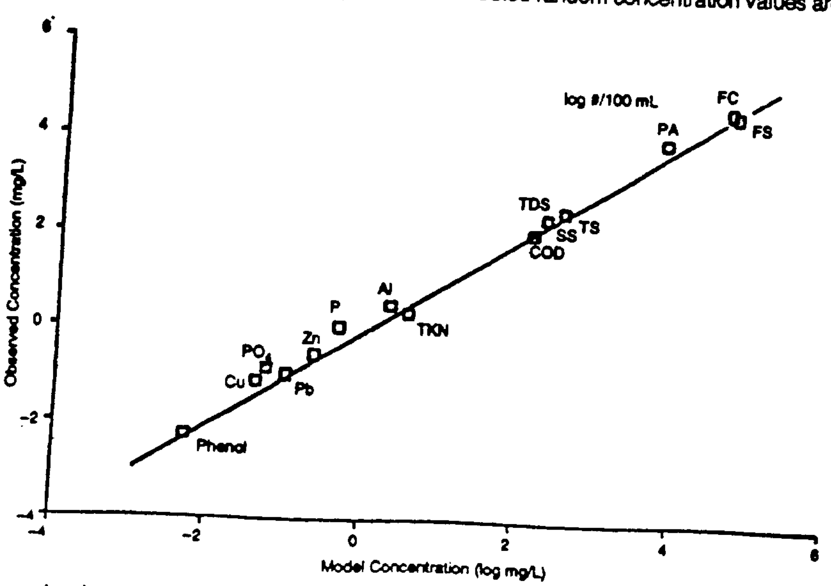

Figure 17. Observed and modeled pollutant concentrations (Toronto industrial site) (8).

for these different areas. The results are predictions for concentration distributions at the outfall. This can provide estimates of criteria violations for different stormwater pollutants at an outfall for long, continuous simulations.

An Example Analysis Using SLAMM To Identify the Sources of Pollutants and To Evaluate Different Control Programs

Table 2 is a field sheet that has been developed to assist users of SLAMM to describe test watershed areas. This sheet is used to evaluate stormwater control retrofit practices in existing developed areas, and to examine how different new development standards effect runoff conditions. Much of the information on the sheet is not actually required to operate SLAMM but is very important when considering additional control programs, such as public education and good housekeeping practices, that are not quantified by SLAMM. The most important information shown on this sheet is the land use, the type of the gutter or drainage system, and the method of drainage from roofs and large paved areas to the drainage system. The efficiency of drainage in an area, specifically if roof runoff or parking runoff drains across grass surfaces, can be very important when determining the amount of water and pollutants that enter the outfall system. Similarly, the presence of grass swales in an area may substantially reduce the amount of pollutants and water discharged. This information is therefore required to use SLAMM.

The areas of the different surfaces in each land use are also very important for SLAMM. Figure 18 is an example showing the areas of different surfaces for a medium density residential area in Milwaukee. As shown in this

Table 2. Study Area Descriptions

Location:	**Site number:**
Date:	**Time:**
Photo numbers:	**Roll number:**

Land-use and industrial activity:					
Residential:	Low Multiple family Trailer parks High-rise apartments	Medium	High-density single family		
Income level:	Low	Medium	High		
Age of development:	<1930	'30-'50	'51-'70	'71-'80	New
Institutional:	School	Hospital	Other (type):		
Commercial:	Strip	Shopping center	Downtown	Hotel	Offices
Industrial:	Light	Medium	Heavy (manufacturing)	Describe:	
Open space:	Undeveloped	Park	Golf	Cemetery	
Other:	Freeway	Utility ROW	Railroad ROW	Other:	
Maintenance of building:	Excellent	Moderate	Poor		
Heights of buildings:	1	2	3	4+ stories	
Roof drains:	Underground	Gutter	Impervious	Pervious	
Roof types:	Flat	Comp. shingle	Wood shingle	Other:	
Sediment source nearby?	No	Yes (describe):			
Treated wood near street?	No	Telephone poles	Fence	Other:	
Landscaping near road:					
Quantity:	None	Some	Much		
Type:	Deciduous	Evergreen	Lawn		
Maintenance:	Excessive	Adequate	Poor		
Leaves on street:	None	Some	Much		
Topography:					
Street slope:	Flat (<2%)	Medium (2-5%)	Steep (>5%)		
Land slope:	Flat (<2%)	Medium (2-5%)	Steep (>5%)		
Traffic speed:	<25 mph	25–40 mph	>40 mph		

Table 2. Study Area Descriptions (continued)

Traffic density:	Light	Moderate	Heavy	
Parking density:	None	Light	Moderate	Heavy
Width of street:				
Number of parking lanes:				
Number of driving lanes:				
Condition of street:	Good	Fair	Poor	
Texture of street:	Smooth	Intermediate	Rough	
Pavement material:	Asphalt	Concrete	Unpaved	
Driveways:	Paved	Unpaved		
Condition:	Good	Fair	Poor	
Texture:	Smooth	Intermediate	Rough	
Gutter material:	Grass swale	Lined ditch	Concrete	Asphalt
Condition:	Good	Fair	Poor	
Street/Gutter interface:	Smooth	Fair	Uneven	
Litter loadings near street:	Clean	Fair	Dirty	
Parking/Storage areas (describe):				
Condition of pavement:	Good	Fair	Poor	
Texture of pavement:	Smooth	Intermediate	Rough	Unpaved
Other paved areas, such as alleys and playgrounds (describe):				
Condition of pavement:	Good	Fair	Poor	
Texture of pavement:	Smooth	Intermediate	Rough	Unpaved
Notes:				

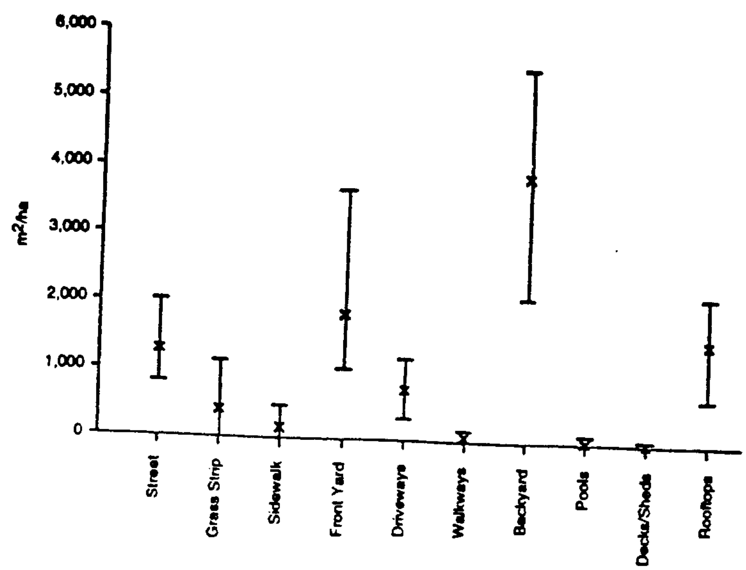

Figure 18. Source areas: Milwaukee medium-density residential areas (without alleys).

example, streets make up between 10 and 20 percent of the total area, while landscaped areas can make up about half of the drainage area. The variation of these different surfaces can be very large within a designated area. The analysis of many candidate areas may therefore be necessary to understand how effective or consistent the model results may be for a general land-use classification.

Control practices evaluated by SLAMM include infiltration trenches, seepage pits, disconnections of directly connected roofs and paved areas, percolation ponds, street cleaning, porous pavements, catchbasin cleaning, grass swales, and wet detention ponds. These devices can be used singly or in combination, at source areas or at outfalls, or, in the case of grass swales and catchbasins, within the drainage system. In addition, SLAMM provides a great deal of flexibility in describing the sizes and other design aspects for these different practices.

One of the first problems in evaluating an urban area for stormwater controls is the need to understand where the pollutants of concern are originating under different rain conditions. Figures 19 through 22 are examples for a typical medium density residential area showing the percentage of different pollutants originating from different major sources, as a function of rain depth. As an example, Figure 19 shows the areas where water is originating. For storms of up to about 0.1 in. in depth, street surfaces contribute about one-half to the total runoff to the outfall. This contribution decreased to about 20 percent for storms greater than about 0.25 in. in depth. This decrease in the significance of streets as a source of water is associated with an increase in water contributions from landscaped areas (which make up more than 75 percent of the area and have clayey soils). Similarly, the significance of runoff from driveways and roofs also starts off relatively high and then decreases with increasing storm depth. Figures 20 and 21 are similar plots for suspended solids and lead. These show that streets contribute almost all of these pollutants for the smallest storms up to about 0.1 in. The contributions from landscaped areas then become dominant. Figure 22 shows that the contributions of phosphates are more evenly distributed between streets, driveways, and rooftops for the small storms, but the contributions from landscaped areas completely dominate for storms greater than about 0.25 in. in depth.

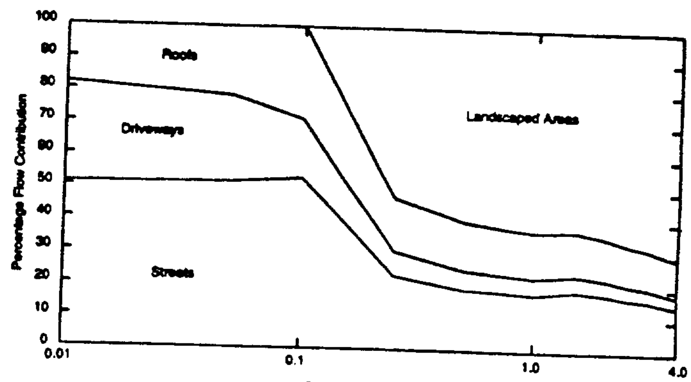

Figure 19. Flow sources for example medium-density residential area having clayey soils.

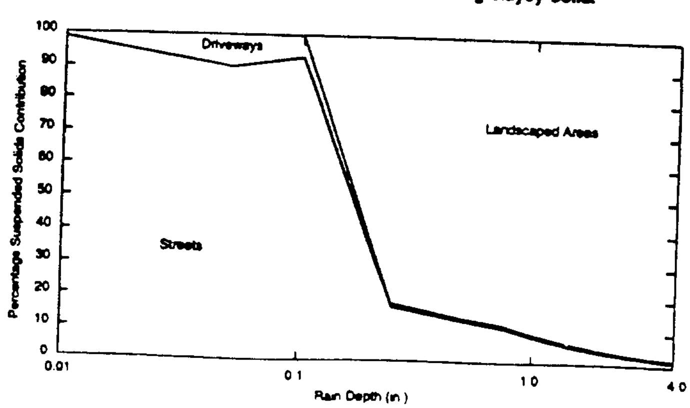

Figure 20. Suspended solids sources for example medium-density residential area.

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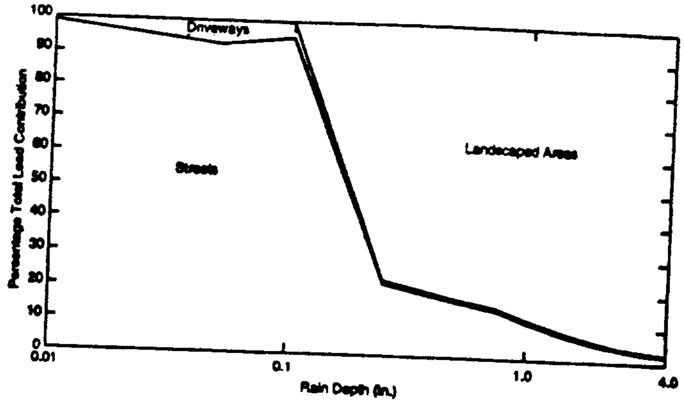

Figure 21. Total lead sources for example medium-density residential area.

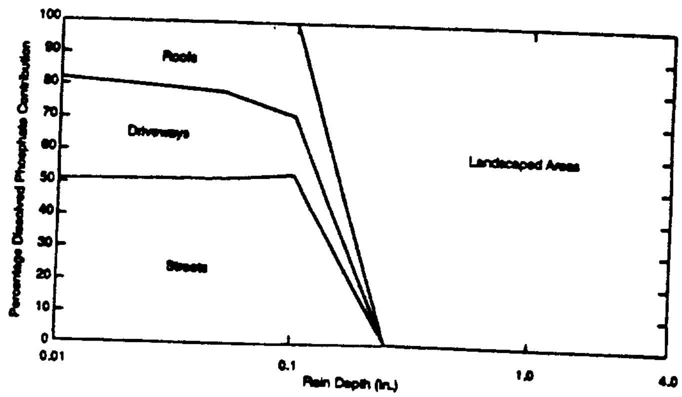

Figure 22. Dissolved phosphate sources for example medium-density residential area.

Obviously, the specific contributions from different areas and for different pollutants vary dramatically, depending on the characteristics of development for the area and the source controls used. Again, a major use of SLAMM is to better understand the role of different sources of pollutants. As an example, to control suspended solids, street cleaning (or any other method to reduce the washoff of particulates from streets) may be very effective for the smallest storms but would have very little benefit for storms greater than about 0.25 in. in depth. Erosion control from landscaped surfaces, however, may be effective over a wider range of storms.

The following list shows the different control programs that were investigated in this hypothetical medium density residential area having clayey soils:

- Base level (as built in 1961 to 1980, with no additional controls).
- Catchbasin cleaning.
- Street cleaning.
- Grass swales.
- Roof disconnections.
- Wet detention pond.
- Catchbasin and street cleaning combined.
- Roof disconnections and grass swales combined.
- All of the controls combined.

This residential area, which was based on actual Birmingham, Alabama, field observations for homes built between 1961 to 1980, has no controls. The use of catchbasin cleaning and street cleaning in the area was evaluated. Grass swale use was also evaluated, but swales are an unlikely retrofit option and would only be appropriate for newly developing areas. It is possible, however, to disconnect some of the roof drainages and divert the roof runoff away from the drainage system and onto grass surfaces for infiltration in existing developments. In addition, wet detention ponds can be retrofitted in different areas and at outfalls. Besides those controls examined individually, catchbasin and street cleaning controls combined were also evaluated, in addition to the combination of disconnecting some of the rooftops and the use of grass swales. Finally, the prospect of using all of the controls together was examined.

The following list shows a general description of this hypothetical area:

- All curb and gutter drainage (in fair condition).
- 70 percent of roofs draining to landscaped areas.
- 50 percent of driveways draining to lawns.
- 90 percent of streets of intermediate texture (remaining are rough).
- No street cleaning.
- No catchbasins.

About one-half of the driveways currently drain to landscaped areas, while the other half drain directly to the pavement or the drainage system. Almost all of the streets are of intermediate texture, and about 10 percent are rough textured. There currently is no street cleaning or catchbasin cleaning.

The level of catchbasin use that was investigated for this site included 950 ft^3 of total sump volume per 100 acres (typical for this land use), with a cost of about $50 per catchbasin cleaning. Typically, catch basins in this area could be cleaned about twice a year for a total annual cost of about $85 per acre of the watershed.

Street cleaning could also be used, with a monthly cleaning effort of about $30 per year per watershed acre. Light parking and no parking restrictions during cleaning are assumed, and the cleaning cost is estimated to be $80 per curb mile.

Grass swale drainage was also investigated. Assuming that swales could be used throughout the area, there could be 350 ft of swales per acre (typical for this land use), with swales 3.5 ft wide. Because of the clayey soil conditions, an average infiltration rate of about 0.5 in./hr was used in this analysis based on many different double-ring infiltrometer tests of typical soil conditions. Swales cost much less than conventional curb and gutter systems but require increased maintenance. Again, the use of grass swales is appropriate for new development but not for retrofitting in this area.

Roof disconnections could also be used as a control measure by directing all roof drains to landscaped areas. The objective would be to direct all the roof drains to landscaped areas. Because 70 percent of the roofs already drain to the landscaped areas, only 30 percent could be further disconnected, at a cost of about $125 per household. The estimated total annual cost would be about $10 per watershed acre.

An outfall wet detention pond suitable for 100 acres of this medium density residential area would have a wet pond surface of 0.5 percent of drainage area for approximately 90 percent suspended solids control. It would need 3 ft of dead storage and live storage equal to runoff from 1.25-in. rain. A 90-degree V notch weir and a 5-ft wide emergency spillway could be used. No seepage or evaporation was assumed. The total annual cost was estimated to be about $130 per watershed acre.

Table 3 summarizes the SLAMM results for runoff volume, suspended solids, filterable phosphate, and total lead for 100 acres of this medium density residential area. The only control practices evaluated that would reduce runoff volume are the grass swales and roof disconnections. All of the other control practices evaluated do not infiltrate stormwater. Table 3 also shows the total annual average volumetric runoff coefficient (Rv) for these different options. The base level of control has an annual flow-weighted Rv of about 0.3, while the use of swales would reduce the Rv to about 0.1. Only a small reduction of Rv (less than 10 percent) would be associated with complete roof disconnections compared with the existing situation because of the large amount of roof disconnections that already occur. The suspended solids analyses shows that catchbasin cleaning alone could result in about 14 percent suspended solids reductions. Street cleaning would have very little benefit, while the use of grass swales would reduce the suspended solids discharges by about 60 percent. Grass swales would have minimal effect on the reduction of suspended solids concentrations at the outfall. (They are primarily an infiltration device, having very little filtering benefits.) Wet detention ponds would remove about 90 percent of the mass and concentrations of suspended solids. Similar observations can be made for filterable phosphates and lead.

Figures 23 through 26 show the maximum percentage reductions in runoff volume and pollutants, along with associated unit removal costs. As an example, Figure 23 shows that roof disconnections would have a very small potential maximum benefit for runoff volume reduction, at a very high unit cost compared with other practices. The use of grass swales could have about a 60-percent reduction at minimal cost. The use of roof disconnection plus swales would slightly increase the maximum benefit to about 65 percent, at a small unit cost. Obviously, the use of roof disconnections alone, or all controlled practices combined, is very inefficient for this example. For suspended solids control, catchbasin cleaning and street cleaning would have minimal benefit at high cost, while the use of grass swales would produce a substantial benefit at very small cost. If additional control is necessary, however, the use of wet detention ponds may be necessary at a higher cost. If close to a 95-percent reduction of suspended solids was required, then all of the controls investigated could be used together, but at substantial cost.

Table 3. SLAMM Predicted Runoff and Pollutant Discharge Conditions for Example[a]

Birmingham 1976 rains (112 rains, 55 in. total, 0.01-3.384 in. each)	Runoff Volume			Suspended Solids		Filterable Phosphate		Total Lead	
	Annual ft³/acre	Flow-wtg Rv	CN Range	Flow-wtg mg/L	Annual lb/acre	Flow-wtg µg/L	Annual lb/acre	Flow-wtg µg/L	Annual lb/acre
Base (no controls)	59,800	0.3	77-100	385	1,430	157	0.58	543	2.0
Catchbasin cleaning:	59,800	0.3	77-100	331	1,230	157	0.58	468	1.7
Reduction (lb or ft³)	0				200		0		0.29
Reduction (%)	0			14	14	0	0	14	14
Cost ($/lb or $/ft³)	NA				0.43		NA		293
($85/acre/yr)									
Street cleaning:	59,800	0.3	77-100	385	1,430	157	0.58	543	2.0
Reduction (lb or ft³)	0				0		0		0.01
Reduction (%)	0			0	0	0	0	0	0.49
Cost ($/lb or $/ft³)	NA				NA		NA		3,000
($30/acre/yr)									
Grass swales:	23,300	0.12	63-100	380	554	151	0.22	513	0.75
Reduction (lb or ft³)	36,500				876		0.36		1.28
Reduction (%)	61			1	61	4	62	6	63
Cost ($/lb or $/ft³)	Minimal				Minimal		Minimal		Minimal
($minimal/acre/yr)									
Roof disconnections:	56,000	0.28	76-100	410	1,430	156	0.55	443	1.6
Reduction (lb or ft³)	3,800				0		0.03		0.48
Reduction (%)	6			-6	0	1	5	18	24
Cost ($/lb or $/ft³)	0				NA		333		21
($10/acre/yr)									
Wet detention pond:	59,800	0.3	77-100	49	185	157	0.58	69	0.26
Reduction (lb or ft³)	0				1,250		0		1.8
Reduction (%)	0			87	87	0	0	87	87
Cost ($/lb or $/ft³)	NA				0.10		NA		73
($130/acre/yr)									
CB and street cleaning:	59,800	0.3	77-100	331	1,230	157	0.58	468	1.7
Reduction (lb or ft³)	0				200		0		0.29
Reduction (%)	0			14	14	0	0	14	14
Cost ($/lb or $/ft³)	NA				0.58		NA		397
($115/acre/yr)									
Roof dis. and swales:	20,900	0.1	63-100	403	526	139	0.18	352	0.46
Reduction (lb or ft³)	38,900				904		0.40		1.6
Reduction (%)	65			-5	63	11	69	35	77
Cost ($/lb or $/ft³)	0.00026				0.01		25		6.4
($10/acre/yr)									
All above controls:	20,900	0.1	63-100	42	55	139	0.18	36	0.05
Reduction (lb or ft³)	38,900				1,375		0.40		1.96
Reduction (%)	65			89	96	11	69	93	97
Cost ($/lb or $/ft³)	0.0066				0.19		638		129
($255/acre/yr)									

[a]Medium-density residential area, developed in 1961-1980, with clayey soils (curbs and gutters); new development controls (not retrofit).

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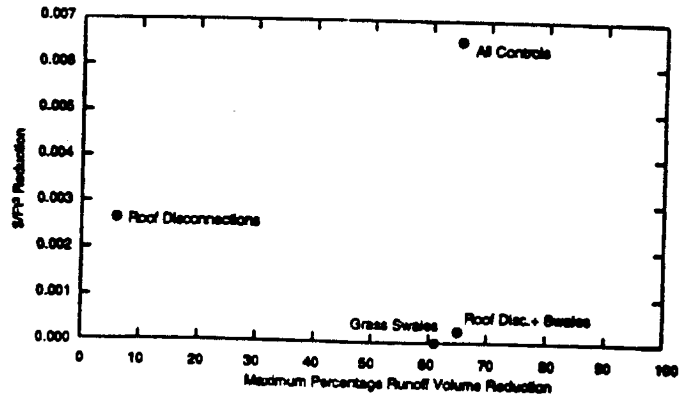

Figure 23. Cost-effectiveness data for runoff volume reduction benefits.

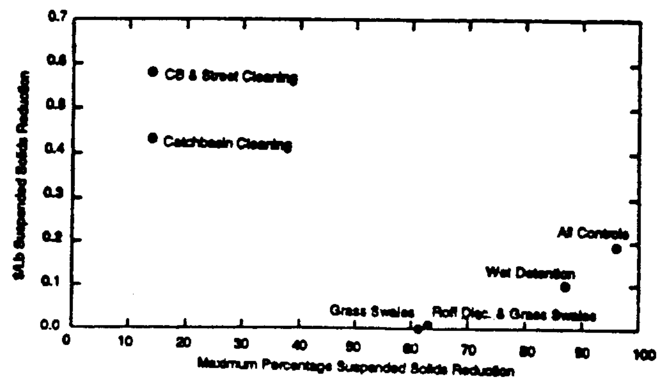

Figure 24. Cost-effectiveness data for suspended solids reduction benefits.

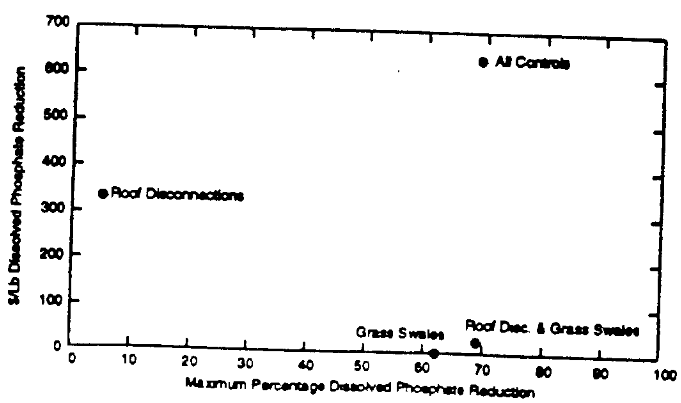

Figure 25. Cost-effectiveness data for dissolved phosphate reduction benefits.

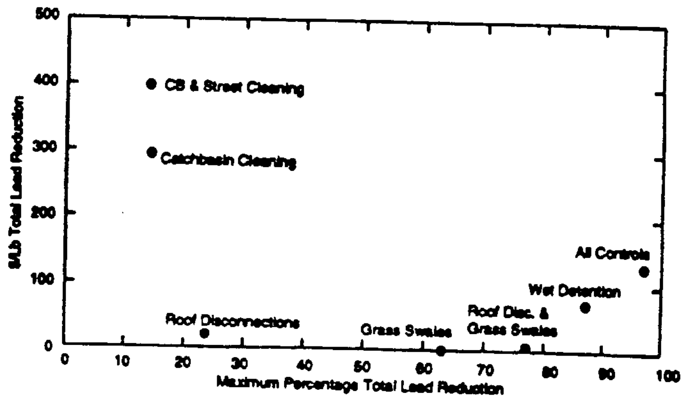

Figure 26. Cost-effectiveness data for total lead reduction benefits.

Conclusions

This paper has shown how SLAMM can be used to estimate the relative contributions of different pollutants from different areas within a complex watershed. SLAMM can also be used to examine the cost effectiveness of different individual control programs, or combinations of control programs, that could be located at source areas or at the outfalls.

SLAMM is unique compared with most stormwater models. Specifically, the use of small storm hydrology to predict the contributions of runoff from different source areas and the use of particulate washoff algorithms have greatly enhanced the accuracy of SLAMM. In addition, SLAMM requires a minimum amount of information to describe the area under consideration and engineering design parameters for different control practices. SLAMM is a very useful tool in guiding planners and watershed managers in devising control strategies. It has also been used to quantify and justify the benefits associated with stormwater controls for newly developing areas.

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Combining GIS and Modeling Tools in the Development of a Stormwater Management Program

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Abstract

A geographic information system (GIS) based Watershed Simulation Model (GWSM) was developed for stormwater pollution control in Prince George's County, Maryland, using the Stormwater Management Model (SWMM 4.2), ARC/INFO (6.1), and data postprocessors. The GWSM was designed to perform planning level assessments of water quality concentrations and loadings for 12 water quality parameters in 41 primary watersheds within the county. The model combines continuous watershed modeling and the spatial analysis capabilities of a GIS in a single, integrated system operating on a Sun Sparc 2 workstation. The user selects a watershed to determine daily, monthly, seasonal, or annual stormwater pollutant loadings using the SWMM output. Additional routines analyze stormwater control structures and user-defined subbasins. GWSM output is saved for watershed comparisons using both graphical and tabular formats.

GWSM allows county water resources planners to perform analyses in the following areas:

- *Prioritize problem watersheds:* Identify where impacts are most severe based on pollutant-specific data. Both temporal and spatial problems and trends are identified.
- *Integration with water quality databases:* Data from national databases, including STORET, WATSTORE, and Reachfile III streams, are used in characterizing the water resources of the study area.
- *Alternative land use assessment:* Water quality impacts and trends, based on land use changes or future master planning scenarios, can be evaluated.
- *Screening solutions/microscale analysis:* Management assessment tools provide planning level screening of controls designed to cost-effectively manage the pollutants of concern. This allows determination of which flows and loads need to be controlled. Smaller, 100- to 400-acre drainage basins can also be evaluated with alternative land uses and management practices.

Introduction

The National Pollutant Discharge Elimination System (NPDES) municipal stormwater permit regulations resulting from the Clean Water Act Reauthorization of 1987 require large counties and municipalities to develop comprehensive stormwater management programs. For complex urban fringe areas such as Prince George's County, Maryland, prioritizing stormwater problems and developing cost-effective management techniques is a primary objective if program resources are to be efficiently allocated. The geographic information system (GIS) based Watershed Simulation Model (GWSM) was designed to support the development and implementation of the county's stormwater management program. GWSM enables planning assessment at the watershed level through estimation of pollutant loads and flows for current land use conditions and future buildout scenarios, with or without structural controls. At the small basin level, alternative stormwater control scenarios can be evaluated for user-defined areas.

Existing Watershed Models

A variety of models are available for simulating water quantity and quality on a watershed scale (1). These range from relatively simple empirical models that predict annual or storm loads to deterministic models that yield flow and pollutant loads for a variety of flow conditions.

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Simple models, such as the U.S. Environmental Protection Agency (EPA) Screening Procedures (2) model and the Simple Method (3), commonly aggregate the physical parameters for an entire watershed and calculate loads on an annual or seasonal time step. Although this reduces the amount of input data and time required to apply the model, it does not allow for an examination of the variations between storm events or water quality problems occurring over a wide range of hydrologic conditions.

Complex models, such as SWMM (4) and the Hydrologic Simulation Program-Fortran (HSPF) (5), simulate hydrologic processes that generate runoff and pollutant loads in a continuous manner rather than relying on simplified rates of change (1). This class of model can use time series climatic data for continuous simulation over several years, enabling analysis of not only annual loads and flows but also of single events or a series of storms.

Previous Studies

GIS is increasingly used for watershed assessment in support of various water resources programs (6). A review of available literature shows that the use of GIS in conjunction with hydrologic models comprises a major part of the current activities. The use of GIS for hydrologic modeling can be divided into two general approaches: 1) performing watershed modeling analyses directly within a GIS package using empirical or lumped models and 2) processing input data for use with a separate or partially linked watershed model.

Empirical modeling within a GIS environment includes an approach using the modified Universal Soil Loss Equation (USLE) for evaluating silvicultural activities and control programs in Montana (7). Tim et al. (8) coupled empirical simulation modeling with a GIS to identify critical areas of nonpoint source pollution in Virginia. On the other hand, linked GIS and hydrologic modeling approaches include a study by Ross and Tara (9) using a GIS to perform spatial data referencing and data processing while traditional hydrologic codes performed the calculations for time-dependent surface- and ground-water simulations. Terstriep and Lee (10) developed AUTO_QI, a GIS-based interface for watershed delineation and input data formatting to the Q-ILLUDAS model.

Modeling Approach: The Prince George's County GIS-Based Watershed Simulation Model

The GWSM developed for the Prince George's County stormwater program combines results from a watershed model with GIS analytic routines. Figure 1 illustrates this modular modeling approach. The GWSM uses a continuous simulation model to generate single land-use water quality and quantity time series data. ARC/INFO, combining GIS coverages from various databases, is used to select a watershed and determine its physical characteristics, including drainage area and land-use distribution. The single land-use time series, along with the land-use and drainage area files, are processed by a series of Fortran routines to determine watershed loads and summary statistics (Figure 1). Results can be interactively displayed for watershed comparisons and management assessment. As with AUTO_QI (10), the GWSM modeling approach uses the GIS to furnish data for use with a continuous simulation model. Unlike other approaches, however, GWSM uses preprocessed output from a watershed model to calculate storm flows and pollutant loads for the study watershed.

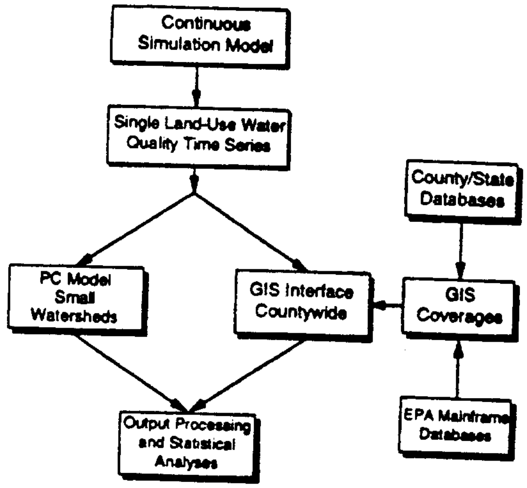

Figure 1. Watershed modeling approach.

Although SWMM was used for this application of GWSM, results from other continuous simulation models can also be included in the model. This modular approach enables increased simulation accuracy as calibrated models become available. Further, several models can be used within a single application, combining the strengths of each. For instance, SWMM could be used for urban areas, while HSPF could be applied to agricultural lands within a single study area.

Input Data Requirements

GWSM requires both ARC/INFO vector coverages and continuous simulation model output for each land-use type modeled. Coverages include watershed boundaries and current land-use files. Input data for SWMM include parameters for the rainfall, temperature, and runoff blocks for each of the nine homogeneous land-use basins.

A Case Study: Collington Branch Watershed

Water resource managers face multiple questions on how best to manage stormwater on a regional, watershed, and subbasin scale. In Prince George's County, an area covering over 480 square miles, there are 41 watersheds of varying size and land-use distribution. The proximity of the county to the fast-growing metropolitan Washington, DC, area makes stormwater management a complex and pressing problem.

An assessment of the predominantly forested and agricultural Collington Branch watershed, covering approximately 14,820 acres and draining to the Western Branch and to the Patuxent River, was performed as a demonstration of the GWSM. Figure 2 is the watershed selection screen from the GWSM, including the land-use distribution for the Collington Branch watershed. This case study demonstrates how the GWSM can be applied using a three-step approach: 1) identify and target problem watersheds, 2) identify pollutant sources and characterize pollutants, and 3) conceptually identify control measures and evaluate future land-use changes.

Watershed Problem Identification and Targeting

Often, the first questions that water resource managers ask are, How can problem watersheds be identified, and how do watersheds compare with each other in terms of pollutant loads and flows? GWSM enables the rapid analysis of the relative contributions of each watershed to the total load, performing a complete assessment and interpretation of the data within 10 minutes. The results

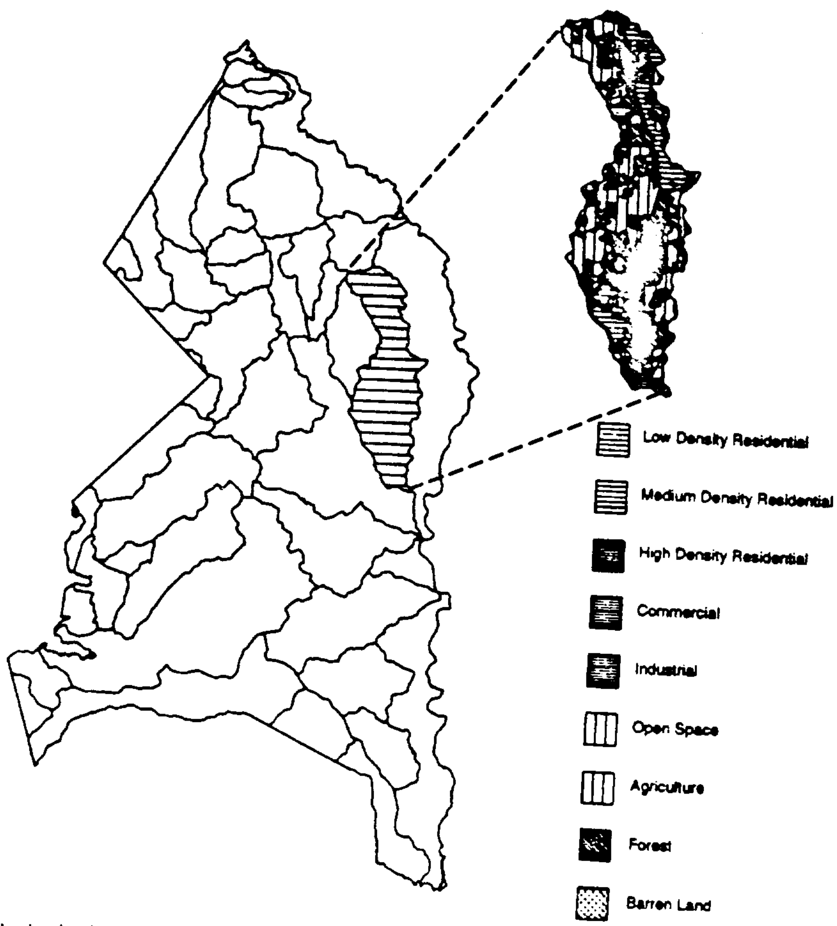

Figure 2. Watershed selection screen for the Collington Branch watershed, including land-use distribution.

include estimates of annual, mean monthly, and monthly loads for the watershed for 12 parameters. Each constituent may be viewed either as a percentage of the total load or in actual units (pounds or cubic feet). Figure 3 presents the graphical display from GWSM showing the total nitrogen load for the Collington Branch, illustrating the changes in loads due to climatic variability.

A comparison between two watersheds is easily performed to assess load and flow estimates and review results graphically. Multiple applications provide a rapid assessment of all the major watersheds in the county. This phase of the GWSM analysis provides information to answer the questions, Which are the likely water quality impacts, and how significant are they compared to other watersheds?

Identify Pollutant Sources and Characterize Pollutant of Concern

Once problem watersheds are identified and targeted for further analysis, the water quality problems must be clearly defined. What are the sources of the pollutants of concern? An analysis of the pollutant contribution by land use is included in GWSM, calculating constituent load by land use for each of the 12 parameters. Figure 4 shows total nitrogen contributions for each land use in the Collington Branch, indicating that agricultural areas are the primary source. This provides important information for targeting control programs throughout the watershed. Characterizing the pollutant loads is an important issue for developing management programs. The following questions are answered at this phase: What pollutants are of primary concern? What are their sources and spatial and temporal characteristics? How do their loads vary seasonally and annually? What are the temporal variations between pollutants? To answer these questions, GWSM provides graphical displays of mean monthly, mean annual, and annual pollutant loads for each pollutant.

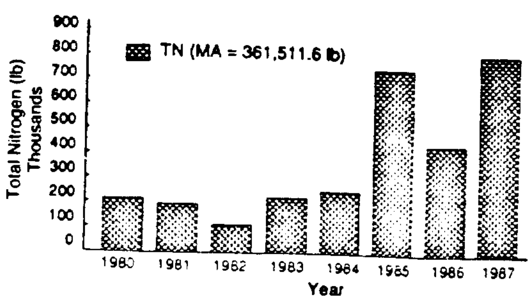

Figure 3. Annual summary of total nitrogen load, Collington Branch watershed, illustrating changes in loads due to climatic variability.

Management Screening

In this phase, implementing the most cost-effective controls is addressed. To address control measures, the relationship between storm size, runoff volume, and pollutant load must be assessed. For example, what storm sizes contribute the largest pollutant loads, and which storm size should be targeted? The analytic routines in GWSM provide graphical answers to these questions. Figure 5 presents lead loads by storm size, indicating that targeting only a percentage of runoff will control over half of the total load. Figure 6 illustrates the rainfall/runoff characteristics of the watershed, with the majority of storms generating less than 0.05 in. of runoff. These estimates will vary by watershed and type of pollutant, but GWSM allows rapid analysis of each pollutant and multiple watersheds.

Management evaluation is done at both watershed- and site-specific levels. Over an entire watershed, what is the optimal control level for structural water quality facilities? GWSM includes a stormwater pond routine that calculates the pollutant mitigating effects of different

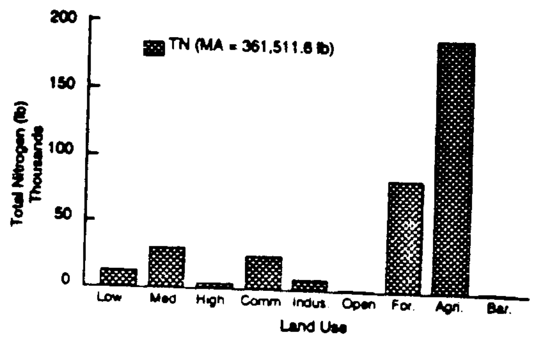

Figure 4. Total nitrogen load by land use, Collington Branch watershed.

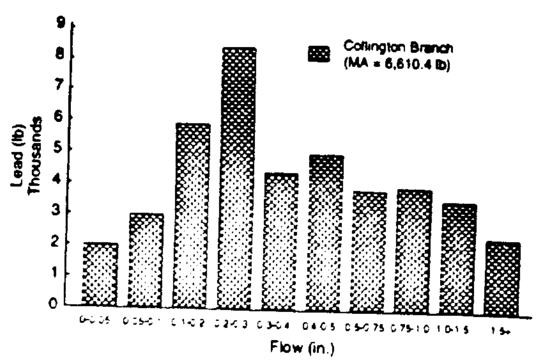

Figure 5. Lead distribution by storm size, Collington Branch watershed.

control levels and retention times. At a site-specific level, such as a proposed new subdivision, similar structures can also be evaluated to allow optimal design criteria to be selected. Figure 7 illustrates the phosphorus contribution for a simulated residential subdivision, and the pollutant reduction from a stormwater pond designed to control for 0.3 in. of runoff. As seen in Figure 7, the mean annual phosphorus load was reduced from 453 to 277 lb by the simulated structure.

Managers must address how future changes will affect water quality. On the watershed level, what will be the impact of urbanization on flow and pollutants loads? At the subbasin level, how will proposed projects change the runoff characteristics? Both land use scenarios can be evaluated in GWSM. On the watershed scale, the current land use can be interactively changed with a "point-and-click" menu. At the subbasin level, a user-defined basin may be modeled, with the land-use distribution entered into a pulldown menu. At both watershed and subbasin levels, once a land-use scenario is selected, GWSM calculates the anticipated pollution loads. The results can then be compared with preexisting conditions. The following questions are answered during the final phase of GWSM: How do pollutant loads relate to rainfall and runoff distribution and intensity?

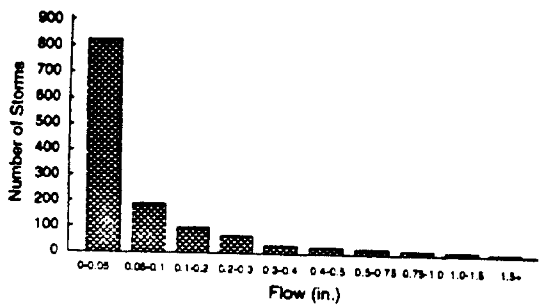

Figure 6. Flow (frequency) distribution by storm size, Collington Branch watershed.

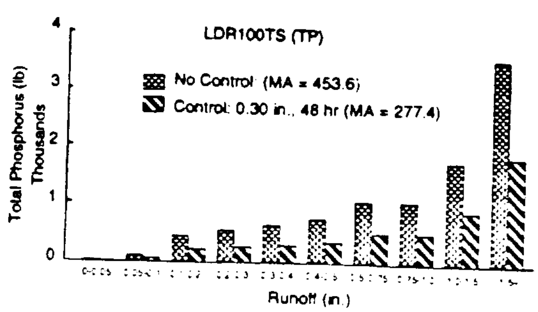

Figure 7. Phosphorus contribution for a simulated residential subdivision with a stormwater pond designed to control for 0.3 in. of runoff.

What is the optimal control level for structural practices? What are the likely impacts of future land-use changes on water quality?

Stormwater Management: Future Model Applications

The NPDES stormwater permit regulations have created new challenges and opportunities for state, county, and city water resource programs. Water resource managers are faced with often conflicting stormwater management objectives and forced to make decisions that weigh the costs and benefits of each. For instance, water quality and flood control objectives do not always coincide. The design and management of regional stormwater ponds will vary depending on whether water quantity control or water quality control is the primary objective.

To address the complex array of stormwater issues, more sophisticated analytical tools and techniques are needed. Watershed models that effectively evaluate alternative scenarios and allow for optimization routines for differing management objectives are in demand. Integrating environmental data, such as wetland areas, bioassessment information, structural and nonstructural best management practice (BMP) optimization, and permit and monitoring information will be required in a user-friendly GIS package.

As the NPDES stormwater regulations are implemented at the county and local level, unique management programs will develop according to specific water quality and resource availability issues. As these programs take shape, GIS and GIS-based models and information management systems are likely to play larger roles in assessing problems and crafting solutions.

Conclusions

The GWSM enabled the rapid assessment of Prince George's County's stormwater problem areas and the evaluation of control measures. GWSM was developed to support the development of the county's stormwater management program. The model incorporates the strengths of continuous simulation modeling with the spatial analysis techniques of GIS in an integrated system. Together, the GIS and data processing routines allow for further analysis and interpretation of time series data from the SWMM model. Combining continuous time series data with georeferenced watershed/land-use data allows for the further analysis and interpretation of the results. As additional data from monitoring both homogenous land-use basins and in-stream locations becomes available from the long-term monitoring program developed as part of the NPDES Part 2 permit, the accuracy of the model will increase.

As technologies for developing and evaluating stormwater programs increase in sophistication, the questions asked of water resource managers are likely to become more difficult. The GWSM will continue to develop to incorporate more functions designed to assist managers to make the best, most informed decisions.

Acknowledgments

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Watershed Screening and Targeting Tool (WSTT)

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Abstract

Screening-level tools allow managers to understand, evaluate, and compare the water quality problems of watersheds so that they can be prioritized. The Watershed Screening and Targeting Tool (WSTT) makes it easier for watershed managers in federal, state, and local agencies to conduct these evaluations by providing access to the necessary data and information and facilitating the assessment itself. This prototype has been developed as a cooperative project for the U.S. Environmental Protection Agency (EPA) Region 4 and the Office of Wetlands, Oceans, and Watersheds in support of the Total Maximum Daily Load (TMDL) program.

The WSTT is an interactive, user-friendly, two-step evaluation and targeting process. The first step allows for preliminary screening based on multiple criteria. Each criterion can be compared with a default or user-defined reference value. Data from EPA mainframe databases allow the user to compare reference values with land-use and water quality observations from watersheds under consideration. The second level of targeting, comparative analysis, allows for a more detailed examination of watersheds. In addition, this analysis permits the user to include subjective weights and additional data to the targeting procedure. The algorithms for this targeting system are based on a hierarchical structure of objectives and criteria, where a set of up to seven criteria can be used to describe the comparison objectives. Although the analysis objectives are project specific, the procedures are developed to use either user-specified data or information from provided databases. Weights can be entered to give greater or lesser value to particular criteria. This paper presents examples of the application of these techniques to sample watersheds in Alabama.

Introduction

Targeting of watersheds is used to allocate increasingly scarce water management resources for data collection, modeling studies, and management assessment, design, and construction. Water resource managers can use screening-level evaluations to help assess, compare, and prioritize the water quality problems of watersheds within their jurisdictions. The Watershed Screening and Targeting Tool (WSTT) makes it easier for watershed managers in federal, state, and local agencies to conduct these evaluations by providing easy access to the necessary data and facilitating targeting assessments. A prototype of WSTT has been developed that allows access to data for Alabama and Georgia. WSTT operates on a personal computer (286+) in a DOS environment.

WSTT provides an interactive, user-friendly, two-step evaluation and targeting process (Figure 1). The first allows for preliminary screening based on multiple criteria. Each criterion can be compared with a default or user-defined reference value. Data from U.S. Environmental Protection Agency (EPA) mainframe databases allow the user to compare reference values with land-use and water quality observations from watersheds under consideration. The second level of targeting, comparative analysis, allows for a more detailed examination of watersheds. In addition, this analysis permits the user to include subjective weights and additional data in the targeting procedure. The algorithms for this targeting system are based on a hierarchical structure of objectives and criteria, where a set of up to seven criteria can be used to describe the comparison objectives. Although the analysis objectives are project specific, the procedures are developed to use either user-specified data or information from provided databases. Weights can be entered to give greater or lesser value to particular criteria.

Watershed prioritization and targeting involve a multistep decision-making process using both technical criteria and subjective judgement. The use of formal targeting procedures throughout this process can assist in structuring the problem while taking into account all pertinent and site-specific concerns.

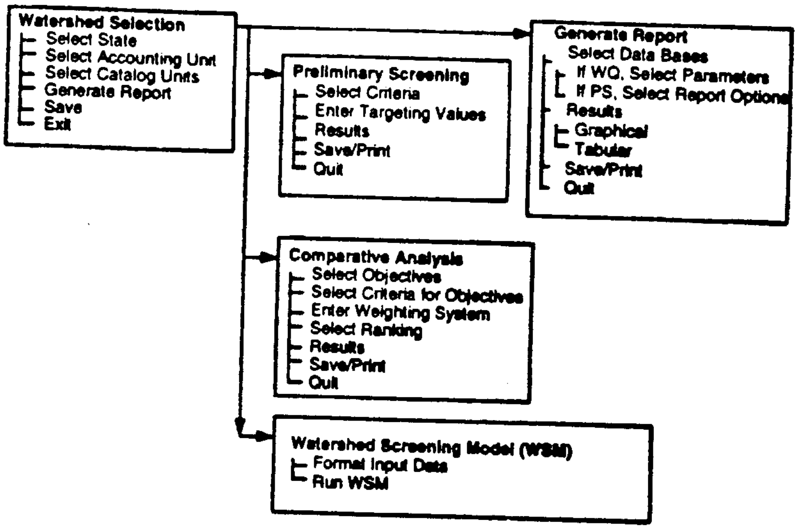

Figure 1. Schematic of WSTT components.

Multicriteria analysis techniques can aid in processing available information in a more structured framework, leading to a rational prioritization of watersheds. These procedures can be used in the Total Maximum Daily Load (TMDL) process to identify data sources, retrieve relevant water quality and watershed data, and analyze these data within a structured framework to determine which watersheds require management. The advantages of structured decision-making techniques—especially when dealing with numerous watersheds where the ranking in order of priority is not obvious *a priori*—include analysis directed toward the selection of pertinent decision criteria and identification of potential candidate watersheds; credibility of the selection process by the use of demonstrated and valid decision-making techniques; reductions in the cost and time for data collection and processing through a multiphase screening process; iterative evaluation of watersheds; and increased understanding of the various tradeoffs.

For the incorporation of targeting criteria and the generation of reports, WSTT is distributed with and relies on data that were selectively downloaded from EPA's mainframe computer. The databases that it uses include an accounting unit/catalog unit (CU) summary table, land use (U.S. Department of Agriculture Natural Resource Inventory summary of acres per land-use category), water quality (EPA STORET ambient water quality data summarized by CU for 50 parameters), reference levels (based on EPA water quality criteria), water supplies (number, flow, location, and type), point sources (number, flow, location, and type), and water bodies (number and size). These data, always available to the public, have traditionally been difficult to access without familiarity with EPA's mainframe. Through WSTT, these data are readily accessible. Using these databases, WSTT can generate reports, in table or graph form, on land use, water quality, water supplies, impoundments, and point source facilities in each of the selected areas.

The data that are distributed with WSTT can also be used to prepare preliminary data input files for a watershed screening model (WSM) which, for this prototype version, can be run for CUs within Georgia and Alabama. The watershed screening methodology permits simple watershed assessments that predict daily runoff, streamflow, erosion, sediment load, and nutrient washoff. The WSM relies on observed precipitation and temperature data from local meteorologic stations, municipal point source load estimations from pollutant concentrations in the literature, and nonpoint source loading functions for selected land uses based on literature values. Users can readily modify or revise the input data to reflect site-specific conditions. Output data from the model simulations can be used to augment information provided by the other databases.

Review of Potential Targeting Procedures

Most multicriteria decision techniques with potential application to the prioritization and targeting process can be grouped into three categories:

- *Sequential elimination:* Techniques to eliminate watersheds that do not show any need for controls.
- *Dominance theory:* Techniques to eliminate inferior or dominated watersheds that demonstrate a need for

pollution control but do not present a character of relative urgency.

- *Ranking procedures:* Techniques to prioritize remaining watersheds.

Sequential Elimination

The first group of analytical procedures target nonpriority watersheds or the nonfeasible set of watersheds. These procedures are typically referred to as sequential elimination techniques. Each watershed is compared with a hypothetical watershed using an amalgamation of standards and criteria. Watersheds that are better than the hypothetical watershed form the nonfeasible set and can be eliminated from further analysis. These techniques provide a preliminary filtering system to ensure the legitimate acceptability of the remaining set of watersheds. Sequential elimination techniques do not differentiate on the basis of relative importance, only on the ability to satisfy a condition of preset limits. Four relevant sequential elimination techniques, available for application in the prioritization process, include the conjunctive approach, the disjunctive approach, the lexicographic approach, and the compensatory approach (1).

The conjunctive approach screens out watersheds by establishing minimum cutoff levels for each discriminating criteria. Depending on the type of criterion and its method of measurement, the constraint or "cutoff level" is defined as either a categorical exclusionary or inclusionary limit. The application of a conjunctive scheme relates the decision criteria and their constraint with the logical "and" so that all constraints must be satisfied for a watershed to be eliminated from further consideration. Evaluation scales do not have to be homogeneous across criteria and can include logical, numeric, or natural scales. Because decision criteria and the set of watersheds are independent, each watershed is compared individually with a hypothetical set of constraints rather than with other watersheds. In general, decision criteria in the conjunctive approach should be carefully selected to focus on criteria with a strict regulatory requirement and technical constraints that cannot be relaxed or are not subject to tradeoffs.

The disjunctive approach is similar to the conjunctive scheme, but it requires that only one criterion be satisfied for a watershed to be eliminated from further consideration. Because this process is characterized by the logical relation "or," problem formulation must be defined in terms of the level of substitutions among the selected decision criteria.

Lexicographic screening differs from the previous techniques in that the value of each criterion is compared across watersheds (2). The criteria are first ordered in terms of their relative importance, and watersheds are then screened, starting with the most important criteria. Watersheds that pass this preliminary test are screened with the next highest ranked criteria until either all criteria are evaluated or the number of watersheds selected for further analysis is sufficiently reduced.

Compensatory analysis is a more elaborate form of conjunctive and disjunctive screening and deals primarily with preferential constraints where the cutoff levels are set by the objectives rather than by the criteria themselves (3). The analysis develops constraints on selected objectives that are represented in the decision problem by a group of two or more criteria. For each identified objective, the corresponding criteria are combined into a discriminating model expressing the degree to which each criterion achieves the objective. The discrimination process can be inclusionary, exclusionary, or both, depending on the screening model.

Dominance Theory

The second group of analytical tools with potential for application in the watershed prioritization and targeting process consist of techniques developed from the dominance approach. This approach serves to identify poorer watersheds rather than rank them completely. In this case, when the first watershed that has criterion values at least as poor as those of a second, as well as one or more values that are poorer, the first watershed will be selected for further analysis rather than the second. The first watershed is said to dominate the second. These techniques add some capability of determining which watersheds are worse than others beyond the simple comparisons offered by the sequential elimination schemes. Although several techniques have been developed based on this decision rule, their application to discrete decision space, such as watershed targeting applications, may not be effective in eliminating many watersheds. Among these techniques are the noninferior curve technique, the indifference map technique, and fuzzy outranking approaches.

The noninferior curve technique uses the distribution of the feasible set of watersheds within the decision space to identify inferior and noninferior sets (4). The curve defines the level of tradeoff between decision criteria where any incremental improvement in one criterion results in a balanced incremental decrease in other criteria. Application of this technique may require excessive computational time and professional training for interpretation of the results (5).

The indifference map technique relies on the representation of the preference structure to determine the family of indifference curves (6). An indifference curve represents points in the decision space for which the preference is equivalent among all criteria. This approach can be used in combination with the noninferior curve technique. Theoretically, if the one indifference curve tangent to the noninferior curve can be located, then watersheds lying farthest from the point of tangency form the set with the highest priority for controls.

Outranking techniques analyze sets of watersheds to derive binary relationships on the set rather than a function from this set to the real numbers, as in the case of the classical theory of decision analysis. This binary relationship also differs from classical decision analysis in the sense that it does not necessarily require a strict transitivity condition (7, 8). Outranking procedures can be used to select one and only one watershed, a set of acceptable watersheds, or a cluster of watersheds in an ordered sequence of indifference classes ranging from best to worst.

Ranking Procedures

The third group of analytical decision techniques ranks the set of watersheds under consideration. Several algorithms with potential application to discrete situations include utility theory, compromise programming and displaced ideal techniques, cooperative game theory, and the analytic hierarchy process.

Decision techniques developed based on the theory of utilities assign a utility function to each decision criterion, then compute the expected utility for each watershed using either an additive or multiplicative model (9). Watersheds that maximize the expected utilities may be eliminated from further analysis, and those with low ranking values form the set to be considered. The difficulties associated with application of the utility models reside in the development of representative utility functions for each criterion and the insurance that all criteria satisfy both preference and utility independence axioms. A utility function refers to a mapping of the values in the range of natural criteria scale to a bounded cardinal-worth scale reflecting the preference structures associated with that criteria as perceived by the decision-maker(s).

Compromise programming techniques have been applied extensively to water resources projects. These techniques attempt to identify watersheds that approach an ideal case (10), assuming that the watershed located the closest to the ideal watershed in the decision space can be eliminated from further consideration. The computation algorithms rank watersheds based on the normalized distance between each watershed and this ideal point. This approach can also be applied to identify watersheds that are the closest to an anti-ideal point using a similar minimization scheme.

Cooperative game theory is a representation of a conflict situation based on the general concepts of rational behavior. Optimization of a set is sought by well-informed decision-makers with conflicting objectives who are aware of their preference structure. The objective of each participant in the game is to identify solutions that are high on the preference scale. A generic algorithm based on this theory for an n-person game was developed by Harsanyi (11). This algorithm was generalized for a regional ground-water pollution problem (12) and for the analysis of wastewater management alternatives (13).

The analytic hierarchy process was developed in an effort to expand the classical decision models to include subjective analysis of multilevel or hierarchical systems (14, 15). The process consists of decomposing the decision problem into smaller subproblems, analyzing each subproblem individually, and then recomposing the results to reach a complete ranking of the set of watersheds considered. It relies strongly on the structuring of the decision problem into an intuitively logical hierarchy of objectives and criteria. The hierarchical structures express the factual relationships between the decision elements (objectives, criteria, and alternatives). This decision process parallels the principles of analytical thinking (16): constructing hierarchies, establishing priorities, and logical consistency.

Targeting Techniques in WSTT

The review of decision analysis techniques, briefly described above, provided the background for the development of the targeting tools used in the WSTT. The development of decision-making techniques for watershed prioritization and targeting was based on the following:

- Ability to perform a multicriteria analysis.
- Applicability to discrete situations with a limited number of watersheds.
- Applicability to selecting the worst watersheds rather than the preferred conditions, as is the case in most decision situations for TMDLs or watershed management.
- Flexibility of problem structuring, data processing, and the ability to decompose the problem into smaller and more homogeneous components.
- Stability of the final ranking using simple scaling procedures.
- Ease of interpreting the rankings.
- Ability to perform sensitivity analysis and consistency testing of the value judgment.

These considerations led to the development of a two-step targeting approach consisting of both a preliminary screening and a formal comparative analysis. A test watershed is used for illustrating examples of the two types of screening techniques (Figure 2).

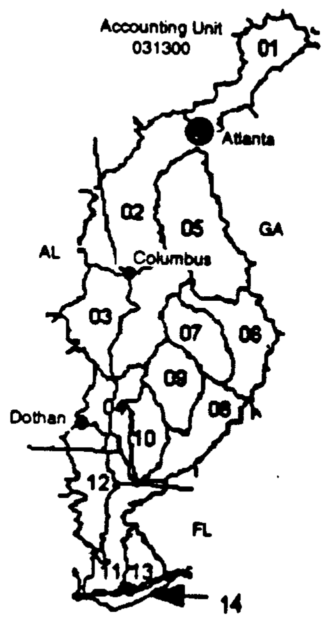

Figure 2. Watersheds selected for preliminary screening.

Preliminary Screening Analysis

The screening level analysis of watersheds at a regional or accounting unit scale is designed to help users understand what the water quality conditions are in each watershed and how the factors governing quality vary from one watershed to the next. The advantage of this procedure is its ability to operate under the WSTT environment, using automatically retrieved values for the desired decision criteria, and iteratively screen out watersheds that do not represent a significant water quality problem.

The screening algorithm used in WSTT consists of a sequential elimination scheme adapted from the conjunctive approach described in the previous section. The objective of this process is to identify watersheds that do not represent a significant water quality problem and consequently reduce the set of watersheds to a workable number. The significance of the water quality problem is, however, indirectly introduced into the analysis through the selection of screening criteria indicative of the problem under consideration and the magnitude of each criterion cutoff level. Figure 3 illustrates this process using a single water quality criterion, and Figure 4 presents the case of a two-criteria screening. Based on the sample cutoff limit shown in Figure 3, six watersheds (1, 2, 3, 4, 5, and 13) would be selected for further analysis. In Figure 4, two criteria are examined. In this case, both acres of urban land and BOD_5 concentrations are selected for examination. Values outside the upper limits for either of the two criteria would be selected for

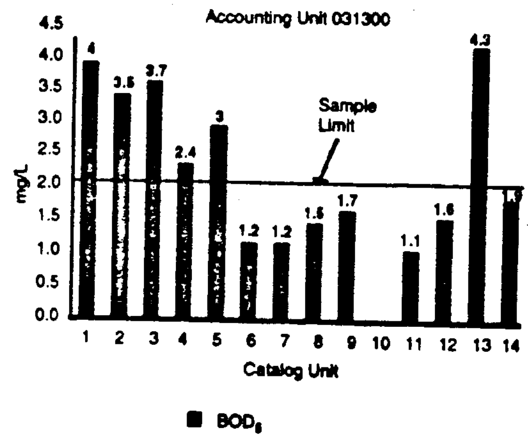

Figure 3. Preliminary screening example with one criterion.

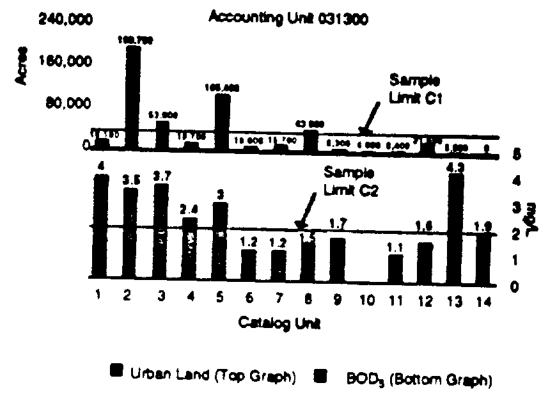

Figure 4. Preliminary screening example with two criteria.

further examination. In this case, seven watersheds (1, 2, 3, 4, 5, 8, and 13) would be selected. The user can select the cutoff limits in an iterative fashion to examine the differences between the watersheds. Multiple criteria can be selected for evaluation, depending on data availability and watershed characteristics. This provides a quick and easy approach for preliminary evaluation of the differences between the watersheds selected for examination.

For a multidimensional problem, each criterion is defined in terms of a cutoff limit representing a vector of threshold values. Depending on the type of criterion and its measurement scale, each value in this vector may either represent an upper or a lower limit. Examples of criteria with an upper limit are water quality parameters for which the cutoff limit represents a concentration that should not be exceeded. On the other hand, criteria with a lower limit include those with ascending scales in which the higher values are better, such as in the case of dissolved oxygen concentration.

The watershed screening level analysis in WSTT allows users to retrieve screening criteria and their values automatically from available, preprocessed databases. When the criteria represent water quality parameters, watershed rating with respect to each criterion can be expressed in terms of a mean value, a median, or a quartile. Multiple databases can be accessed sequentially. Access to the water quality and land-use databases is enabled at the present time. Cutoff limits are user specified and can be modified in an iterative scheme by either relaxing the criteria's cutoff limit and consequently decreasing the set of selected watersheds or by making them more stringent. Watersheds eliminated during this screening level analysis can still be considered in the comparative analysis phase. The output of this algorithm generates a list of watersheds that do not satisfy the criteria's cutoff levels. For these watersheds, the corresponding input data (payoff-matrix) can be accessed through the reporting option of the WSTT. Watersheds that satisfied all user-specified constraints are also tabulated. As noted earlier, the screening analysis does not take into consideration the relative differences in the exceedence of the observations beyond the upper limit. For examination of the relative importance and actual ranking of the watersheds, the comparative analysis technique is used.

Comparative Analysis in WSTT

The objective of the comparative analysis is to provide a system that captures both the importance of the selection objectives and that of the criteria describing these objectives. Comparative analysis can provide a complete ordering of watersheds. The process requires that the targeting problem be formulated in terms of a decision situation and that judgement values be incorporated into each phase of analysis. At this level of analysis, additional measurable and subjective criteria are usually incorporated into the analysis; therefore, the algorithm provides a logical scaling system to evaluate the importance of these objectives on a common basis. The algorithm also incorporates a mathematical framework to amalgamate the value judgement and the watershed observations with respect to each criterion or objective in terms of a ranking index.

Four subroutines incorporated in the development of the comparative analysis algorithm in the WSTT are described below.

Structuring of the Targeting Problem

The formulation of watershed prioritization problems in WSTT consists of a multilevel hierarchical structuring of the selection objectives, the decision criteria, and the alternative watersheds. This formulation separates the selection problem into several smaller and homogeneous subproblems which can be easily compared. Figure 5 illustrates a generic representation of a clustered hierarchy in which the project is decomposed into a set of simple and smaller subprojects. Each subproject can be analyzed separately, and the results can be reintegrated to obtained an overall ranking of the watersheds.

Value Judgment

The decision-maker's value judgment is introduced in terms of the importance weight coefficients of the objectives and criteria. The derivation of criterion importance weights proceeds according to the hierarchical structure of the decision problem, starting from the higher level objectives. This routine takes the decision-maker through a series of paired comparisons cluster by cluster in the order shown by the roman numerals in Figure 5. For each paired comparison between two criteria, the decision-maker defines which criterion of the pair is more important and determines the magnitude of the importance using the integer ratio scale presented in Table 1. The magnitude of importance is not the desired importance weight but rather a measure of a pairwise ratio defined as follows:

$$a_{ij} = \frac{W_i}{W_j} \qquad \text{(Eq. 1)}$$

where a represents the ratio of importance weight W of criterion i over that of criterion j.

The use of the ratio scale defined in Table 1 generates a square, positive, and reciprocal matrix in which the importance weight coefficients consist of the entries of the eigenvector corresponding to the maximum eigenvalue of the this matrix. The characteristics of the resulting comparison matrix are summarized as follows:

$$a_{ij} = \frac{1}{a_{ji}} \qquad \text{(Eq. 2)}$$

for all i and j;

$$a_{ii} = 1 \qquad \text{(Eq. 3)}$$

for all i=1 to n where n is the number of criteria; and

$$a_{ik} = a_{ij} + a_{ik} \qquad \text{(Eq. 4)}$$

The rationale for determining the eigenvector corresponding to the maximum eigenvalue as the importance weight coefficient vector derives naturally from the type of scale used in the pairwise comparisons and the as-

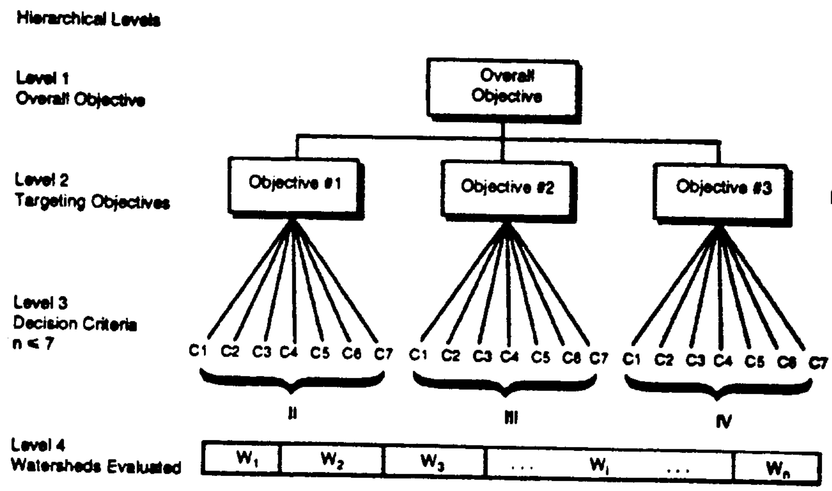

Figure 5. Generic representation of the watershed targeting problem in WSTT.

Table 1. Evaluation Scale Developed by Saaty (14) for Use in the Analytic Hierarchy Process

Intensity of Importance	Definition	Explanation
1	Equal importance	Two activities contribute equally to the objective.
3	Weak importance of one over another	Experience and judgment slightly favor one activity over another.
5	Essential of strong importance	Experience and judgment strongly favor one activity over another.
7	Demonstrated importance	An activity is strongly favored, and its dominance is demonstrated in practice.
9	Absolute importance	The evidence favoring one activity over another is of the highest possible order of affirmation.
2, 4, 6, 8	Intermediate values between the two adjacent judgments	Compromise is needed.
Reciprocal of above nonzero	If activity i has one of the above nonzero numbers assigned to it when compared with activity j, then j has the reciprocal value when compared with i.	
Rational	Ratio arising from the scale	Consistency is forced by obtaining n numerical values to span the matrix.

sociated matrix theory used in solving nonlinear systems, expressed in matrix form as

$$A \cdot W = n \cdot W, \qquad \text{(Eq. 5)}$$

where A is the comparison matrix with n entries, n is the number of criteria, and W is the vector of importance weight coefficients. The solution of the above eigenvalue problem for each cluster in the order shown in Figure 5 provides a partial weight coefficient for each criterion. The overall weight can be derived by multiplying the partial weight of the dominant objective by that of the criteria:

$$W_i = W_p\,(objective) \cdot W_p(criteria_i). \qquad \text{(Eq. 6)}$$

Consistency of the Preference Structure

When dealing with large numbers of objectives and criteria, the preference structure tends to lose its transitive character. As intransitive comparisons are introduced, the resulting matrices become less consistent, and the importance weight coefficients may not represent the true preference structure.

For a perfectly consistent positive reciprocal matrix, the maximum eigenvalue should equal the order of the matrix. This suggests that the remaining eigenvalues are equal to zero. As small inconsistencies are introduced into the matrix because of intransitive judgements, they lead to very small perturbations in the original set of eigenvalues. This represents the fundamental theory of consistency measurement in positive reciprocal matrices (14). The more the maximum eigenvalue deviates from that of a consistent matrix, the less consistent the pairwise comparisons are. A consistency index developed by Saaty (14) was introduced into the targeting subprogram in WSTT to indicate the degree of consistency at the end of each series of pairwise comparisons. A consistency index of 0.0 indicates a perfect consistency, and a value of 1.0 indicates a fully inconsistent matrix. Because of the use of an integer scale in addition to the nonlinearity of certain subjective judgments, a slight nonconsistency in developing importance weight coefficients is common. In fact, a fully consistent comparison is not required to reach the desired accuracy. Analysis of the sensitivity of eigenvalue solution shows that matrices with a consistency ratio of up to 0.1 are acceptable (17).

Ranking of Watersheds

The hierarchic representation of the watershed targeting process is a logical structure for integrating the decision elements into a single problem and deriving the selection priorities defined in terms of objectives, criteria, and their respective weight coefficients. To derive the overall ranking of the watersheds, a simplified form of the additive utility model is used. This model is described in much of the relevant literature as the best known of the multiattribute utility functions because of its relevance to a wide range of decision problems, its stability in ranking alternatives, and its simplicity of application. This model is also used in most index calculations. Its generic expression when applied to a hierarchic problem takes the following form:

$$U_i = \sum_{j=1}^{N} W_j \cdot \sum_{k=1}^{M} W_k \cdot V_{ik} \qquad \text{(Eq. 7)}$$

where

W = weight coefficient
N = number of objectives
M = number of criteria under each objective
U = ranking of watershed i
V = measurable value of lower level criteria

This model uses normalized values of the criteria in an ascending scale, meaning that the higher values are better. The ranking is therefore performed on a descending scale so that watersheds with the lowest scores are identified as the priority watersheds.

The results of a sample application are shown in Table 2 below. For illustration purposes, a comparative analysis was applied, using WSTT, to six watersheds in Alabama. Three criteria were selected for examination—BOD5, ammonia, and iron—based on the 85th percentile of all data available on STORET since 1980. The values used for the comparative analysis are shown first. Three types of weights are shown: equal weights and two variable options. The final section of Table 2 shows how the changes in weights affect the resulting ranking of the watersheds. The ability to adjust weights and test a variety of user- and system-provided criteria allows for a wide range of flexibility in the assessment of watershed ranks. Users can thereby incorporate best professional judgement and local knowledge into the targeting procedure in a systematic fashion.

Table 2. Description of Comparative Analysis Application

Values Used for Comparative Analysis (Payoff Matrix)

Catalog Unit	Criterion 1 BOD_5 (mg/L)	Criterion 2 NH_4 as N (mg/L)	Criterion 3 Fe (µg/L)
0313001	4.0	0.27	1,100
0313002	3.5	0.62	1,600
0313003	3.7	0.30	315
0313004	2.4	0.14	680
0313005	3.0	0.66	2,900
0313013	4.3	0.16	370
Calculated Importance Weight Coefficients			
Criteria	**Equal**	**Variable 1**	**Variable 2**
1 (BOD_5)	0.333	0.122	0.637
2 (NH_4 as N)	0.333	0.648	0.258
3 (Fe)	0.333	0.230	0.105
Final Watershed Ranking			
Catalog Unit	**Equal**	**Variable 1**	**Variable 2**
0313001	3	3	3
0313002	4	2	1
0313003	5	4	5
0313004	6	6	6
0313005	1	1	4
0313013	4	5	2

Application of the comparative analysis requires users to evaluate which criteria are relevant and significant to the local watershed conditions. Often, application will be constrained by the availability of water quality sampling information or other data. Consideration should also be given to possible dependence between two criteria selected. Criteria should be independent for accurate assessment of watershed ranking.

Conclusions

The WSTT program and associated databases provide watershed managers with the tools to effectively target and assess watersheds on a broad scale. The two levels of targeting tools included with the WSTT allow for a range of targeting applications—from simple to sophisticated—depending on project needs. The incorporation of the comparative targeting tool provides the valuable addition of subjective judgement and user-defined parameters to the decision-making structure. This powerful algorithm allows managers to refine decision-making criteria and evaluate multiple and often conflicting objectives. The incorporation of targeting tools and databases into a user-friendly PC environment can make these powerful techniques convenient and accessible to a wide range of water resources professionals.

Acknowledgments

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Hydrocarbon Hotspots in the Urban Landscape

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Abstract

This paper reports on a monitoring study that compared hydrocarbon, polycyclic aromatic hydrocarbons (PAHs) and trace metal levels in stormwater runoff captured within standard oilgrit separators (OGSs) serving five automotive-related land uses in the Maryland Piedmont. Composite priority pollutant scans and trace metal samples were collected from the pools and the trapped sediments of 17 OGSs serving gas stations, convenience commercial, commuter parking lots, streets, and residential townhouse parking lots. Previous studies indicated that OGSs were not effective in trapping sediments over the long term, based on sediment accumulation rates over time. Oily sediments, however, were retained over a short term, making the OGS sites useful sampling ports to characterize differences in hydrocarbon and toxic levels in small, automotive-related land uses.

Gas stations had significantly higher hydrocarbon, total organic carbon, and metal levels than all other sites in both the water column and the sediments. Convenience commercial and commuter parking lots had moderate levels of contamination, with the lowest levels recorded for streets and residential townhouse parking lots. Mean hydrocarbon concentrations of 22 mg/L and 18,155 mg/kg were recorded for the water column and the sediments at gas station OGS sites. The priority pollutant scan identified 37 potentially toxic compounds in the sediments and 19 in the pools of gas station OGS sites. This can be compared with non-gas-station sites, which had 29 and 7 toxics in the sediment and water column, respectively. Some of the gas station priority pollutants included naphthalene, phenanthrene, pyrene, toluene, xylene, chrysene, benzene, phenols, acetone, and numerous trace metals.

The source of these pollutants appears to be spillage or leakage of oil, gas, antifreeze, lubricating fluids, cleaning agents, and other automotive-related compounds. The study suggests that numerous "hotspots" exist in the urban landscape that generate significant hydrocarbon and PAH loadings, particularly where vehicles are fueled, serviced, and parked for extended periods. Preliminary computations suggest a possible link between these hotspots and sediment PAH contamination of a local estuary.

Introduction

Over the past decade, nearly one thousand oil grit separators (OGSs) have been installed in the metropolitan Washington area to treat urban stormwater runoff from small drainage areas. These structures consist of two precast chambers connected to the storm drain system (Figure 1). The first chamber is termed the grit chamber and is used to trap coarse sediments. The second chamber, termed the oil chamber, is used to temporarily trap oil and grease borne in urban runoff so that they may ultimately adsorb to suspended sediments and settle to the bottom of the chamber.

Most OGSs control runoff from highly impervious sites of an acre or less and have a storage volume of 0.06 to 0.12 in. of runoff, depending on the local design. As such, OGSs were never expected to achieve high rates of pollutant removal (1). Rather, they are intended to control hydrocarbons, floatables, and coarse sediments from small parking lots that cannot normally be served by other, more effective best management practices.

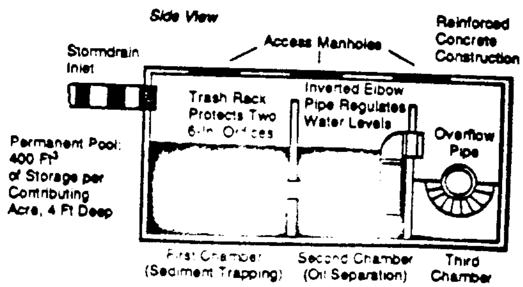

Figure 1. Schematic diagram of an OGS (1).

From a monitoring standpoint, OGSs are interesting in that they act as a very useful and standardized sampling port to extract runoff samples from very small areas of differing automotive land use. It was hypothesized that hydrocarbon and trace metal levels might be greater at sites where vehicles were parked, serviced, or fueled. These potential "hotspots" had never been systematically monitored in the metropolitan Washington area before.

Methods

A two-tiered monitoring strategy was employed to test the effectiveness of OGS systems and to detect hydrocarbon hotspots. In the first tier of sampling, 110 OGS systems were surveyed to determine their general characteristics in the field. Each structure was sampled for the mass and particle size distribution of trapped sediments, land use, age, maintenance history, secchi depth, and other engineering parameters (2).

The emphasis on the second tier of sampling was to characterize the range of pool and sediment quality found within OGS and related systems. Nineteen of the Tier 1 sites were selected for additional detailed sampling of the quality of pool water and trapped sediments. The sites were grouped into five land-use categories: townhouse parking lots, streets, all-day parking lots, gas stations, and convenience store parking lots. Sediment and pool samples were collected from each chamber and were subsequently analyzed for nutrients, soluble and extractable metals, total organic carbon (TOC), and total hydrocarbons.

In addition, six priority pollutant scans were conducted based on composite sediment and pool water samples from gas station sites, non-gas-station sites, and all five land-use sites combined. The samples were analyzed for the presence of 128 compounds outlined in the U.S. Environmental Protection Agency's (EPA's) priority pollutant list. A complete description of the sampling and analytical protocol is contained in Schueler and Shepp (3).

Results

Retention of Sediments In OGS

The field surveys indicated that OGS systems had poor retention characteristics. The average wet volume of trapped sediments in 110 OGSs was 11.2 ft^3, with an average sediment depth of only 2 in. If OGS systems were highly retentive, the mass of trapped sediments would be expected to increase with age. No such relationship was evident, however, in the 110 OGSs surveyed (Figure 2), suggesting that frequent scour and resuspension occur.

Monthly sampling of sediment depths in individual OGS systems revealed sharp fluctuations in depth over time (Figure 3), with up to a 50-percent decrease in sediment depths recorded in a single month. Dye tests indicated pool residence times of less than 30 min during storms. Consequently, it is thought that the mass of trapped sediments contained within an OGS at any given point represents only a temporary accumulation of pollutants.

General Characteristics of OGS Systems

Trapped sediments within OGSs were coarse-grained, highly organic, oily in appearance, and interlaced with litter and debris. Sediments were also quite soupy; only 45 percent total mass of sediment existed as dry weight. The proportion of volatile suspended solids, a measure of the general organic content of the sediments, averaged 15 percent of total mass.

OGS pools frequently had a thin oil sheen or surface scum, and oil stains were present on the chamber walls. Despite the sheen, the pool water was relatively transparent, with an average secchi depth of 14 to 22 in. Floatable trash was present in low to moderate quantities.

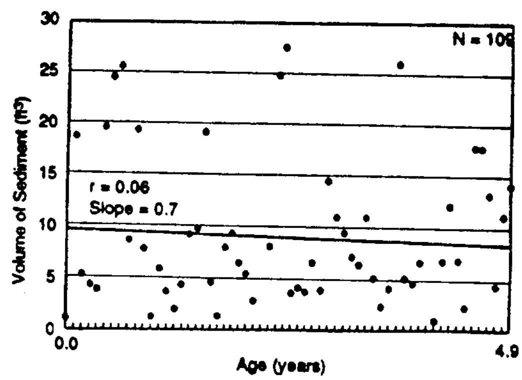

Figure 2. Relationship of OGS age and volume of trapped sediments (2).

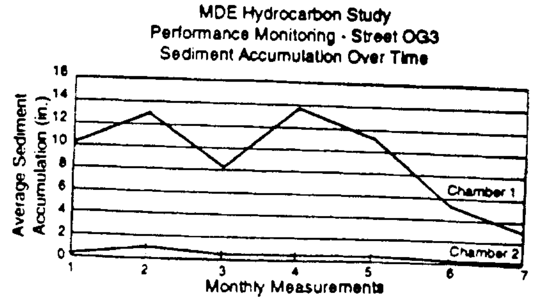

Figure 3. Monthly change in depth in OGS (1).

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Table 1. Characterization of Pollutant Concentrations in the OGS Water Column: Effect of Land-Use Condition (Mean Values)

Sampled Parameter	All-Day Parking (N = 8)	Convenience Commercial (N = 6)	Gas Stations (N = 7)	Streets (N = 6)	Townhouse/ Garden Apartments (N = 6)
OP (mg/L)	0.23	0.16	0.11	ND	0.11
TP (mg/L)	0.30	0.50	0.53	0.06	0.19
NH_3-N (mg/L)	0.20	1.58	0.11	0.19	0.20
TKN (mg/L)	1.16	4.94	2.5	0.84	1.00
OX-N (mg/L)	0.65	0.01	0.21	0.92	0.17
TOC (mg/L)	20.60	26.80	95.51	9.91	15.75
Hydrocarbons (mg/L)	15.40	10.93	21.97	2.86	2.38
TSS (mg/L)	4.74	5.70	—	9.60	7.07
ECD (µg/L)	6.45	7.92[a]	15.29[a]	ND	ND
SCD (µg/L)	3.40[a]	ND	6.34[a]	ND	10.34[a]
ECR (µg/L)	5.37	13.85	17.63[a]	5.52[a]	ND
SCR (µg/L)	ND	ND	6.40[a]	ND	4.79[a]
ECU (µg/L)	11.61	22.11	112.63	9.60[a]	3.62
SCU (µg/L)	8.22[a]	ND	25.64	ND	2.40
EPB (µg/L)	13.42	26.87	162.38	8.23	ND
SPB (µg/L)	8.10[a]	ND	26.90[a]	ND	ND
EZN (µg/L)	190.00	201.00	554.00	92.00	NA
SZN (µg/L)	106.70	43.70	471.00	69.00	59.00

[a]Mean is for all observations in which the indicated parameter was actually detected.
ND = not detected; NA = not applicable.

OP = ortho phosphate phosphorus
TP = total phosphorus
NH3-N = ammonia nitrogen
TKN = total Kjeldahl nitrogen
OX-N = oxidized nitrogen
TOC = total organic carbon
Hydrocarbons = total hydrocarbons
TSS = total suspended solids
ECD = extractable cadmium
SCD = soluble cadmium
ECR = extractable chromium
SCR = soluble chromium
ECU = extractable copper
SCU = soluble copper
EPB = extractable lead
SPB = soluble lead
EZN = extractable zinc
SZN = soluble zinc

The influence of contributing land use on the quality of OGS pool water is evident in Table 1. In general, the concentration of conventional pollutants such as nutrients and suspended solids was similar to many other reported urban stormwater runoff datasets (1). The pool water concentrations of total hydrocarbons, TOC, and soluble and extractable trace metals, however, were much higher. In particular, the average concentration of total hydrocarbons exceeded 10 mg/L in three of the five land uses studied. Analysis of variance indicated that gas station OGS sites had significantly greater pool water hydrocarbon, TOC, zinc, copper, lead, and cadmium levels that any other OGS sites.

The influence of contributing site land use was even more pronounced when sediment quality was analyzed (Table 2). OGS sediments were all heavily enriched with hydrocarbons, TOC, nutrients, and metals. The gas station OGS sites had significantly higher hydrocarbon, TOC, phosphorus, and metals concentrations compared with the other four land uses. Convenience commercial and all-day parking sites generally had higher levels than streets and townhouse parking lots.

Effects of Automotive Land Use

Previous priority pollutant scans of stormwater runoff and pond sediments from primarily residential land uses in the metropolitan Washington area had failed to detect the presence of polycyclic aromatic hydrocarbons (PAHs) (4). Numerous PAHs and other compounds on EPA's priority pollutant list, however, were detected in the automotive-influenced sites of the OGS study (Tables 3 and 4).

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Table 2. Characterization of the Quality of Trapped Sediments in OGS: Effect of Land Use

Parameter (mg/kg)	All-Day Parking (N = 8)	Convenience Commercial (N = 6)	Gas Stations (N = 7)	Streets (N = 6)	Townhouse/ Garden Apartments (N = 6)
TKN	1,951.0	5,528.0	3,102.0	1,719.0	1,760.0
TP	466.0	1,020.0	1,058.0	365.0	266.7
TOC	37,915.0	55,617.0	98,071.0	33,025.0	32,392.0
HC	7,114.0	7,003.0	18,155.0	3,482.0	894.0
Cadmium	13.2	17.1	35.6	13.6	13.5
Chromium	258.0	233.0	350.0	291.0	323.0
Copper	186.0	326.0	786.0	173.0	162.0
Lead	309.0	677.0	1,183.0	544.0	180.0
Zinc	1,580.0	4025.0	6,785.0	1,800.0	878.0

TKN = total Kjeldahl nitrogen, TP = total phosphorus, TOC = total organic carbon, HC = total hydrocarbons. All metals are extractable.

A total of 19 priority pollutants were detected in pool water at the gas station OGS sites, compared with seven detected at non-gas-station sites, most of which were metals. Thirteen volatile and semivolatile priority pollutant compounds were detected in pool water at the gas station OGS sites. Semivolatile compounds included phenols, naphthalene, and plasticizers, whereas the volatile compounds included acetone, benzene, toluene, xylene, and ethyl benzene. Most, if not all, of these compounds are linked to gasoline and its derivatives, lubricants, and cleaning agents customarily found at gas stations (5).

An even greater number of priority pollutants, 26, were detected in the trapped sediments of gas station OGS sites. An additional 11 priority pollutants were indicated but were below analytical detection limits. Metals and PAHs dominated the list of confirmed priority pollutants. PAHs found at the highest concentrations in the sediment included 2-methylnapthalene, naphthalene, phenanthrene, fluoranthene, pyrone, and christen. Three of these PAHs have been listed as toxics of concern by the EPA Chesapeake Bay Program (5). Most of these PAHs are strongly associated with gasoline and its byproducts. The gas station OGS sites had the highest sediment metals levels, particularly for cadmium, copper, chromium, lead, and zinc.

Only nine PAHs were recorded at the non-gas-station OGS sites, and in nearly all cases the concentration in the sediments was lower. Interestingly, the only pesticides detected in the sampling were discovered at the more residential non-gas-station sites.

Discussion

The monitoring study has several interesting implications for urban stormwater runoff and its effective control, which are discussed below.

Hydrocarbon Hotspots in the Urban Landscape

The results suggest that hotspots of possible hydrocarbon and metal loading do exist in the urban landscape, and that these are likely to occur where vehicles are fueled, stored, or serviced. In this study, gas stations and, to a somewhat lesser degree, frequently used parking lots clearly exhibited greater hydrocarbon and metal loading potential than more residential sites. Future monitoring may reveal other potential hotspots such as bus depots, loading bays, highway rest areas, and vehicle maintenance operations.

The traditional management approach for urban runoff quality has been to specify a uniform treatment standard for all impervious areas across the urban landscape (e.g., the first half inch of runoff). Based on the results of this study, a more effective strategy might be to supplement uniform standards with more stringent treatment requirements when a possible hydrocarbon hotspot may be involved.

Only nine PAHs were recorded at the non-gas-station OGS sites, and in nearly all cases the concentration in the sediments was lower. Interestingly, the only pesticides detected in the sampling were discovered at the more residential non-gas-station sites.

Possible Link to Estuarine Sediment Contamination

The bottom sediments of most of the nation's urban estuaries are frequently contaminated with hydrocarbons, PAHs, and metals. The sources of the ubiquitous and pervasive contamination may include air deposition, fuel spills, leaking underground storage tanks, leachate from landfills or industrial sites, industrial discharges, and waste oil dumping, among others. This study suggests

Table 3. Priority Pollutants Detected in Composite Scans of OGS Sediments

Compound (µg/kg)	Gas	Nongas	All Site
Semivolatile Organics			
Napthalene	9,000	—	S
2-Methylnapthalene	24,000	S	S
Acenapthene	1,800	—	—
Fluorene	3,200	—	—
Phenathrene	11,500	1,800	S
Fluoranthene	3,400	2,000	20,000
Pyrene	5,800	2,300	26,000
Butylbenzylpthalate	3,400	S	S
Chrysene	2,200	1,200	S
bis (2-Ethylhexyl) pthalate	44,000	13,000	220,000
Di-n-octyle pthalate	2,900	S	S
Benzo (b) flouranthene	1,400	S	S
Indeno (123-cd) pyrene	1,400	S	S
Benzo (g,h,i) perylene	1,900	S	S
Di-n-butyl pthalate	S	1,800	S
Volatile Organics			
Toluene	6,800	2,300	7,500
Ethylbenzene	S	3,100	—
Total xylenes	6,900	13,000	—
Methylene chloride	S	S	—
Pesticides and PCBs			
Aldrin	—	29	950
4,4-DDT	—	29	—
Metals			
Antimony (mg/kg)	5.1	—	—
Arsenic	4.1	2.6	6.2
Beryllium	0.3	0.5	1.6
Cadmium	6.5	0.8	7.2
Chromium	123	37	91.3
Copper	126	36	132
Lead	493	46	145
Nickel	50	50	95
Silver	—	—	2
Zinc	953	261	1,650
Cyanide and Phenols			
Phenol	25.6	8.0	76.2
Cyanide	—	—	—

S = detected but at concentrations under the detection limit
— = not present

Table 4. Priority Pollutants Detected in Composite Scans Within the OGS Water Column

Compound (µg/kg)	Gas	Nongas	All Site
Semivolatile Organics			
Benzyl alcohol	10	—	—
2-Methylphenol	22	—	—
3,4-Methylphenol	32	—	—
2,4-Dimethylphenol	16	—	—
Napthalene	100	—	—
2-Methylnapthalene	43	—	—
bis (2-Ethylhexyl) pthalate	14	—	—
Chrysene	—	—	12
Volatile Organics			
Acetone	57	13	46
2-Butanone	16	—	—
Benzene	18	—	—
Toluene	140	5	—
Ethylbenzene	41	—	—
Total xylenes	230	—	—
Pesticides and PCBs	—	—	—
Metals			
Antimony	—	—	—
Arsenic	1.0	1.0	—
Beryllium	—	1.2	—
Cadmium	—	—	8
Chromium	5	6.2	5
Copper	72	6.3	15
Lead	48	3.3	5
Nickel	—	—	—
Silver	—	—	—
Zinc	373	65	132
Cyanide and Phenols			
Cyanide	—	—	—
Phenol	86	10	24

that the washoff of leaked fuels and fluids from vehicles may also be a key source of sediment contamination.

The significance of runoff from hydrocarbon hotspots in sediment contamination may be great. For example, 12 out of 13 PAHs present in the sediments of the tidal Anacostia estuary were also present in the trapped sediments of gas station OGS sites. On average, the concentration in OGS sediments was seven times greater than that recorded in the tidal estuary. Of even greater interest is the finding that the relative composition of PAHs in both the river and OGS sediments was quite similar (3). While the possible link between runoff from hydrocarbon hotspots and estuarine sediment contamination remains suggestive rather than conclusive at this point, the subject merits further monitoring and analysis.

Opportunities for Pollution Prevention at Hotspots

Because leakage, spills, and improper handling and disposal of automotive products appear to be the key source of many of the pollutants observed at hydrocarbon hotspots, an effective control strategy involves the use of pollution prevention practices. For small vehicle maintenance operations, these may include techniques to run a dry shop, reduce run-on across work areas, use less toxic cleaning agents, control small spills, store automotive products in enclosures, and, perhaps most importantly, train employees to reduce washoff of automotive products from the site (6).

Implications for OGS Cleanout and Disposal

The original purpose of the study was to establish the characteristics of trapped sediments and pool water within OGS sites to determine the most appropriate and safe disposal method. Based on preliminary data, OGS residuals do not quite meet criteria to be considered hazardous for landfilling (7). Many local landfills, however, may set more stringent criteria and will not accept OGS sediments unless they are fully dewatered. Introduction of OGS residuals into the sanitary system appears also to be prohibited due to utility pretreatment requirements.

Regular cleanout of OGS systems appears to be quite rare. For example, none of the 110 OGS systems surveyed in the field appeared to have been maintained in the last year (2). Given the poor retention characteristics of existing OGS designs, a minimum frequency of quarterly cleanouts would seem warranted to ensure that the trapped residuals are removed before they are resuspended. The cost to cleanout an OGS system and safely dispose of the trapped sediments, however, could exceed $400 per site visit. The need for frequent and costly cleanouts, coupled with the ambiguities regarding the possible toxicity of trapped sediments, raises serious concerns about the effectiveness of the current generation of OGS systems.

Outlook for Improvements in OGS Design and Performance

The study indicates that the current generation of OGS systems does not retain trapped pollutants and therefore must be maintained at an unrealistically high frequency. Clearly, the retention characteristics of OGS must be sharply increased if they are to become a credible urban best management practice.

Several design improvements have the possibility of increasing the retention of pollutants. These include designing the OGS to be fully off-line, so that larger runoff events bypass the OGS and reduce the frequency of sediment resuspension; providing larger treatment volumes; using sorptive media, fabrics, or pads within chambers; and modifying the geometry of each chamber to reduce turbulence in the vicinity of trapped sediments. Until the improved retention of these design modifications is confirmed in the field, however, it may not be advisable to use OGS systems on a widespread basis.

Given the possible importance of hydrocarbon hotspots in the urban landscape and the apparent inadequacy of the current generation of onsite best management practices to control them effectively, it is strongly recommended that an intensive research and demonstration program be started to evaluate alternative small-site runoff treatment technologies.

Acknowledgments

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Design Considerations for Structural Best Management Practices

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Abstract

Upon selection of the appropriate structural best management practice (BMP) to address an urban runoff management need, the design process begins. Successful BMP design does not consist merely of achieving required technical performance levels specified in a government regulation. To meet both the letter and spirit of the regulation and to help encourage the public participation vital to the future of urban runoff management, a responsible BMP designer must also acknowledge and address several other technical and nontechnical considerations.

This paper emphasizes the need for a strong theoretical understanding of standard design models and equations. It also recommends a technique for identifying and evaluating a structural BMP's inherent maintenance, safety, and aesthetic needs that may not be readily apparent when using more conventional design procedures. The paper also identifies the individuals and agencies that will interact with a structural BMP during its design and/or following its construction, and emphasizes the need to include their interests in the BMP design process.

Finally, in recognition of the nascent state of nationwide stormwater management, the paper encourages BMP designers to contribute to the continued development of the field by conducting their designs in an open and objective manner and by continually seeking new and better responses to the many stormwater management challenges we face.

Introduction

> design \di-zine\ vb 1: to conceive and plan out in the mind; 2: to devise for a specific function or end; 3: to conceive and draw the plans for (Merriam-Webster Dictionary)

This definition succinctly describes both the scope and sequence of activities typically undertaken by the designer of a structural best management practice (BMP). Having identified a stormwater management problem or need that can best be solved through the construction of a structural BMP, the designer then selects the most appropriate type of BMP, conceptualizes its function and operation, and determines the specific characteristics necessary for the BMP to achieve its desired performance. Having completed this, the designer must then transform these characteristics into a physical entity. This is done through the development of detailed construction plans and specifications, which are used to construct the BMP in the field.

Throughout the entire endeavor, the structural BMP designer must, of course, fulfill certain technical responsibilities if the BMP is to comply with the standards and requirements of the community's overall stormwater management program. To do so, the designer must be familiar with these program requirements as well as the technical data, equations, and analytic techniques commonly used to meet them. If stormwater management is to grow beyond its traditional concerns for stormwater quantity to address stormwater quality and nonpoint source (NPS) pollution, however, such technical compliance is not enough. Instead, the BMP designer must also recognize his or her unique responsibilities both to the success of the overall stormwater management program and to the people who will live, work, or travel past the structural BMP they are creating. Only by fulfilling these larger design responsibilities will stormwater management be able to achieve and sustain the public support and participation it needs to effectively address the complex problems that lie ahead of it. A description of each of these design responsibilities is presented below, along with recommendations for fulfilling each.

The Responsibilities of the BMP Designer

As noted above, the effective BMP designer must fulfill several levels of responsibility. First and foremost, the designer is responsible for complying with the technical requirements and standards of the overall stormwater management program of which the

BMP will be a part. This typically includes achieving the required level and range of peak outflow control necessary to prevent or reduce downstream flooding as well as the detention times and pollutant removal rates necessary for stormwater quality enhancement. Additional technical requirements contained in the stormwater management program may include emergency discharge capacity to insure dam or embankment safety, as well as structural and geotechnical standards to achieve stability and strength. The BMP designer must be familiar with the specific technical requirements of the stormwater management program as well as the theoretical basis for and use of the various hydrologic, hydraulic, structural, and geotechnical analyses typically used to comply with them.

The responsible BMP designer should not only be familiar with the program's technical requirements but also understand the program's overall intent or goals, for the designer must recognize that the program's technical requirements are only the means through which we hope to achieve the program's goals or ends. As such, a structural BMP will contribute more towards those goals if its designer understands, for example, not just what detention time the BMP should have, but why it should have one, why it should be a certain duration, and what will happen if it does not. Such understanding also produces BMP designs that are better able to achieve satisfactory results over a much wider range of real-world conditions than the more limited conditions that are normally analyzed during the design process.

In addition, due to the inherent complexities of stormwater quality and nonpoint source (NPS) pollution, we have not been able in many instances to define the technical requirements of our stormwater management programs as well as we have been able to specify their goals. For example, it is considerably easier to select a goal of 80 percent removal of suspended solids from stormwater runoff than it is to specify the exact technical measures that must be implemented to do so. This disparity between means and ends can be overcome to a great degree by the responsible designer who, aware of the disparity, is willing and able to look behind and beyond the program's somewhat limited technical requirements and produce designs that do a better job of achieving the program's goals.

Another BMP design responsibility is based on the fact that the final product of the designer's efforts will be a real structure that must be constructed and maintained and that will occupy space in a real environment. As such, it is vital that the BMP be both simple and practical in terms of construction, materials, operation, maintenance, and safety. Such characteristics can only be achieved by a designer who is aware of their importance and can define them in physical terms. In addition, such vital characteristics cannot, at times, be achieved by strictly adhering to a stormwater management program's technical standards and may, in fact, require that they even be ignored or broken. Such instances demand the involvement of a responsible designer who will be able to achieve a more informed, effective balance between technical compliance and practicality than is achievable through strict compliance alone.

In the design of any structural BMP, cost must also be an important factor, and the responsible designer not only appreciates this fact but also can accurately and objectively determine both the benefits that a structural BMP provides and the costs of doing so. A true measure of a BMP's cost effectiveness can only be achieved by understanding, quantifying, and comparing both. To do so, the designer has a responsibility to fully understand both the cost of BMP construction, operation, and maintenance and the relative values or benefits to be gained from it. This requires, among other traits, a high degree of objectivity to ensure that the costs and benefits determined by the designer are based on reality and not the interests or desires of his or her client or supervisor, or a government regulator.

Finally, the responsible BMP designer understands the importance of professionalism and will always conduct the design process in an open, honest, and objective manner. In view of the nascent state of stormwater management nationwide, such tenets are particularly vital if we are to close the present gap between what we seek to gain from stormwater management and how we can best achieve it. Such conduct will also enable us to more quickly identify uncertainties, conflicts, and errors in our present understanding of stormwater runoff and NPS pollution and to develop more effective and efficient solutions.

BMP Design Considerations: Points To Ponder

From the above, it can be seen that the responsible BMP designer must not merely be concerned with the technical requirements of a stormwater management program but, instead, must strive to produce facilities that also achieve and even advance the program's goals and intentions. The structural BMPs that result from such an effort will become assets to the community that they serve and promote the public interest and involvement necessary for overall program success. The BMP must also be practical, safe, aesthetically pleasing, easy to build, and even easier to maintain. Faced with such a formidable list of requirements, the responsible designer must not only bring competent technical ability to the design process but also an informed, open attitude and even a sense of mission or purpose. To help promote such an attitude and more fully prepare the BMP designer for the job ahead, the following points regarding BMP design, construction, and operation are offered. The BMP designer should consider these points before undertaking a design effort.

Interested Parties

To produce a BMP design good enough to earn an "approved" stamp from a stormwater management program regulator (who is presumably interested in ensuring compliance with the program's regulations), a BMP designer must identify with those interests and make sure they are reflected on the construction drawings. To further ensure that the BMP will truly be an asset to the community and will make a positive statement about the value of stormwater management, the BMP designer must consider several interested parties.

The Client

Including the client on a list of parties having an interest in a BMP design should not come as a surprise; however, a review of what the client's interests really are just may be. Therefore, the responsible BMP designer will not automatically assume to know the client's interests (however obvious they may appear) but will instead fully discuss them with the client.

The prospect of such a discussion may then lead the designer to ask the following question: What should the client's interests be? Does the client have a misinformed or misguided attitude towards the goals of stormwater management? Is this attitude based on a lack of understanding or information? In such cases, the responsible designer can, through education (and a touch of diplomacy), both expand the client's understanding and improve his or her attitude towards stormwater management, thereby enhancing the designer's own chances of producing a positive BMP design.

The Regulator

Similar to the client, the regulator is also an obvious choice for an interested party list. Once again, the following questions may be raised: What are the regulator's interests, and what should they be? Because a regulator's review of a BMP design can sometimes stray from the program's technical standards into more subjective areas (due, in part, to a lack of such standards), it is often helpful to know what interests the regulator has stored up in those areas. Are those interests both in keeping with the goals of the stormwater management program and within the program's (and, therefore, the regulator's) jurisdiction?

For example, a regulator may have a strong interest in promoting proper land use as a means of achieving a program's goals. If regulating land use is beyond the program's scope or authority, however, then such interests have no rightful place in the regulator's review of the BMP design. Should such interests become part of the review, it is the designer's responsibility to point this fact out and redirect the review back to its proper direction. In doing so, all of the diplomatic skills the designer has developed from educating the client will prove invaluable.

Similar to the client, a BMP designer may also encounter a regulator who, through a lack of knowledge or an abundance of wrong information, either misunderstands the program's requirements or lacks the ability to fully ensure their compliance. Once again, the responsible BMP designer can, through education and a competent, comprehensive design, expand the regulator's understanding and ability so that the designer's intentions can be better understood.

The Constructor

As noted earlier, one of the key responsibilities of the structural BMP designer is to transform the BMP from concept to reality by preparing detailed plans and specifications of how it should be built. It is then up to the constructor to finish the project by actually building the BMP from these plans and specifications. Therefore, the responsible designer appreciates the efforts of the constructor and does not see his or her own efforts as an independent exercise, but rather as an integral part of a much larger process—a process that requires the constructor to complete.

As such, the responsible BMP designer recognizes and responds to the constructor's interests by producing a well thought-out design that can be constructed as easily and simply as possible. Because this may not always be possible, particularly when faced with complex performance requirements or difficult site conditions, the responsible designer also takes extra care to bring any difficult or unusual aspects of the design to the constructor's attention before the start of construction, even consulting with the constructor during the design phase to mutually devise the best construction technique, material, or sequence.

Under ideal circumstances, the BMP designer will also continue his or her involvement in the project throughout the construction phase and will work with the constructor to correct mistakes, address oversights, and develop revised designs as necessary to overcome problems that may be encountered in the field.

The Maintainer

Once construction of the BMP has been completed, the designer's involvement with the process (assuming it lasted through construction) normally ends. However, there are interested parties whose involvement with the BMP is just about to start and whose interests the designer must also consider. These are the maintenance personnel who will be responsible for mowing the grass, removing the sediment, clearing the debris, managing the habitats, and performing the necessary repairs at the BMP for the rest of its serviceable life. Similar to the constructor, the maintainer's actions will be governed by what the designer creates on paper. Because construction has been completed and the designer has moved on to other projects, however, it is considerably more difficult for the maintainer to have deficiencies or oversights in the design corrected.

As such, the designer must understand and address the interests of the maintainer before it is virtually too late. As described in more detail in later sections, this can be accomplished by designing a facility that, optimally, requires a minimal amount of maintenance that can be performed as easily as practicable.

The Resident

This interested party may also be the worker, commuter, shopper, student, or local government official who will interact with the structural BMP on a regular basis. This interaction may be physical (through the sense of touch, sight, hearing, or smell) or psychological (as anyone who has worried about children's safety or the value of his or her property will understand).

In any case, these are the people who have, perhaps, the strongest interest in seeing that a positive BMP design is achieved. These are also the people who will soon be asked to participate in the community's non-structural stormwater management programs by changing some of their aesthetic values and even their lifestyles. Therefore, the person responsible for producing the BMP design must be aware of their interests and incorporate them into the design as well.

Operating Conditions

Just as a wide range of people have an interest in the BMP design, the BMP must operate under a wide range of conditions. Just as the BMP designer may fail to recognize the full range of interests, he or she often fails to consider all of the real-world conditions that the BMP will be subject to by focusing solely on those design conditions necessary for official program approval. This is unfortunate, because the design conditions that received all of the designer's attentions will, in reality, only occur during a small fraction of the BMP's existence. However, its performance during the remainder of its existence, while ignored by the designer, will largely determine the community's opinion of its value.

Therefore, it is important that the BMP designer be aware of all of the weather and other site conditions to which the BMP will be subjected.

Design Conditions

These are obviously the designer's first concern and, as noted above, are normally established by the community's stormwater management program. In the case of runoff quantity control, these conditions usually include either a single event or a range of relatively extreme storm events, the runoff from which must be stored and released at a predetermined rate. New Jersey's Stormwater Management Regulations, for example, require that the runoff from a proposed land development site for the 2-, 10-, and 100-year storm events be controlled so that the peak rate of site runoff after development for each storm does not exceed the peak rate that existed before development. The Somerset County, New Jersey, standards are stricter, requiring a peak rate after development that is actually less than existing to account for development-induced changes in runoff volume and overall hydrograph shape as well.

In the case of stormwater quality control, typical design conditions may include the temporary storage and slow release of the runoff from a much smaller, more frequent storm event to promote pollutant removal through sedimentation. For example, the New Jersey Stormwater Management Regulations require the temporary storage of runoff from a 1-year storm event, with release occurring over 18 to 36 hours depending on the character and intensity of the proposed development. The state of Delaware requires extended storage of the first inch of runoff from a proposed site, with release occurring over 24 hours.

Whatever exact design conditions the stormwater management program may specify, it is vital that the structural BMP function properly under them or the goals of the program cannot be met.

Extreme Conditions

In addition to the program's design conditions, which have been selected with the goal of runoff quantity and/or quality in mind, the responsible BMP designer must also recognize that more extreme storms may also occur. Therefore, due to the inherent dangers of storing runoff and the exceptionally large quantities of runoff that can be produced by these extreme events, it is vital that the BMP designer also address the goal of safety by ensuring that the BMP will also function properly under such extreme conditions. This will typically include the provision of an emergency spillway or other auxiliary outflow device that will safely convey the extreme event runoff that exceeds the capacity of the BMP's normal outflow structure. It will also include protection of critical portions of any embankment, dam, or discharge points that may be subject to scour or erosion from the high flow velocities generated by the storm event.

Dry Weather Conditions

While design and even extreme storm conditions can be expected to occur periodically, the most common operating condition at a structural BMP will be dry weather with various seasonal temperatures, winds, humidities, and periods of daylight. While dry weather may be the most prevalent operating condition, it is also the one that is most frequently overlooked by the BMP designer. As a result, how the BMP will look, smell, and even sound during the majority of its operating life is then left to chance. This can be particularly unfortunate for the BMP maintainer and, more critically, the resident, worker, or commuter who will interact most often with the BMP during dry weather conditions. Therefore, the responsible BMP designer will not only address extreme storm events but will also make sure that the BMP performs satisfactorily when it isn't raining at all.

Design Methodologies

Before starting the actual design process, the responsible designer will have an adequate understanding of the selected design methodologies. These methodologies can cover such aspects as rainfall-runoff computations, hydrograph routings, infiltration and ground-water movement, structural design, and geotechnical issues. In doing so, the designer's understanding should include the methodology's theoretical basis, assumptions, limitations, and applicability. In addition, the responsible designer will also have an understanding of both the accuracy needed to perform the design and the accuracy of the method he or she has selected to do it. From this, the responsible designer will neither waste time producing unneeded accuracy nor attempt to achieve a level of accuracy beyond the limits of the method. Finally, the responsible designer will understand the sensitivity of each of the method's input variables and will appropriately allocate his or her time and resources in developing each one.

Facility Type

The final point for the BMP designer to ponder before beginning the actual design process is the type of structural BMP to be used. Presently, a wide range of facilities are available for use, ranging from relatively simple vegetated filter strips and swales to large ponds and constructed wetlands. Selection of the appropriate BMP depends on several factors, including program requirements, BMP location, site conditions, maintenance needs, safety, cost, and performance characteristics.

Similar to BMP operating conditions, the BMP designer may often consider only a few of these factors, most notably program requirements (keep the regulator happy) and cost (keep the client happy, too), in making his or her selection. The responsible designer, however, will recognize the performance, needs, uncertainties, and risks inherent in each type of BMP and will then select (or help influence the selection of) the most appropriate type of BMP for the site. This process typically begins with the identification of the fundamental characteristics of each type of BMP, along with the project's physical, economic, social, and regulatory constraints. The process then becomes one of comparison and analysis, with the best match found by eliminating the worst.

For example, a site with porous soils, low ground-water table, and close proximity to residences may not be best suited for a wet pond or constructed wetland, while the active recreational needs of the residents may benefit from a dry, extended detention basin that can also serve as an athletic field. Although perfect matches rarely occur, comparisons and analyses such as this will help reduce the number of potential BMPs, improve the thoroughness and objectivity of the overall selection process, and ideally produce the optimal facility type. This process can even help identify inherent weaknesses in or problems with the selected type, which will enable the responsible BMP designer to devote additional time and effort towards correcting them during the design phase.

To undertake such a selection process obviously requires a designer who understands the fundamental characteristics and needs of each BMP and who can objectively assess all of the pertinent site constraints. Such a designer must also be willing and able to confront the differing opinions of other, less objective or informed parties (including the regulator and client) to ensure that the best BMP is selected. As noted throughout this paper, achieving an optimal BMP design is a complex and demanding process that must incorporate numerous interests and requirements. Starting the process with the wrong facility type, however, transforms a complex and demanding process into an impossible one.

BMP Design Considerations: A Checklist

Having completed the BMP selection process with honor, idealism, and design contract still intact, and armed with both the necessary technical and regulatory knowledge and economic and social sensitivity, the responsible BMP designer is ready to begin the actual design process. Presented below is a checklist of six key design considerations to help guide this effort. Ideally, these six items have or will become an integral part of the designer's thought process and will automatically be included in each design effort. These items can also serve as guidelines for those responsible for the review and approval of specific BMP designs as well as goals for those developing new stormwater management programs.

Safety

For several reasons, the safety of the structural BMP must be the primary concern of the designer. Due to its "structural" nature and, in many instances, the fact that it will impound water either permanently or temporarily, the structural BMP will inherently pose some degree of safety threat.

Those at risk include people living, working, or traveling downstream of the BMP whose safety and/or property will be jeopardized if the BMP were to fail and release stored runoff. Because this is a risk that has been created solely by the BMP, the designer must ensure that the probability of such a failure is acceptably small.

Also at risk at a structural BMP are maintenance personnel, inspectors, mosquito control personnel, and equipment operators, who must work in and around the facility. Typical hazards include deep water, excessively steep slopes, slippery or unstable footing, limited or unsafe access, and threats posed by insects and animals. As noted above, the responsible BMP designer understands the importance of facilitating BMP maintenance. Providing a safe working environment for the BMP maintainer is one important way to do it.

Finally, those living, working, attending school, or playing in the vicinity of a structural BMP may also be at risk, particularly if the BMP serves both as a stormwater management and recreational facility. Once again, such things as standing water, steep slopes, unstable footings, and insect and animal bites must be addressed by the designer to avoid creating a facility that is a detriment to the community it is intended to serve. Failure to do so will only alienate those members of the community who will be asked to play a vital role in future stormwater management efforts.

Performance

Having made a strong commitment to safety, the BMP designer must then consider facility performance. This normally includes achieving the necessary stormwater detention times, flow velocities, settling rates, peak flow attenuation, and/or ground-water recharge for the range of storm events to be managed. Again with a commitment to safety, the designer must also ensure that the BMP performs adequately under emergency conditions, most notably when the peak rate and/or volume of runoff flowing into the basin exceeds the discharge capacity of the BMP's principal outlet. This will require the inclusion of emergency or auxiliary outlets in the BMP to safely convey this excessive inflow through the BMP without jeopardizing its structural integrity.

In most instances, the performance standards that the BMP design must meet will be specified in the stormwater management program's regulations. Experience has shown, however, that these performance standards may, at times, be vague, contradictory, or even impossible to meet. For example, many BMP designers have been confronted with a requirement to reduce both the peak rate and total runoff volume from a developed (or developing) watershed to predeveloped levels. This has often lead to much head scratching, for the solution normally requires the use of an infiltration or recharge basin which, due to site constraints, may either be impractical or impossible. Faced with such circumstances, the responsible designer looks beyond the written regulations and investigates their origins and true intent with regulatory personnel. Direct inclusion of these individuals in the design process will also help ensure more positive overall results.

Constructability

Up until now, the designer's efforts to achieve adequate BMP safety and performance levels have been achieved only on paper or computer disk. Because the ultimate goal of the design process is to actually create a BMP, the BMP designer must also give careful consideration to how it is to be constructed. Achieving exceptional safety and performance characteristics in a BMP that cannot actually be built solves nothing and wastes much. Achieving required levels of safety and performance in a BMP that can be reconstructed with relative ease using readily available materials, equipment, and skills is commendable and not only solves a specific stormwater management problem, but also helps to advance the community's overall program. "Constructability" can be defined as a measure of the effort required to construct a structural BMP. A BMP that is highly "constructable" utilizes materials that are readily available, relatively inexpensive, and do not require special shipping or handling measures. They will be both durable and easily modified in the field to meet specific site conditions. Similarly, the construction techniques and equipment required to construct the BMP will also be relative simple, straightforward, and familiar to the people who will be performing and operating them.

It is important to note that the above description is not intended to discourage the use of new or innovative materials or construction techniques, nor to inhibit creativity in the BMP design process. In fact, innovation in design and construction is vital to the future growth of stormwater management. Instead, the above description of "constructability" is intended to remind designers that they must consider the construction aspects of the BMP in the design process and strike a balance between performance and safety requirements, constructability, and innovation for each design they undertake.

Maintenance

The same reminder stated above for constructability must also be said for BMP maintenance. Similar to construction, the degree of effort and expense required to adequately maintain a structural BMP will help determine the overall success of its design. A BMP with manageable maintenance needs can be expected to remain in reasonably good condition and has a stronger chance of becoming an asset to the surrounding community. On the other hand, a BMP with excessive maintenance needs is likely to be neglected and will quickly become a community liability. As such, BMP maintenance can directly effect the overall success of the community's stormwater management program.

The BMP designer can help determine a BMP's maintenance needs by considering several aspects of that maintenance in the design process. First, the BMP design should include the use of durable materials that are able to withstand the many and varied physical conditions that the BMP will experience over its lifetime. Secondly, suitable access to key BMP components and areas is vital if required maintenance levels are to be achieved. This will include provisions for walkways, staging and disposal areas, access hatches and gates, and safe, stable working areas. The frequency of maintenance has a large impact on both maintenance cost and quality, and it is the designer's responsibility to achieve an appropriate level. Finally, the BMP designer should always strive to minimize the overall amount of maintenance at the BMP and to make that amount as easy as practicable to perform.

Cost

Inclusion of a BMP's cost in a list of design considerations is not surprising. Once again, however, a review of the full costs associated with a structural BMP may yield a few surprises that may increase designers' understanding and encourage them to give BMP costs the full consideration they deserve.

The most obvious BMP cost is its construction. This can be estimated with reasonable accuracy and is the cost most directly borne by the designer's client. As such, designers most often focus on this cost during the design process to the exclusion of all others.

What other costs may be overlooked? One may be the designer's own fee, which is part of the overall BMP cost but which has probably been excluded from consideration because it has already been determined. The designer's fee, however, has a direct impact on the BMP design because it determines the effort and resources the designer uses to produce it. The level of effort expended during the BMP design can have a similarly direct effect on the effort and cost of both construction and maintenance. The greater cost of a more thorough BMP design can ultimately result in cost savings to the client during subsequent project stages. Therefore, while this is not a signal to BMP designers to raise their fees, it is meant to remind designers that their fee is part of the overall BMP cost and that it is their responsibility to determine what level of design effort and cost represents the best investment for both the client and the community.

Another portion of total BMP cost that is frequently overlooked is the cost associated with its maintenance. While this cost on an annual basis is usually a small percentage of the construction and even the design cost, it must be remembered that, unlike construction or design, maintenance costs are recurring and must be paid throughout the life of the BMP. Therefore, while a maintenance cost savings may appear to be insignificant on a per-operation basis and not worth the extra investment in design or construction required to achieve it, its value may be viewed quite differently when multiplied by the numerous times it will be realized. As such, an added investment in design to produce a trash rack that will require less frequent cleaning or an added investment during construction to reduce the frequency of repairs may quickly yield a positive return in the form of reduced maintenance costs. Similar conclusions can be reached for many other design and construction efforts, such as providing better access, using more durable materials, and selecting a BMP that best suits site conditions.

Community Acceptance

The final recommended design consideration once again involves those people who may have the greatest interest in the structural BMP. Not coincidentally, these are the same people who will have the greatest role in the various nonstructural programs intended to augment and even replace structural BMPs in the future. To protect those interests and encourage assumption of that role, it is up to the designer to help achieve a structural BMP that will be reviewed as a community asset rather than a liability.

As discussed above, this can be achieved by considering the aesthetic value of the BMP, preventing the creation of nuisances and safety threats, as well as achieving required performance levels. Through all three, stormwater management gains the understanding and credibility it requires within the community.

Suggested Design Review Techniques

Throughout this paper, the BMP designer has been encouraged to consider a wide range of interests, operating conditions, costs, and other responsibilities

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throughout the design process. Presented below are two recommended techniques to help accomplish it. They can either be used as review techniques following completion of a preliminary BMP design or, ideally, be incorporated into the overall design process and used continually throughout it.

Spend a Mental Year With the BMP

To use this technique, the BMP designer simply imagines conditions at the constructed BMP throughout a full year. This should not only include rainy and sunny weather, but also light rain showers (with little or no runoff), light and heavy snowfalls, and frozen ground conditions. Other site conditions may include late autumn, when trees have lost their leaves and the BMP has found them, and hot, dry weather or even drought, when the turf or other vegetation is stressed or even killed. Finally, the designer may wish to imagine what the BMP will be like at night.

As these conditions are visualized, the designer should also imagine how those conditions may effect not only the operation of the BMP itself but also the people that will interact with it. Can blowing snow completely fill the BMP, leading the unsuspecting pedestrian to think that the grade is level? Will the outlet structure's trash rack be particularly prone to clogging by fallen leaves, particularly from the trees the designer just specified for the BMP's bottom?

What about the ice that will form on the surface of a pond or constructed wetland? Can someone fall through? Could that someone be a child taking a shortcut home? How will people be warned not to? How will they be rescued if they do anyway? What about night conditions? Will the constructed wetland next to the office parking lot that is so attractive during summer lunch hours become a safety hazard to workers walking to their cars in the winter darkness? Or will that same summer sun and a lack of rainfall produce some of the wonderful aromas of anaerobic decomposition?

At first, it may be exasperating to realize that the possible site conditions and circumstances can be as numerous and varied as the number of possible BMP uses. But then again, that is the point of the exercise. It is intended to help the designer consider and design for all conditions at the BMP, not just the 1- or 100-year storm event required by the regulations. In doing so, the BMP designer will not only meet the letter of the regulations but will raise the spirit of the entire stormwater management program.

Who, What, When, Where, and How?

The second recommended review technique a BMP designer may employ is to simply focus on one or more characteristics or functions of the BMP and then ask (and attempt to answer) the above questions. For example, let's consider BMP maintenance and then ask:

- Who will perform it? Does the BMP design require specialists, or will someone with general maintenance equipment and training be able to do the job?
- What needs to be maintained? Preparing a list of all the BMP components included in a design that will need attention sooner or later may prompt a revised design with a shorter list.
- When will maintenance need to be performed? Once a day? A week? A year? Remember, the recurring costs of BMP maintenance can be substantial. In addition, can maintenance only be performed during dry weather? If so, what happens during 2 or 3 weeks of wet, rainy weather? What happens when repairs need to be made or debris removed during a major storm event? In terms of effort and possible consequences, it is easier for the designer to find answers to these questions now than for maintenance or emergency personnel to scramble for them later.
- Where will maintenance need to be performed? Will the maintainer be able to get there? Once there, will he or she have a firm, safe place to stand and work? In addition, where will such material as sediment, debris, and trash removed from the BMP be disposed of? Before answering that question, do you know what is in it? Are there toxics or hazardous materials in the sediment or debris? If so, is the place you originally intended to use still suitable? Once again, it is easier to address these questions now then when the dump truck is loaded and the engine's running.
- How will maintenance be performed? The simple instruction to remove the sediment or harvest the vegetation can become rather complicated if no provisions have been made to allow equipment to get to the bottom or even into the site. "Mowing the grass" can become "risking your limbs" on long, steep slopes. How will you explain to your client why the BMP in which he or she has invested has become a liability to themselves and their community?

Similar exercises can be performed with constructors, inspectors, and residents as the object of inquiry. For example, where will the nearest residence be? How will the constructor build the emergency spillway? When will the inspector need to visit to check for mosquitos?

Similar to the "mental year" review technique, the questions raised in this technique are intended to make the designer more aware of all the possible impacts the BMP may have and, further, to encourage the designer to address those impacts now, during the design phase, rather than leave them for others to cope with later. Even if the designer cannot completely answer all of the questions, he or she will be able to advise the others of any unavoidable needs or problems that will be inherent in the BMP and allow them to adequately prepare.

Summary

Stormwater management must still be considered a relatively new endeavor, particularly on a nationwide basis. Despite its nascent state, it has been charged with the responsibility of addressing some very complex environmental problems. For stormwater management to grow to the level demanded by this charge, the designers of structural BMPs must be willing to assume a degree of responsibility for that growth. BMP designers can fulfill that responsibility by producing BMP designs that do not merely meet official regulations and standards, but help inspire new, better, and more comprehensive ones. BMP designers must also incorporate a wide range of interests into the BMP design, including those held by stormwater program regulators, BMP constructors and maintainers, and all those members of the community who will interact with the BMP over its lifetime. During the design process, BMP designers must not only consider the BMP's performance but also its cost, durability, ease of construction, and maintenance needs. Finally, BMP designers must always recognize the BMP's impacts both on the community around it and on the stormwater management program with which the community has entrusted them.

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Targeting and Selection Methodology for Urban Best Management Practices

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Abstract

Selecting best management practices (BMPs) to implement as part of a stormwater management plan is quite difficult and controversial because of a variety of technical, regulatory, institutional, and financial factors and constraints. Specifically, the nature and sources of stormwater-borne pollutants and the water quality and ecological problems these pollutants cause are not well understood. The cost, effectiveness, and applicability of many BMPs are also not well understood, although several BMP manuals summarize existing information. The federal National Pollutant Discharge Elimination System (NPDES) stormwater regulations provide flexibility in selecting BMPs to control urban pollutants. EPA gives only general guidance on the types of BMP programs that are desirable and does not require the implementation of specific BMPs. Several other factors contribute to difficulties in selecting and implementing BMPs. In many cases, institutional jurisdictions do not correspond to watershed boundaries, and water management institutions' roles and responsibilities are fragmented for effectively dealing with the myriad nonpoint sources of pollution associated with stormwater drainage systems. Finally, the availability of funds, which are currently very limited, significantly determines BMP implementation.

This paper provides guidance on the selection of BMPs given this current environment and based on experience in developing stormwater management plans for areawide programs, individual municipalities, industries, developments, and government facilities. The paper describes the current tools available for BMP selection, a 10-step "model" selection process, and case studies for a large areawide municipal program and for an industrial facility.

Introduction

In October 1990, the U.S. Environmental Protection Agency (EPA) issued regulations requiring certain municipalities and industries to select and implement best management practices (BMPs) to control pollution associated with stormwater runoff and dry weather discharges into storm drain systems. Such BMPs would be selected and described in stormwater management plans and implemented in compliance with an NPDES permit. The specific regulatory language in Section 402(p) of the Clean Water Act is "Permits for discharges from municipal storm sewers shall require controls to reduce the discharge of pollutants to the maximum extent practicable . . . ." The maximum extent practicable (MEP) standard has a legal definition; however, considerable uncertainty exists in the regulated community about what constitutes technical compliance with the MEP standard.

Other existing and proposed regulations require BMP selection. Section 303 of the Clean Water Act requires that delegated states and EPA establish total maximum daily loads (TMDLs) for designated "water quality limited" water bodies. The TMDL process considers both point and nonpoint sources. For nonpoint sources, water quality management plans must be developed to meet load allocations for urban and other land uses. The 1990 Coastal Zone Act Reauthorization Amendments (CZARA) require the development of state nonpoint source control plans for the coastal zone using BMP guidance recently released by EPA and the National Oceanic and Atmospheric Administration (NOAA).

Finally, watershed planning is gaining favor as a way of meeting water quality goals for the nation's waters. The watershed planning approach requires examination of all land uses and activities in a watershed and development of BMPs to protect water quality. EPA is considering the watershed approach for the phase II portion of the NPDES program.

This paper describes our experience in selecting BMPs for clients complying with the NPDES stormwater regulations; the process would also be applicable to TMDL, coastal zone, and watershed planning. We discuss types of BMPs and sources of information on BMPs available for developing management plans. Based on our experience, we also describe the attributes of a good selection process and describe the steps involved in a "model" selection process. Because of numerous site-specific conditions that enter into any selection process, the actual process chosen must be adapted to each situation. To illustrate how such a process might be adapted to different circumstances, we describe two case studies, one for a large areawide municipal program and one for multiple federal facilities regulated as industrial dischargers.

Best Management Practices

Although BMPs may be organized in many ways, it is useful in the selection process to distinguish controls based on how they function. BMPs based on function are often considered as source controls, treatment controls, and hydraulic controls.

- *Source controls* are intended to prevent pollution in the first place (i.e., pollution prevention) or to intercept the pollutants before they enter the storm drainage system. Preventing pollution in the first place often involves behavior modification, which requires public information and education, an important source control BMP. Street sweeping and catch basin cleaning are examples of source controls that intercept pollutants before stormwater carries them into receiving waters.
- *Treatment-based controls* are controls that remove pollutants from stormwater, usually through some structural means such as a detention basin or grassy swale.
- *Hydraulic controls* are structural controls that reduce the volume of runoff (or otherwise alter the runoff hydrograph) or divert flows away from source areas. Examples of hydraulic controls are infiltration systems.

In general, the effectiveness of these types of controls are not well understood. The effectiveness of treatment and hydraulic controls generally can be measured through monitoring, and there is an increasing body of literature regarding the effectiveness of treatment and hydraulic controls under limited conditions. Federal, state, and local agencies have developed numerous BMP guidance manuals to help identify, select, and design BMPs. The following is a partial list of manuals, starting with design manuals that contain detailed control selection and design information.

- U.S. EPA. 1993. Handbook: Urban runoff pollution prevention and control planning. EPA/625/R-93/004.
- City of Austin Environmental Resource Management Division. 1991. Environmental criteria manual. Environmental and Conservation Services Department (February 19).
- Metropolitan Washington Council of Governments (MWCOG). 1987. Controlling urban runoff: A practical manual for planning and designing urban BMPs. Prepared for Washington Metropolitan Water Resources Board (July).
- State of Florida Department of Environmental Regulation. 1988. The Florida development manual: A guide to sound land and water management (June).
- State of Washington Department of Ecology. 1992. Stormwater management manual for the Puget Sound Basin (the technical manual) (February).
- Urban Drainage and Flood Control District. 1992. Urban storm drainage criteria manual. Denver, CO (September).
- Metropolitan Washington Council of Governments (MWCOG). 1992. Design of stormwater wetland systems. Prepared for the Nonpoint Source Subcommittee of the Regional Water Committee (October).

The following documents primarily discuss control effectiveness and do not contain control selection and design information:

- City of Austin Environmental Resource Management Division. 1990. Removal efficiencies of stormwater control structures. Environmental and Conservation Services Department (May).
- Metropolitan Washington Council of Governments (MWCOG). 1992. A current assessment of urban best management practices. Prepared for the U.S. Environmental Protection Agency (March).
- U.S. EPA. 1990. Urban targeting and BMP selection: An information and guidance manual for state nonpoint source program staff engineers and managers. Region 5, Water Division, Chicago, IL 60604 (November).
- Metropolitan Washington Council of Governments (MWCOG). 1992. Analysis of urban BMP performance and longevity.
- U.S. EPA. 1993. Guidance specifying management measures for sources of nonpoint pollution in coastal waters. EPA/840/B-92/002. Washington, DC (January). (Includes costs.)
- California State Stormwater Task Force. 1993. California BMP handbooks for municipal, construction, and industrial/commercial (April).

Finally, the following document addresses BMP costs:

- Southeastern Wisconsin Regional Planning Commission. 1991. Costs of urban nonpoint source water pollution control measures. June.

These manuals describe BMP function, requisite site conditions, existing performance information, and cost ranges. In general, these manuals are well written and provide a good starting point for developing an understanding of the advantages and disadvantages of many treatment-based controls. For some BMPs, there is limited information on effectiveness and cost; for these, pilot testing may be helpful under site-specific conditions.

Treatment-based controls are especially applicable in construction and new developments, where structural measures may be incorporated into the construction process and site design. The cost of constructing and maintaining treatment-based controls is a major concern to municipal and industrial dischargers.

In contrast to treatment-based controls, source control effectiveness in terms of water quality improvement cannot easily be measured, if at all. For example, the effect of a public education program on improving water quality cannot be determined, although some public education activities obviously are more effective than others. The effectiveness of street sweeping and catch basin cleaning on water quality requires careful and expensive paired catchment types of studies. Source controls are generally considered the most cost-effective long-term solution because they address the cause of the problem; thus, we see many programs focusing on source control measures.

Attributes of a Good Selection Process

The following sections describe some attributes of a good selection process.

Keep It Simple and Straightforward

BMP selection for nonpoint source controls is in its infancy compared with point source controls, for which treatment technologies and associated costs are well understood. Instead of traditional cost benefit analysis, nonpoint source BMP selection is more of an art and requires experience, sound judgement, and common sense. Though the process of selection may involve several steps, the process itself must be easily understandable and accepted by the various interest groups involved, including public agency staff and decision-makers, environmental groups, and regulatory personnel.

Document the Process

It is essential to carefully document the process by which BMPs were selected and the various assumptions and considerations made during the selection process. In other words, the process, even though it may be subjective in part, should not be "arbitrary and capricious." The selection process must be clear to reviewers in evaluating the adequacy of the process in meeting the intent of the regulations. Also if the process is clear, it can be improved or modified in the future as more information becomes available or policies change.

Be Comprehensive

The federal regulations require a comprehensive approach such that a broad range of controls are evaluated for various land uses and activities. The selection process must evaluate a comprehensive list of BMPs to address pollutants of concern and their sources.

Plan for Implementation

Human nature being what it is, effectively implementing many BMPs at once is difficult. The solution to this dilemma is to minimize the number of BMPs chosen, prioritize or phase their implementation, and/or group related BMPs into a few categories, sometimes called program elements.

Involve Affected Parties In the Process

A second element of human nature is adverseness to implementing someone else's plan. Therefore, BMPs are selected ideally by those who have to implement them (with guidance, of course). A second alternative is that the process heavily involves those who will implement the BMPs in a review and approval role. If neither of these approaches are followed, the plan is not likely to be well implemented.

Indeed, involvement of the affected parties in the selection process is probably more important to the success of the program than the exact nature of the process itself. Through this process, the parties become educated regarding problems, possible solutions, and the need for teamwork in implementing solutions.

Model of a Good Selection Process

There is no one correct selection process as the process must be tailored to local institutional, political, and regulatory conditions. Figure 1 is a schematic showing six steps in a BMP evaluation, selection, and planning process that are generally applicable. The following is a somewhat expanded discussion of BMP selection steps appropriate for most areawide municipal programs.

Step 1: Establish Program Goals and Objectives

The clients must agree on a compliance strategy from which will stem goals and objectives for the program. The strategy should address such issues as organization and administration, decision-making, coordination with other interest groups, and degree of proactiveness.

Step 2: Identify Receiving Waters, Problems, Pollutants, and Resources

The ultimate intent of the regulations is to protect and improve the water quality and ecology of receiving waters, and this goal should drive the BMP selection proc-

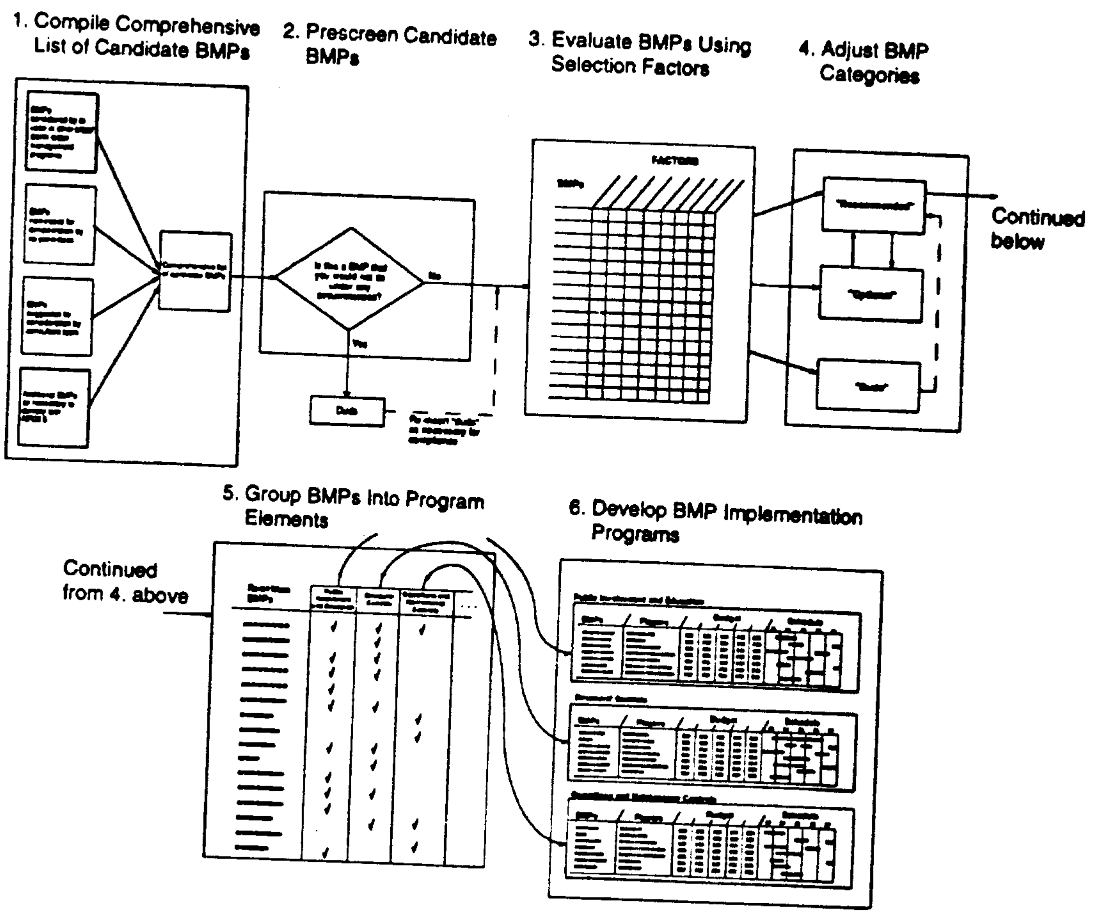

Figure 1. BMP evaluation, selection, and planning process.

ess to the extent possible. Ideally this step identifies water resources of particular value that are especially critical to protect, as well as impaired water bodies (e.g., 304(L) segments) that are currently not meeting water quality objectives appropriate for the beneficial uses. Where data are available, pollutants to be controlled should be identified. Without this step, much work and resources may be focused on activities that do not necessarily translate into an improved aquatic environment. Many programs find that a nontechnical one- or two-page "fact sheet" on receiving water problems, pollutants, sources, and management implications helps to develop support from taxpayers and decision-makers.

Step 3: Identify Sources and Pathways

Given the problems, the next step is to try to identify the important point and nonpoint sources of pollutants that are causing the problems. This is an essential step, because control of nonpoint sources only makes sense to the extent that it is a major source of the problem pollutant. For nonpoint sources, try to describe the pathway from source to receiving water, because this helps identify the BMPs that can most effectively intercept the pollutant along the pathway. For example, dumping waste oil into catchbasins can be mitigated by labeling storm drain inlets and/or requiring a monetary deposit at the point of purchase. It should also be pointed out that some sources may be quite difficult to control (e.g., natural erosion).

Step 4: Prioritize Sources (Areas) for Control

Targeting sources for BMP application is the next step. Focusing resources on selected areas is important, otherwise resources tend to be spread too thin to be effective. This is particularly important in municipal programs, where some early "successes" encourage the participation and financial support of local citizens.

A systematic targeting scheme using a ranking process based on stream size, beneficial uses, pollutant loads, and ease of implementation of the BMP is provided in U.S. EPA (1) and U.S. EPA (2). Use of these manuals might be appropriate after an areawide plan is developed; for example, a BMP might be to begin basin planning for selected basins within a city. The targeting manual (1) could be used to identify the basin and subbasins for BMP selection.

Step 5: Identify and Evaluate Existing BMPs

Compile a list of existing BMPs that are currently being conducted and organize them according the sources identified in Step 5. Identifying existing measures is often very difficult. Some municipalities do not know their system very well and are organized into departments in such a way that no one department is aware of what stormwater measures are currently being implemented. Carefully crafted questionnaires work quite well at developing information on existing practices that affect stormwater quality. Evaluate the effectiveness of these measures and improve or discontinue as appropriate.

This step also involves identifying existing environmental programs that are conducting activities that relate to stormwater pollution control and with whom cooperation should be sought. Examples include pretreatment programs, HAZMAT programs, solid waste control and recycling programs, and public information programs.

Step 6: Compile Candidate BMPs

Compile a comprehensive list of candidate BMPs that may be appropriate. This list should contain both source- and treatment-based controls and include such things as regulatory authority. Attach attributes to each BMP, including (if available) pollutant type controlled, cost, and effectiveness. (Recall that such information is generally not available for source controls.) Note dependencies or synergistic relationships between BMPs. For example, some BMPs may be more effective if or may require that another BMP is implemented before or at the same time.

Step 7: Develop Selection Criteria

In addition to the obvious criteria that the BMP address the problems and sources identified in Steps 2 and 5, developing a list of additional criteria that can be used to assist in the selection process is helpful. Such criteria include regulatory requirement compliance, effectiveness, reliability and sustainability, implementation and continuing costs, equitability, public and agency acceptability, risk and liability, environmental implications, and synergy with existing or other BMPs.

Step 8: Apply Criteria for Selection of Baseline Measures

Selection criteria may be applied in numerous ways. For example, applying different criteria in multiple screening "passes" is a common procedure. BMPs may be required to meet "critical criteria" such as obtain co-permittee acceptance, address the problem pollutants and sources, and meet regulatory requirements. Then, in a second "pass," those BMPs that met the critical criteria are further evaluated by applying additional criteria that would help to select preferred BMPs. Such criteria could include effectiveness, cost, and reliability. Often the second pass allows the municipality to help determine what is financially feasible. In the second pass, qualitative (e.g., high, medium, low) or simple quantitative (e.g., 1, 2, 3) scoring might be used to help rank preferred BMPs. Unequal weighting can be assigned to each criteria as appropriate.

BMP selection should also anticipate the evolution of the program. For example, we often recommend that a set of "baseline" BMPs be selected that fully exploits the existing control measures and focuses on additional source control. The selection process can then be used to select the baseline measures and also candidates for a reserve list of BMPs that could be implemented at a later time based on experience with the baseline BMPs.

Step 9: Implement Baseline Measures

Implement the baseline measures with appropriate phasing to allow for planning, pilot testing, etc., prior to full scale implementation. For each BMP, develop measures of effectiveness. As described above, baseline measures tend to be source controls.

Step 10: Monitor Effectiveness and Reevaluate BMPs

Monitor the effectiveness of each BMP and, based on monitoring, annually reevaluate each BMP. As appropriate, delete or select additional BMPs. Annual evaluation should also include any new information obtained through monitoring receiving waters and/or source identification studies.

Case Study 1: Areawide Municipal Program

The following describes a case study of the BMP selection process that multiple agencies who were part of an areawide stormwater program conducted.

County X is 200 square miles in area and contains 20 co-permittees consisting of municipalities, the county, and a special district. The county population is 1 million people. The municipalities cover a wide range of sizes and land uses, from one city of 100,000 population with major industrial facilities down to small residential cities of 10,000 population. At the behest of the state environmental agency, the co-permittees elected to form a countywide stormwater pollution control program to comply with the federal NPDES stormwater regulations. During the Part I application, the co-permittees compiled a list of existing BMPs.

The co-permittees were very concerned that their management plans reflected local conditions and resources and insisted that they each conduct the BMP selection process themselves. We refer to this approach as the "bottom up" approach, in contrast to the "top down" approach in which BMP selection is conducted by the program and then distributed to the co-permittees for their review and approval. Woodward-Clyde Consultants (WCC) acted as facilitators by designing a process for BMP selection that included development of guidance documents, workshops for all co-permittees, and meetings with individual cities. Program representatives and WCC met with the individual jurisdictions three times throughout the process to provide assistance or clarification. The process from start to finish took about 9 months.

The following guidance documents were developed:

1. Description of Management Plan Development Process
2. Selecting the "Right People" To Participate in the Process
3. Source Identification
4. BMPs for Industrial Facilities
5. BMPs for Agency Activities
6. Transportation BMPs
7. Illicit Discharge Elimination BMPs
8. Commercial Area BMPs
9. Construction and New Development BMPs
10. Public Education and Industrial Outreach BMPs
11. How To Complete Your Stormwater Management Plan

The guidance documents included tables that each co-permittee was asked to complete based on guidance provided. The tables formed the basis of each entity's plan. A key element in the process was a problem and source identification step (Guidance Document 3), in which each entity identified receiving water problems, water resources of special interest, and pollutant sources. Based on this problem identification, cities selected BMPs to address source areas in their jurisdictions.

Guidance Documents 4 through 9 described a menu of individual BMPs from which the cities could select. In addition, WCC recommended a basic list of BMPs applicable for most jurisdictions. The co-permittees chose to participate in a countywide public education program involving various BMPs described in Guidance Document 10. Guidance Document 11 explained how to "put it all together."

An example of a BMP description is given in Table 1. The information provided consisted of a BMP name and identifier, description, steps for implementation, methods to assess effectiveness, and remarks. For those BMPs selected, co-permittees were asked to show when tasks would be completed, and the budget for each BMP over the 5-year permit period.

The BMP information was intended for guidance only, and some jurisdictions revised or created new BMPs that better addressed their circumstances. Some jurisdictions showed real creativity and enthusiasm in developing BMPs. This participatory process results in a much more implementable, practical, and effective stormwater management plan.

Case Study 2: Industrial Facility

Selection of BMPs for industrial facilities is more site specific and tends to be guided by the types of activities being conducted at the facility. The process of BMP selection then involves identifying industrial activities that could potentially generate sources, identifying the types of pollutant releases associated with

Table 1. Best Management Practices for Agency Activities and Facilities

Number	AA-11
Best Management Practice	Reduce agency use of herbicides and pesticides.
Description	Reduce the use of herbicides and pesticides on city streets, landscaping in parks, flood control channels, municipal golf courses, etc.
Steps for Implementation	1) Assess current herbicide and pesticides uses (e.g., types, amounts, areas used). 2) Research areas where less toxic substances could be substituted or usage could be eliminated altogether (e.g., use of mosquitofish rather than pesticides). 3) Develop implementation programs for various areas.
Methods To Assess Effectiveness	Compare amounts and types of herbicides and pesticides currently used with amounts and types used after implementation of the program(s) to demonstrate overall reduction and/or transition to less toxic substances.
Remarks	Coordinate with public education and industrial outreach component for public education in the area of residential herbicide and pesticide use.

each source, identifying optional BMPs that would prevent or eliminate that source, and selecting the preferred option. The following describes a pared-down process of BMP selection that we have used on several industrial projects.

Step 1: Identify Drainage System and Receiving Water

Define the drainage system and receiving waters, including water quality and other concerns in receiving waters. Ensure plant personnel (particularly nonenvironmental personnel) understand the receiving water and regulatory issues when they are involved in the BMP selection process.

Step 2: Identify Industrial Activities and Associated Pollutant Sources

Discuss what industrial activities are conducted at the facility and how these activities might lead to discharges into storm drain systems. This can best be accomplished through a combination of a site investigation and a sit-down brainstorming session with plant personnel. Table 2 shows the result of this step for a steam plant. Indicated in the table are the source activities, drainage areas within the facility where these sources are located, potential pollutants associated with the source, and a relative measure of the importance of the source for creating receiving water problems.

Contamination potential:

1 = high

2 = medium

3 = low

Step 3: Develop Candidate Control Measures

Develop candidate control measures for consideration that address each of the potential and known sources of pollutants. The last column in Table 2 shows these measures.

Table 2. Example of Source and Pollutant Identification and BMP Selection for Industrial Facility

Source Areas	Drainage Areas	Potential Pollutant	Contamination Potential	Recommended Control Measure
Parking lots	1, 2, 4	Oil and grease TSS	2 2	• Inspect and clean catchbasins • Conduct good housekeeping practices
Loading docks	1, 2	Oil and grease Toxics	3 3	• Provide mats to cover catchbasins if spill occurs while raining
Construction equipment parking	1, 2	Oil and grease TSS	2 2	• Inspect and clean catchbasins • Conduct good housekeeping practices
Materials storage	1	TSS Metals Toxics	2 2 3	• Sweep after loading and unloading materials from concrete vaults • Place materials with greatest contamination potential under Ferry St. overpass
Curing oil storage	1	Oil and grease	2	• Move drums inside or to a bermed area that is covered
Vehicle fueling	2	Fuel Oil and grease	3 3	• None
Aboveground fuel storage	2, 3	Fuel	3	• None
Utility pole storage	2	PCP1 Creosol Metals Oil and grease	1 1 1 1	• Determine feasibility of moving poles under Ferry St. overpass
Vehicle rinse area	2	TSS Oil and grease	2 1	• Clean sediment trap more often • Consider adding oil/water separator
Steam cleaner	2	TSS Oil and grease Detergents Toxics	3 3 3 3	• Enlarge pad area • Post signs providing employees with proper instructions • Rinse pad after cleaning • Clean oil/water separator more often

Table 2. Example of Source and Pollutant Identification and BMP Selection for Industrial Facility *(Continued)*

Source Areas	Drainage Areas	Potential Pollutant	Contamination Potential	Recommended Control Measure
Transformer cleaner	2	Mineral oil	3	• None
		PCBs	3	
Sodium hypochlorite storage	2	NaOCl	2	• Relocate drums inside or to a bermed area that is covered
Hogged fuel pipe	3	Tannin and lignin	3	• Sweep street after heavy winds
		BOD	2	• Clean catchbasin more often
		COD	3	
Sulfuric acid storage	3	H_2SO_4	3	• None
Oil drum storage		Oil and grease	3	• None
Ash handling area	4	TSS	2	• Enlarge the loading area
		pH	2	• Improve the loading procedure
		Toxics	2	• Clean the catchbasins in the immediate area more often

Step 4: Conduct BMP Evaluation and Selection

Conduct a BMP evaluation and selection session with plant personnel. Just as in a municipality, involving the right plant personnel in the process is very beneficial. Such involvement allows the plan to reflect their extensive knowledge of the site and industrial activities, and encourages the plant staff to take ownership of the management plan. Often, we have found that personnel have been trying to implement some of the BMPs, and the NPDES permit requirements now give them the impetus to get them more fully implemented. In these sessions, we have sometimes used a formal decision process, while at other times a less formal, but still documentable, discussion of the potential BMPs was used to select BMPs. The focus of BMPs at industrial sites where we have worked has been source control. Compared with municipalities, however, industries tend to be more willing to consider installing or retrofitting structural controls.

Step 5: Prioritize BMPs and Develop Monitoring Program

Prioritize BMPs and develop and implement "monitoring" programs for assessment of effectiveness.

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A Catalog of Stormwater Quality Best Management Practices for Heavily Urbanized Watersheds

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Abstract

Various federal and state environmental programs require the use of onsite structural best management practices (BMPs) to control the quality of stormwater discharges from development sites. Space constraints, extremely high property values, soil conditions, and the proximity of other building foundations often preclude the use of conventional stormwater BMPs for infill construction or redevelopment in the intensely builtup centers of major cities, where pollutant loads are usually the greatest. Unconventional solutions must be applied in these heavily urbanized environments.

Alexandria, Virginia, has adopted and published design criteria for several nonconventional BMPs, many of which employ intermittent sand filter technology; some of these BMPs were developed by pioneering jurisdictions throughout the United States; the city's engineering staff devised others:

- Stormwater sand filter basins in widespread use in Austin, Texas, are readily adaptable for large development projects.
- Underground vault sand filters employed in the District of Columbia (DC) allow full economic use of surface areas.
- Double-trench sand filters adopted by the state of Delaware can be placed either in or adjacent to paved areas.
- Simple trench and modular sand filters developed by the city of Alexandria are suitable for small or medium-size sites.
- A peat-sand filter adapted from a Metropolitan Washington Council of Governments design is applicable to situations where high pollutant removal is required.
- Water quality volume detention tanks for use in Alexandria's combined sewer areas capture the most polluted stormwater for later treatment in the wastewater treatment plant.

The Heavily Urbanized Environment

The U.S. Environmental Protection Agency (EPA) program for National Pollutant Discharge Elimination System (NPDES) permits for stormwater discharges envisions the use of onsite structural best management practices (BMPs) to control the quality of runoff from development sites. Many state programs already impose the requirement for onsite BMPs on developers. Under the Virginia Chesapeake Bay Preservation Act (VCBPA), no net increase in pollutants in stormwater runoff is allowable from previously undeveloped sites in Chesapeake Bay Preservation Areas (CBPAs). Runoff from redevelopment sites in CBPAs must contain 10 percent fewer pollutants than existed before redevelopment. In devising a local program to meet these pollutant removal performance requirements, Alexandria confronted the dilemma of which structural BMPs to employ. The entire city is designated as a CBPA. Most of the land is already developed, and large areas are heavily built up, in many cases with lot-line to lot-line structures. Property values are also extremely high. Such conditions exist in the central business districts of most metropolitan areas.

Use of conventional structural BMPs is often impractical in the heavily urbanized environment. Space and cost constraints severely inhibit the use of dry detention ponds and wet ponds. Soil conditions and high water tables in the river valleys where most older cities are located frequently preclude the use of infiltration devices because of the prevalence of marine clays. Unconventional solutions had to be found to remove the pollutants from stormwater runoff created by development activity. Research by the engineering staff of Alexandria's Transportation and Environmental Services Department revealed that very little information is available on how to remove pollutants from runoff in heavily urbanized environments.

BMP Design Criteria for Heavily Urbanized Areas

The Alexandria engineering staff consulted with jurisdictions throughout the United States where BMPs addressing heavy urbanization are being investigated, then synthesized the information obtained into comprehensive design criteria for local developers. The staff also developed several additional BMPs for use in the city. Design criteria for these BMPs for heavily urbanized areas were published in the *Alexandria Supplement to the Northern Virginia BMP Handbook* in February 1992 (1). The publication is being used by the Virginia Chesapeake Bay Local Assistance Department as a guide for other urban stormwater programs within the commonwealth.

The Concept of BMPs for Heavily Urbanized Areas

Stormwater quality management in the heavily urbanized environment involves the following activities for the most polluted runoff:

- Collection
- Pretreatment to remove sediments
- Storage
- Treatment to remove pollutants of a specific quantity

In Virginia, the minimum quantity of stormwater to be treated is the first 1/2 in. of runoff from the impervious areas on the site—the water quality volume (WQV). The WQV for each impervious acre is just over 1,800 ft^3.

Capturing the WQV

A typical approach for achieving isolation of the WQV is to construct an isolation/diversion weir in the stormwater channel or pipe such that the height of the weir equals the height of the water in the BMP when the entire WQV is being held. When additional runoff greater than the WQV enters the stormwater channel or pipe, it will spill over the isolation/diversion weir, and the extent of mixing with water stored in the BMP will be minimal. The overflow runoff then enters a peak flow rate reducer or exits directly into the stormwater collection system. Figure 1 illustrates this approach.

Pretreatment Requirements

Several conventional BMPs, such as buried infiltration devices, and most unconventional BMPs require some type of pretreatment system to remove excessive sediments, which would result in premature failure of the BMP. Pretreatment mechanisms may be installed either at the point of collection or after separation of the WQV. These mechanisms may be either separate devices or an integral part of the BMP itself.

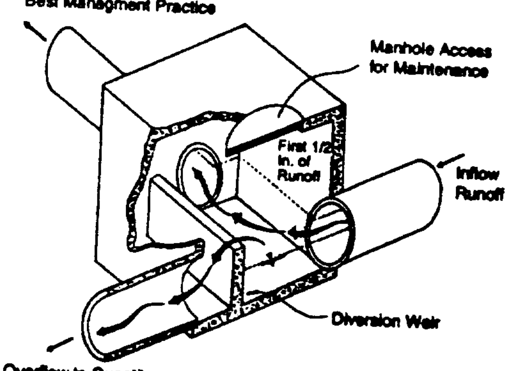

Figure 1. Typical isolation/diversion structure.

Water quality inlets (WQIs), or oil-grit separators (OGSs), have been employed for several years for the removal of grit and oil, which are found in large quantities in parking lots and other areas where vehicular traffic is significant. Recent studies by the Metropolitan Washington Council of Governments (MWCOG), however, have established that WQIs provide little or no pollutant and questionable hydrocarbon removal (3).

Sedimentation basins have traditionally been the first step in water or wastewater treatment. Where site conditions allow, presettling basins may provide a low cost approach to removal of sediments, which can clog infiltration devices or filter systems. In situations where space is not a problem, presettling basins may be built directly into the ground. In the heavily urbanized environment, where space utilization is an important economic consideration, underground presettling chambers in vaults or pipe galleries may provide a more feasible solution. Alexandria sizes sedimentation basins using a methodology based on the Camp-Hazen equation, published by the State of Washington Department of Ecology (4).

Grassed filter strips are a common method employed in northern Virginia for removing sediments from stormwater to be treated in infiltration systems. To be effective, the strip must be at least 20 ft wide, have a slope of 5 percent or less (5), and be stabilized.

Storage of the WQV

Following isolation of the WQV and pretreatment to remove sediments and other pollutants, water must be stored until it can be processed in the primary treatment device (up to 40 hours in Alexandria). Creating over 1,800 ft^3 of water storage per impervious acre on the site is often the most costly item in the overall BMP system. In some cases, as with sedimentation basins, storage may be combined with pretreatment. In others, separate storage galleries of round or arched-section pipe may be required. Some BMPs for heavily urbanized areas combine pretreatment, storage, and primary treatment in a single underground vault.

Treatment of the WQV

Most of the BMPs described in this paper employ intermittent sand filters. Originally developed during the 1800s for treating both water supplies and wastewater, intermittent sand filters have regained popularity for use in the treatment of small wastewater flows (6).

Austin, Texas, and the state of Florida pioneered the use of sand filters in the treatment of stormwater runoff. Alexandria uses the Austin sand filter equation derived from Darcy's Law by the Austin Environmental and Conservation Services Department to size sand filters (2):

$$A_f = I_a H d_f / k(h+d_f)t_f$$

where

A_f = surface area of sand bed (acres or square feet)
I_a = impervious drainage area contributing runoff to the basin (acres or square feet)
H = runoff depth to be treated (feet)
d_f = sand bed depth (feet)
k = coefficient of permeability for sand filter (feet per hour)
h = average depth (feet) of water above surface of sand media between full and empty basin conditions (half maximum depth)
t_f = time required for runoff volume to pass through filter media (hours)

Based on long-term observation of existing sand filter basins, Austin uses k values of 3.5 ft/day for systems with full sedimentation pretreatment and 2.0 ft/day for systems with only partial sedimentation pretreatment. Alexandria has also adopted these values. Both Austin and Alexandria use a BMP drawdown time (t_f) of 40 hours. With these constants, the equation for sand filter systems with full sedimentation protection reduces to

$$A_{f(FS)} = 310 I_a d_f/(h+d_f),$$

where A_f is in cubic feet and I_a is in acres.

For sand filter systems with partial sedimentation protection, the equation reduces to

$$A_{f(PS)} = 545 I a d_f/(h+d_f),$$

where A_f is in cubic feet and I_a is in acres.

Descriptions of BMPs for Heavily Urbanized Areas

The BMPs discussed below should not be thought of merely as drainage structures. They are low technology treatment works that use water and sewage treatment technology from the late 19th century. Treatment works cannot always be made to function by gravity flow, although it is usually desirable from a cost-effectiveness standpoint.

Surface Sand Filter Basin Systems

Austin, Texas, was a pioneer in the use of intermittent sand filtration systems for treating stormwater runoff. The Austin program is managed by the Environmental and Conservation Services Department, which has published design criteria in their *Environmental Criteria Manual* (2).

Typical intermittent sand filters employ an 18- to 24-in. layer of sand as the filter media underlain by a collector pipe system in a bed of gravel. A layer of geotechnical cloth separates the sand and gravel to keep the sand from washing into voids in the gravel. Austin pretreats the stormwater runoff in a sediment trapping structure to protect the filter media from excessive sediment loading.

Figure 2 is a centerline cutaway of one Austin sand filter configuration. In this system, the sedimentation structure is a basin designed to hold the entire WQV, then release it to the filtration basin over an extended drawdown period. An alternate design allows use of a smaller sedimentation chamber but requires increasing the filter size to compensate for increased clogging of the filter media. While the system shown uses concrete basins, a sediment pond and a geomembrane-lined filter built directly into the ground may be used where terrain and soil conditions allow. The Austin sand filter systems are most appropriate for large developments covering several acres.

Austin has monitored the performance of their sand filters for several years and currently recognizes up to 60 percent phosphorus removal efficiency based on these studies (7). Alexandria is currently recognizing a 40 percent phosphorus removal rate pending further sand filter monitoring results by Austin and the District of Columbia. (Phosphorus is the "keystone pollutant" used to measure compliance with the VCBPA.)

Underground Vault Sand Filter Systems

Truong developed a stormwater quality sand filtration system in an underground vault (8). Over 70 of the structures have been installed since 1987. Figure 3 is a centerline cutaway of the original concrete vault DC sand filter. DC sand filters may be placed underneath parking lots, alleys, or driveways, taking up no usable space on the surface. This is an important advantage in the heavily urbanized environment. Truong believes that

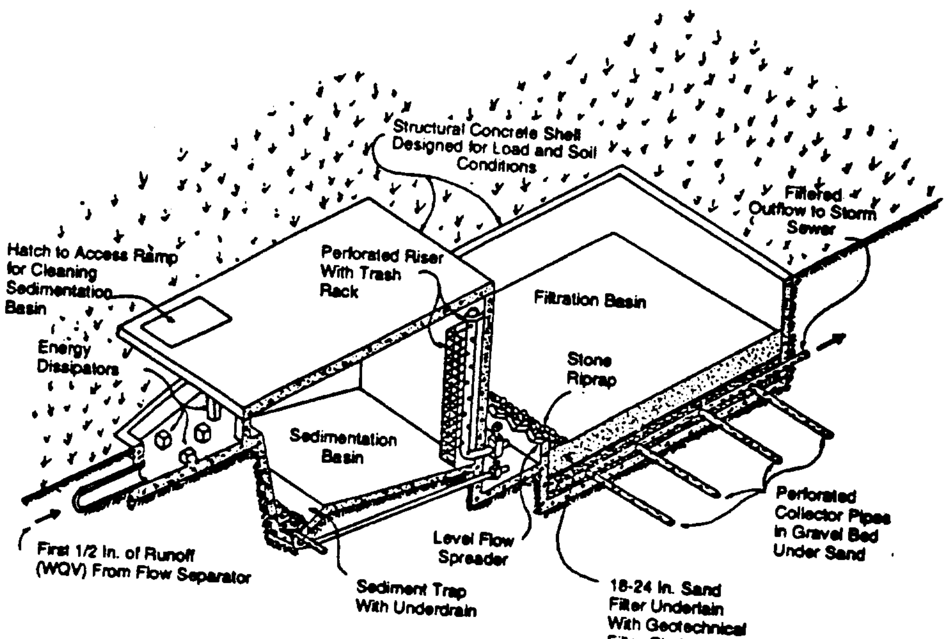

Figure 2. Austin basin sand filter system.

this system works best on watersheds with 1 acre or less of impervious cover.

The DC sand filter is a three-chamber gravity-flow system. The first chamber and the throat of the second chamber contain a permanent pool that traps grit and floating organic material, such as oil, grease, and tree leaves. A submerged rectangular opening at the bottom of the first dividing wall connects the two parts of the pool. The second chamber also contains a 24-in. deep sand filter underlain by a layer of geotechnical fabric and collector pipes in gravel. A top layer of plastic-reinforced geotechnical filter cloth held in place by a 1-in. layer of gravel is provided above the sand to compensate for the smallness of the sedimentation chamber.

New runoff entering the structure causes the pool to rise and overflow onto the filter. After percolating through the sand, the treated water enters the underdrains and flows out into the third chamber, or clearwell. The clearwell conveys the treated water to the storm sewer or drainage system. If possible, this BMP should be configured to allow gravity outflow; however, in instances where filters must be placed below the storm drainage system elevation, such as under the entrance driveway to a parking garage, a sump pump must be used.

The trash and hydrocarbon water trap in the first chamber must be pumped out and refilled with clean water every 6 months for proper functioning. Every 3 to 5 years, the top filter cloth layer and gravel must be removed and replaced because of fine sediment clogging. Placement of the second chamber manhole directly above the center of the filter allows the corners of the cloth to be peeled up and bound together to form a bag that can be lifted out as a unit.

The District of Columbia Environmental Regulation Administration is conducting a program of monitoring to establish the actual removal rates of this system. As of this writing, no data are available.

The Austin partial sedimentation sand filter may also be placed in underground vaults. Figure 4 shows a modified vault design developed by Alexandria from both Austin and District of Columbia methodologies. The Austin approach uses a gabion wall to separate the partial sedimentation chamber from the filter area. The gabion absorbs energy and provides initial filtration. Heavy sediments are deposited in this first chamber to dry out between storms. The filter is exactly like that used in the DC sand filter system.

Double Trench Sand Filter Systems

Shaver developed a surface sand filter system for use in Delaware (9). The Delaware sand filter is intended to be an in-line facility processing all stormwater exiting the site until it overflows.

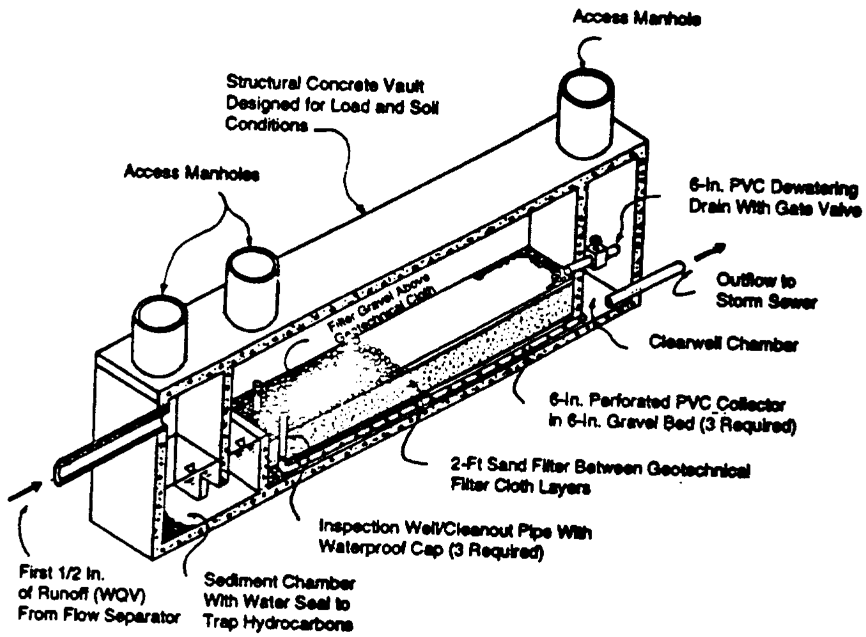

Figure 3. DC underground vault sand filter.

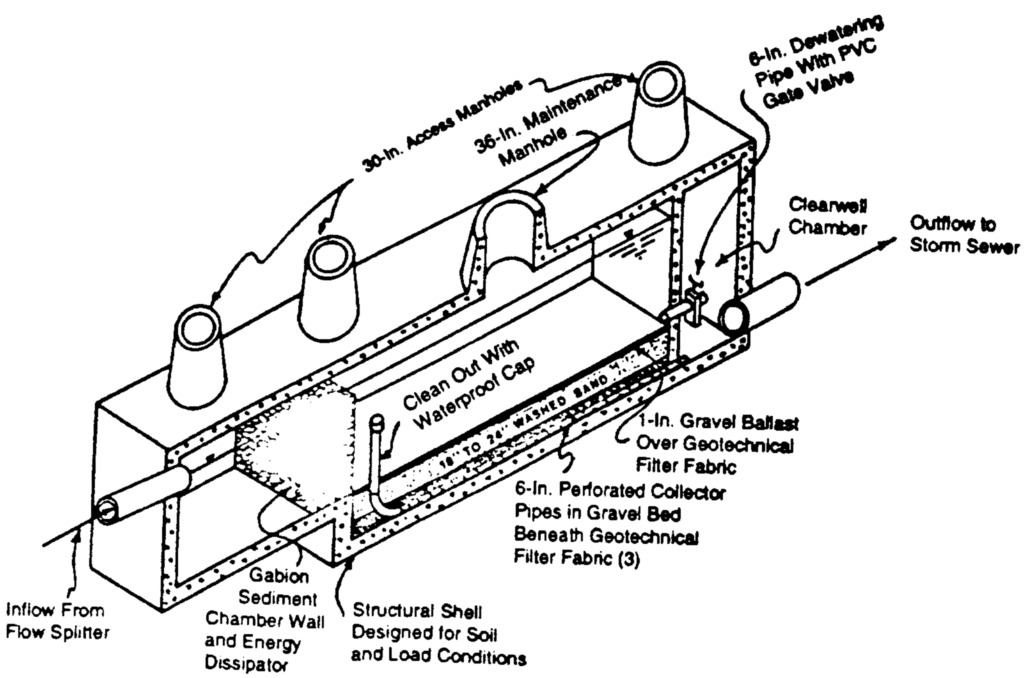

Figure 4. Dry vault stormwater sand filter.

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Figure 5 is a schematic drawing of the Delaware sand filter system. The concept uses two parallel waterproof trenches connected by close-spaced wide notches in the top of the wall between them. The trench adjacent to the site being served is the sedimentation chamber. Polluted stormwater must be conveyed to the chamber in enclosed storm-drain pipes. The permanent pool in the sedimentation chamber inhibits resuspension of particles that were deposited in earlier storms and prevents the heavier sediments from being washed into the filter chamber. As new stormwater enters the system, the permanent pool overflows through the weir notches and onto the filter as sheet flow to prevent scouring out the sand.

The second chamber contains an 18-in. sand filter that is always fitted with a solid cover. No underdrain piping is provided. Water percolates through the sand and escapes from the filter through a geotechnical cloth-covered grate at the downhill end of the filter chamber.

Four Delaware sand filters were constructed in Alexandria during 1992. The first two systems served small parking lots and were built according to the original Delaware design. The third application, involving two separate filters, was used to treat runoff from a large (1.7 acre) parking lot. The high cost of steel grates and covers led the developer's consultant to propose moving the filter off the lot and providing slotted curb ingress and precast concrete lids. Premature failure of one of the filters led the owner to install a collector pipe in gravel below the sand layer. This design is shown in Figure 6.

Although the filters illustrated are contained in reinforced concrete shells, these systems may be installed in any waterproof container that will bear the wheel loads or soil pressures involved with the particular application; molded fiberglass or other plastic materials would work well. Delaware sand filters made of timber lined with rubberized roofing material have been proposed for use on temporary parking lots for development sales offices.

Delaware does not rate these systems for nutrient removal efficiency. Delaware has made a determination, however, that when treating the first 1 in. of runoff, this sand filter provides 80-percent suspended solids removal, as required by state environmental regulations (9).

Stone Reservoir Trench Sand Filter Systems

The filter system concepts embodied in the Austin and District of Columbia designs may be readily adapted for small and less complex applications. Alexandria's engineering staff has developed a simple trench sand filter for use on such projects as townhouses or small commercial developments in areas where infiltration devices are not practicable.

Figure 7 is a schematic drawing of a stone reservoir trench sand filter. The system is constructed in an excavation lined with impervious geomembrane (such as EPDM roofing material) sandwiched between protective layers of filter cloth. The bottom of the trench contains a simple sand filter that is connected to the storm sewer. The upper part of the system is built the same as an infiltration trench designed to treat the first 1/2 in. of runoff. Placement of perforated pipes in the stone reservoir greatly increases the voids available for storage.

Dispersed overland sheet flow is treated in a grassed filter strip before entering the system. The reservoir is further protected from sediment clogging by a layer of geotechnical filter cloth 6 in. beneath the top surface of

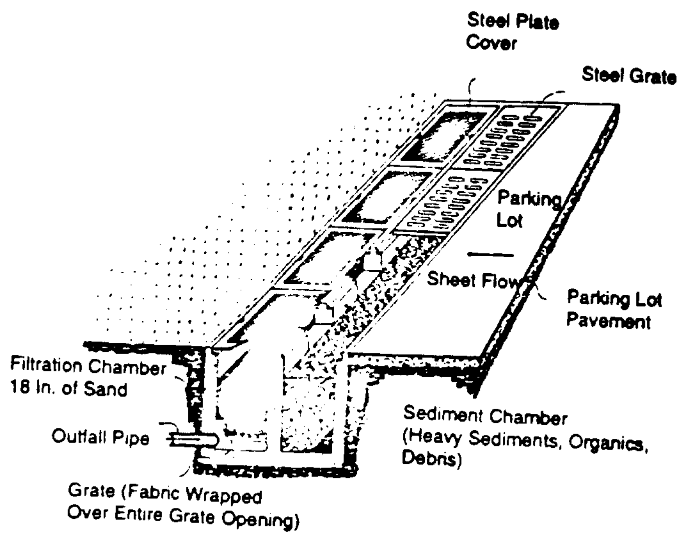

Figure 5. Delaware sand filter with grated inlets.

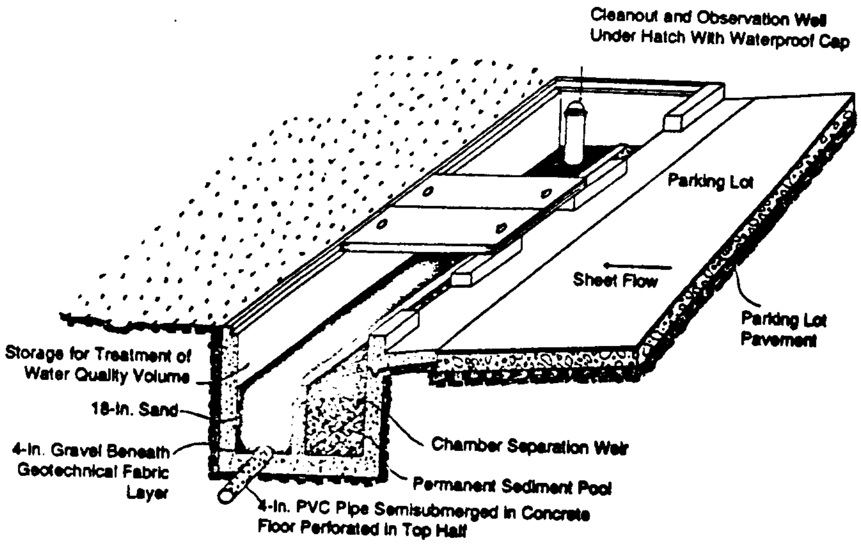

Figure 6. Slotted curb Delaware sand filter.

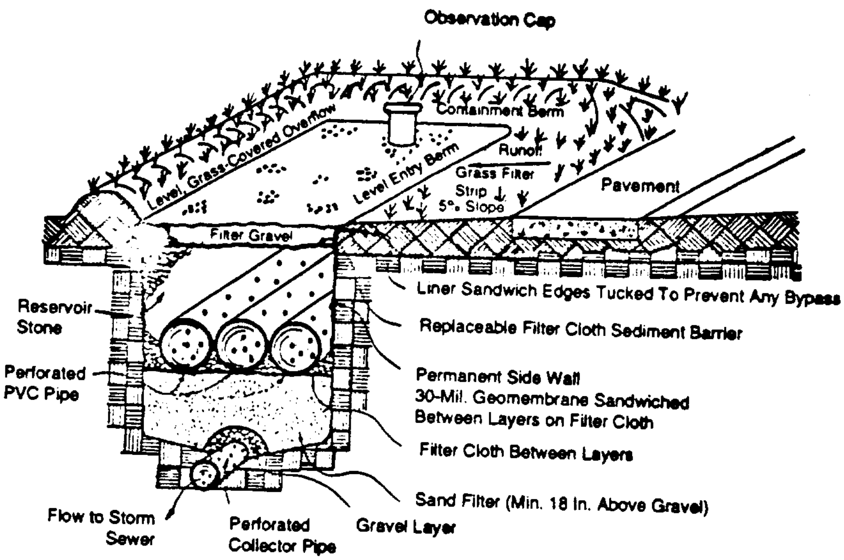

Figure 7. Stone reservoir trench sand filter.

the aggregate. The WQV flows into the reservoir until the voids in the rock and perforated pipes are completely full. Any overflow is directed to the storm sewer. Runoff collected in the reservoir filters down through the sand to the collector pipe, from which it is conveyed to the storm sewer.

Trench sand filter systems should have the same removal efficiency as an Austin sand filter.

Peat-Sand Filter Systems

Because of their high pollutant removal capabilities, simple design, low-maintenance, and affordability, peat-sand filters (PSFs) are potentially effective in heavily urbanized areas. A stormwater "end-of-pipe" PSF system was scheduled to be constructed in Montgomery County, Maryland, in the summer of 1993. MWCOG staff participated heavily in the development of this project.

Figure 8 is a centerline cutaway of a stormwater PSF system concept developed by the Alexandria engineering staff. It combines features of the Austin sand filtration system with the PSF design proposed by John Galli of MWCOG for use in the Montgomery County application (10). The Alexandria concept is intended to operate as an off-line system treating the WQV from each storm. Any additional detention required for stormwater quantity restrictions should be provided separately downstream of the PSF system. PSFs would be appropriate for commercial developments for which a high pollutant removal is required or for end-of-pipe treatment of entire storm sewer watersheds.

The sedimentation basin design is essentially the same as that of the Austin sand filter. Because PSF systems cannot normally operate during the more severe winter months of the mid-Atlantic region, however, a gate-valve equipped bypass is provided to divert flow from the basin directly to the storm sewer. The invert of this pipe is placed at an elevation that will detain a permanent pool in the basin averaging at least 4 ft deep. In effect, this configuration converts the sedimentation basin to a small extended detention/wet pond during the winter months. As with the Austin sand filter, the basins may be either walled with concrete, as shown, or, if soil conditions permit, be constructed as soil structures.

The filtration basin is basically the Austin design with the sand filter enhanced by adding a 12- to 18-in. thick surface layer of hemic or fibric peat, a layer of calcitic limestone (for greater phosphorus removal), and a 4-in., 50:50 well-mixed layer of peat and fine-medium grain sand atop the normal filter sand and collector underdrains. A nutrient-removing grass-cover crop must be planted and maintained in the top of the peat layer. (PSFs will not function in underground applications because anaerobic conditions would develop.)

The system shown is designed for gravity flow. In situations where the terrain does not provide sufficient relief, pumps must be added to move the stormwater between basins.

Based on information provided by MWCOG (10), the Alexandria engineering staff estimates that their PSF design should have a phosphorus-removal efficiency approaching 90 percent during the months in which the filter is in operation. Assuming that the filter would be bypassed from mid-December to mid-March in the mid-Atlantic region, the annual phosphorus removal efficiency of the overall system, including the small extended detention/wet pond, is estimated at 70 percent.

Water Quality Volume Storage Tanks

This concept involves the collection and storage for later treatment in the wastewater treatment plant of the WQV from each storm. WQV storage tanks are used on all developments or redevelopments that require a BMP within Alexandria's combined sewer watersheds. Figure 9 shows a centerline cutaway of a WQV storage tank. The stored water is released into the combined or sanitary sewer system by telemetry-controlled pumps or automatic valves that ensure that none of the WQV escapes while combined sewer overflows into streams

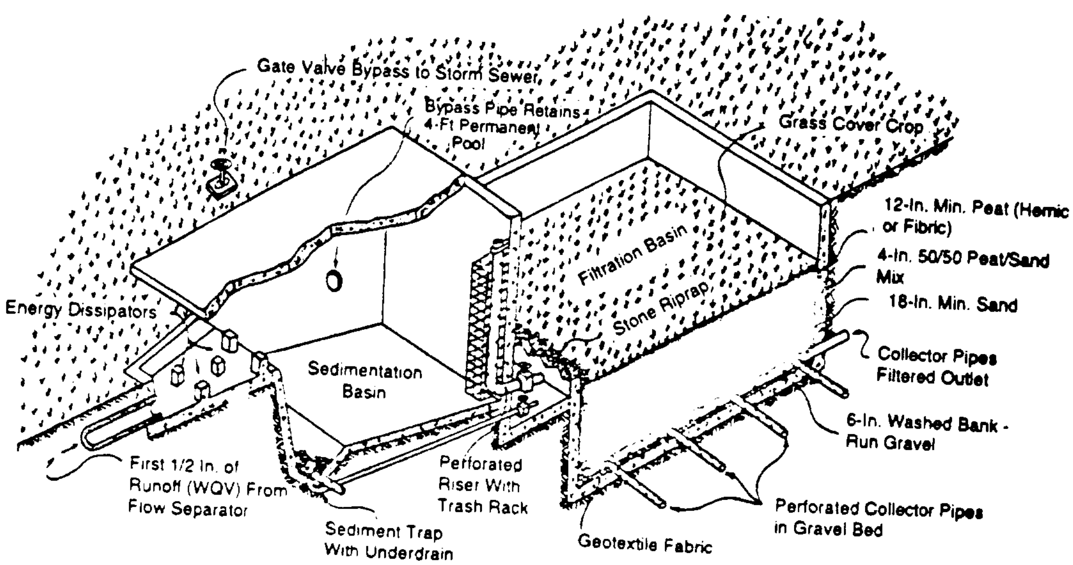

Figure 8. Stormwater peat-sand filter system.

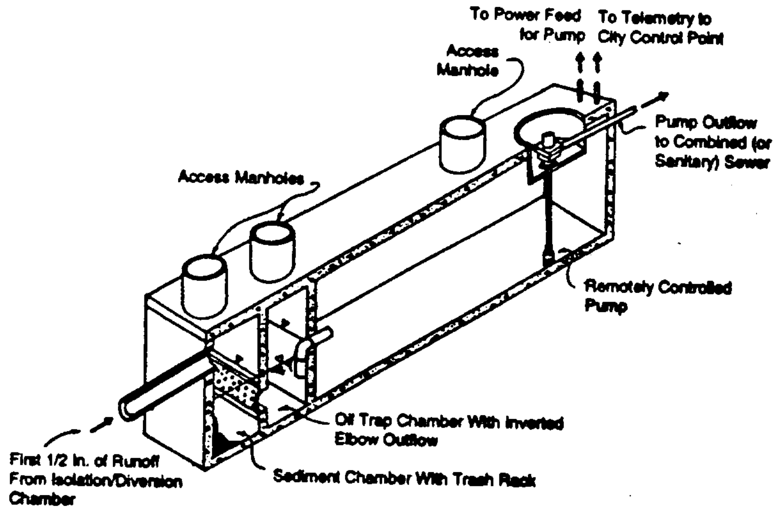

Figure 9. Water quality volume storage tank.

are occurring or in periods when inflow and infiltration are taxing the capacity of the wastewater treatment plant. This approach conforms to EPA's August 19, 1989, National Combined Sewer Overflow Strategy, which requires establishment of a high-flow management plan that maximizes the capacity of the combined sewage system for storage and treatment.

The tank shown in Figure 9 has a water quality inlet to provide sediment and petroleum hydrocarbon removal before the runoff is allowed to enter the storage tank. The inlet must be pumped out and refilled with clean water every 6 months for proper functioning.

WQV storage reservoirs may be either prefabricated tanks or vaults fabricated on site from such materials as Portland cement. Either single or multiple tanks may be employed. Although originally developed for use in combined sewer watersheds, WQV storage tanks may be applied in other situations where WQV runoff will not be routed into the storm sewer (e.g., landscaping irrigation systems or "gray water" toilet flushing systems).

When WQV water is discharged directly into a combined or sanitary sewer or used in gray-water flushing systems, the pollutant removal efficiency of the system becomes that of the receiving wastewater treatment plant. The phosphorus removal capacity of such plants is typically in the 95- to 100-percent range. When the WQV water is reused and retained on site for landscape irrigation, pollutant removal may approach 100 percent if the water is not allowed to escape from the site.

Challenges in Development and Use of BMPs for Heavily Urbanized Areas

The field of BMPs for heavily urbanized areas is in its infancy. The next few years must bring much wider use of this technology if the pollutant removal objectives of the NPDES stormwater program and other federal and state clean water initiatives are to be met. Several significant challenges need to be addressed.

Reduce Construction Effort and Costs

The construction cost for Austin sand filters serving projects with approximately 1 acre of impervious cover ranged from $13,000 to $19,000 in 1990 (1). The cost of DC sand filters was approximately $35,000 per impervious acre when the filters were first introduced but has since fallen to approximately $12,000 to $16,000 through the introduction of precasting and the maturity of the design (11). The large, slotted-curb Delaware sand filters recently constructed in Alexandria cost approximately $40,000 to serve 1.7 acres of impervious cover. This was, in essence, a prototype facility, and costs are expected to fall in a manner similar to the DC sand filter costs as contractors and engineers become familiar with the technology.

Applying prefabrication and modular concepts, especially for smaller projects, should further reduce construction effort and costs. Alexandria and the District of Columbia are exploring the rationalization of sand filter vaults in circular sections with manufacturers of aluminized corrugated pipe and fiberglass underground tanks. The pipe manufacturer has indicated that filters that would serve up to 1 acre of impervious cover could be prefabricated in a shop and delivered as a unit to a job site. The District of Columbia has also developed a sand filter in a standard precast sewer manhole. By introducing the runoff through a large catch basin with a hooded outlet, the addition of a 6-ft manhole with a sand filter in the bottom makes a BMP suitable for treating the runoff from approximately 5,200 ft^2 of impervious cover; 8-ft manhole filters can serve approximately 10,000 ft^2. Alexandria is examining the feasibility of adapting standard large highway precast curb inlets as the shells of both Delaware sand filters and underground vault sand filters. Storage of runoff awaiting filtration in arched corrugated-pipe galleries appears to be a promising approach in areas where storm sewers are too shallow to employ vault filters without pumping. Much more innovation is still needed for heavily urbanized areas.

One of the major costs of BMPs for heavily urbanized areas is creating a container to store the runoff before it undergoes treatment. More studies need to be performed characterizing different types of runoff to determine whether all sites need similar treatment. For instance, pollutants in runoff strictly from roofs may be concentrated in a smaller amount of "first flush." Pollution concentration versus time studies of roof water might well establish that treatment of a smaller amount of runoff would meet pollutant removal performance requirements. This development would likely have a significant impact on costs.

Reduce Maintenance Requirements and Costs

All BMPs for heavily urbanized areas require significant maintenance. Permanent pools require pumping out on a periodic basis (currently twice per year in Alexandria) to remove accumulated sediments and trapped hydrocarbons. As discussed above, sand filters require the replacement of the top few inches of sand or overlying layers of geotechnical cloth every 3 to 5 years. Trash must be removed from all BMPs as it accumulates to prevent premature clogging. Special care must be taken to ensure that sand filter systems are not placed in service before all open areas are stabilized with vegetation. Otherwise, the filters might quickly clog with topsoil, as occurred with one of Alexandria's Delaware sand filters. Trash screens need to be included in all designs to preclude the intrusion of materials into filter chambers that can cause premature failures. The provision of ready maintenance access is an absolute necessity. The initial cost/maintenance cost tradeoff must be carefully examined during the BMP design process.

Enhance Removal of Pollutants

The 1990 Austin report on removal of pollutants by that city's sand filters is the only scientific data available at present on long-term monitoring of such systems (7). The reported results are encouraging, but more monitoring data is needed to assess the impact of such factors as acid rain and variations in chemical content of the filter media on performance before the Austin experience can be generalized for application to other regions of the country.

While Austin reports very promising phosphorus removal values, enhancing the nitrogen and perhaps the heavy-metal removal efficiencies of BMPs may develop as a more pressing need as NPDES runoff monitoring data become available. One avenue that appears promising is the employment of a wet gravel filter component to introduce biological activity in the treatment process, an approach that is already being used to treat individual home sewage in Anne Arundel County, Maryland (12). The District of Columbia is considering adding a layer of activated carbon to a sand filter to assess the benefits through monitoring. BMPs for heavily urbanized areas represent a field that is ripe for additional innovation. Universities should take a more active role in developing BMP technologies for these areas.

Spread the Technology

Currently, the use of BMPs for heavily urbanized areas is limited to a relatively small area in the mid-Atlantic states, the Austin area in Texas, and the state of Florida. The technology is applicable to all areas of the country where pollution in stormwater runoff must be controlled under the NPDES permit program. Information on these BMPs needs to be disseminated throughout the country by EPA and other environmental agencies so that the technology is available to all parties who are wrestling with the problems of attaining NPDES compliance. This paper was written to facilitate that process.

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Postconstruction Responsibilities for Effective Performance of Best Management Practices

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Abstract

Effective performance of best management practices (BMPs) is vital to achieving the high goals and justifying the equally high estimated costs of urban runoff management. This paper identifies inspection, maintenance, and performance monitoring as three key postconstruction activities for ensuring correct and continued performance of BMPs. These activities are equal in importance to planning, design, and construction BMPs.

The paper demonstrates how failure to meet inspection and maintenance BMP responsibilities not only leads to diminished BMP performance but may also create new health and safety threats that exceed those the BMPs were intended to prevent. It further demonstrates how such a result represents both a failure to realize a gain on the resources already invested in BMPs and the cause of significant additional expenditures.

The paper also describes the key components of a successful postconstruction inspection and maintenance program, including the need for self-evaluation and feedback components to inform planners, designers, construction contractors, and maintenance personnel about ways to reduce or facilitate future maintenance. Additionally, the paper emphasizes the importance of a stable source of program funding and discusses various methods for achieving it.

Finally, the paper emphasizes the need for accurate, scientific monitoring and reporting of BMP performance to achieve optimal BMP designs and expand the ability to address urban runoff impacts on a regional or watershed basis.

Introduction

One of the top priorities of any stormwater management program is the effective performance of structural best management practices (BMPs). Effective BMP performance not only helps ensure that the program's goals are accomplished but also represents a positive return on the time, effort, and materials invested in the structural BMP's planning, design, and construction. To achieve such performance, however, everyone involved with the stormwater management program must fulfill several key responsibilities before, during, and after construction.

Before construction, these responsibilities include the development by program managers of design standards and practices that are both accurate and practical. Designers must use these standards and practices to produce construction drawings that accurately convert their ideas into a tangible structure. Using these drawings, construction contractors must create a durable structure that meets the designers' requirements and is true to the regulators' intentions.

While stormwater management remains a relatively new field, the results to date of these relatively short-term preconstruction activities have been greatly improved by several factors, including the maturation of older flood control programs; the continued growth of hydrologic and hydraulic databases, design methods, and training programs; and the implementation of formal construction inspection programs. Other factors that have assisted in the improvement of regulatory, design, and construction activities include the continued development and greater availability of computer software and hardware and the greater level of construction experience and capability. As a result, the ability of program managers, designers, and construction contractors to meet their responsibilities for effective BMP performance has increased significantly in recent years. Furthermore, these improvements have helped to kindle further interest and involvement in stormwater management.

In addition to planning, design, and construction responsibilities, however, three key areas of responsibility must be met once construction has been completed and the structural BMP has been put into operation. These responsibilities consist of the inspection, maintenance, and monitoring of the structural BMP. For the purposes of this paper, these three activities are defined briefly as follows:

- *Inspection:* Periodic observation and evaluation of a structural BMP and its individual components by qualified personnel to determine maintenance needs.
- *Maintenance:* Periodic preventative and corrective measures taken by qualified personnel to ensure safe, effective, and reliable BMP performance.
- *Monitoring:* Extended observation and evaluation of BMP performance by qualified personnel to determine effectiveness and improvement needs.

Of the three activities, inspection and maintenance are the most well established in terms of BMPs, while monitoring represents a somewhat more recent aspect of stormwater management. More complete descriptions of each activity and their growing importance is presented in later sections of this paper. For now, it is important to note that each activity represents a long-term, ongoing responsibility carried out after the shorter term planning, design, and construction efforts have been completed. It is also important to note that BMPs for inspection, maintenance, and monitoring have not received the same level of attention typically devoted to planning, design, and construction. While lack of adequate funding may be a cause, the reasons for this imbalance are generally unclear. This is unfortunate, because such an imbalance may critically affect the long-term success of stormwater management programs and regulations. Possible reasons include the ongoing, long-term, and somewhat routine nature of inspection and maintenance in particular, which may not offer either the intellectual and creative challenge of planning and design or the immediacy of construction. Additional reasons may be an unacknowledged reluctance to confront the reality of current planning, design, and regulatory efforts (particularly the negative aspects of that reality), or the failure to fully appreciate the importance of BMPs in regard to inspection, maintenance, and monitoring and the serious consequences of their prolonged neglect.

Regardless of the reasons, it is apparent that BMPs for inspection, maintenance, and monitoring have suffered the neglect typical of long-term, ongoing activities. As noted above, this neglect has critical implications for the long-term success of efforts to manage stormwater, particularly through the use of structural BMPs. In an effort to correct this problem, this paper presents information emphasizing the importance of and need for BMPs in inspection and maintenance and describes the key components of a comprehensive inspection and maintenance program. Additionally, the paper highlights the increasing need for monitoring as a means to improve BMP performance and effectiveness and to reduce required inspection and maintenance efforts.

The Importance of BMP Inspection and Maintenance

A common requirement of virtually all stormwater structures, particularly those that encounter various weather conditions, is their need for periodic inspection and maintenance. While these needs may be obvious in a general sense, the particular importance of inspection and maintenance for structural BMPs needs to be stressed.

Perhaps the most recognizable reason is the need to reliably and consistently achieve the performance levels required by the stormwater management program and designed into the BMP. For example, a BMP that relies on the temporary storage of stormwater runoff to achieve required peak outflow or pollutant removal rates must be periodically cleaned of accumulated sediment and debris to maintain required storage capacity and prevent re-suspension of captured pollutants. The outlet structures at these facilities must also be periodically cleared of accumulated debris to maintain discharge rates at required levels. Maintenance of vegetation is also important, particularly for those BMPs that use the vegetation for pollutant filtration and/or uptake. This maintenance can range from mowing, seeding, and fertilizing turf grass areas to ensure stability and prevent erosion to harvesting wetland vegetation to promote and manage growth.

The maintenance described can also be viewed as an effective means of ensuring a positive return on the time, effort, and materials invested in the planning, design, and construction of a BMP. The total amount of this investment for a single BMP can be considerable, with total construction costs exceeding $50,000 and total project costs exceeding $100,000. Failure to adequately inspect and/or maintain such a facility can lead to ineffective performance, structural failure, and, consequently, a failure to realize a return on the investment. It is generally recognized that the cost of providing comprehensive water quality protection may be considerably greater than our present ability to pay for it. In such cases, we must strive to achieve the greatest possible return on the resources we do invest in such protection.

Perhaps the most important need for BMP inspection and maintenance is the need to avoid the health and safety threats inherent in their neglect. The foremost of these threats is the potential for structural failure, which can rapidly release stored waters and flood downstream areas, causing property damage, injury, and even death. The fact that this flooding threat would not exist if the BMP had not been constructed further highlights the need for proper inspection and maintenance to prevent it from ever occurring. Another health and safety threat from maintenance neglect is mosquito breeding, which can threaten a broad area in the general vicinity of the BMP. Other undesirable insects, animals, and odors can also result from maintenance neglect, adversely affecting those who must live or work nearby. In all such cases, the BMP can actually have worse environmental impacts than those it was originally constructed to prevent.

A final reason for effective BMP inspection and maintenance lies in preserving and nurturing the community and political support that stormwater management efforts have gained to date. Such continued support is vital to the success of our stormwater management efforts, particularly because much of the solution to stormwater pollution lies in source controls and lifestyle changes that the public will be asked to adopt. We cannot count on even passive public support, however, let alone active public involvement in nonstructural programs, if we are unable to create and maintain structural BMPs that are community assets rather than liabilities. Any support that we now have or hope to generate in the future will quickly be lost if we allow structural BMPs to become aesthetic nuisances or safety hazards due to a lack of adequate inspection and maintenance.

Comprehensive Inspection and Maintenance: An Overview

The key components of a comprehensive inspection and maintenance program for structural BMPs are described below. The exact character of each component and the manner in which it is implemented depends on the specific economic, political, environmental, and social characteristics of the community in which the program functions.

Official Inclusion of Inspection and Maintenance in Overall Stormwater Management Program

BMP inspection and maintenance should not be an afterthought but should be included from the beginning in the community's overall stormwater management program. As the overall program develops, determining how (and how often) inspections and maintenance efforts are performed is as important as determining allowable peak outflow rates and extended detention times. To ignore this fact is to invite eventual program failure through diminishing BMP performance and increasing health and safety threats. To ensure a secure role for inspection and maintenance in the overall stormwater management program, both the importance of inspection and maintenance and the ways in which they are achieved should be officially included in any implementing ordinances, resolutions, or laws establishing the overall program.

Sufficient and Stable Funding

Because BMP inspection and maintenance requires specific actions by qualified personnel, the availability of sufficient and stable funding may be the single most important component of a comprehensive program. The best intentions, talent, and equipment cannot overcome a paucity of funds, nor can regular, consistent inspections and maintenance be achieved if funding levels are erratic and/or uncertain.

Therefore, during the development of the overall stormwater management program, a stable source of funding for inspection and maintenance must be identified and formalized. This may include the use of general or specialized tax revenues, dedicated contributions from land developers or owners, and/or permit fees from those creating the need for the structural BMP. Funding may also be secured through the creation of a stormwater utility, which would provide BMP inspection and maintenance services funded by fees paid by those within the utility's service area. While the creation of a stormwater utility requires a significant amount of effort to organize and operate, several successful stormwater utilities have been created throughout the country in recent years.

Adequate Equipment and Materials

Having sufficient equipment and materials is particularly important for BMP maintenance efforts, which involve the regular performance of preventative maintenance activities such as grass mowing and debris removal and the prompt execution of emergency repairs and restorations. The long-term, repetitive nature of the preventative activities, in particular, demonstrates how a positive return can be quickly achieved from investments in equipment that expedite maintenance efforts and in materials that prolong the life of BMP components.

Fortunately, due in part to the basic nature of stormwater and its management, the character of the equipment necessary to conduct most maintenance efforts is not particularly complex or specialized. Instead, standard and relatively simple equipment such as lawn mowers, shovels, rakes, compressors, and trimmers can be used to perform the majority of maintenance tasks. This helps simplify the selection and acquisition process and keeps costs at more manageable levels.

Trained and Motivated Staff

Similar to equipment needs, many BMP maintenance tasks are not particularly complex or specialized. This means that, under most circumstances, program staff can be assembled from a relatively large labor pool, either directly by a public agency performing maintenance in house or by a contractor hired to provide such services. These factors, however, should not diminish the need for thorough training of maintenance staff. This has become increasingly true in recent years as the role of structural BMPs expands to provide higher levels of stormwater treatment and more comprehensive control of runoff rates. This has led to increasingly sophisticated facilities containing specialized vegetation and diverse habitats that require management as well as maintenance. This trend is expected to continue, further emphasizing the need for thoroughly trained staff.

The importance of motivation and enthusiasm must also be emphasized. Unfortunately, the repetitive and relatively simple nature of many BMP maintenance tasks can lead to indifferent staff performance. In addition to poor overall results, this indifferent attitude can also be dangerous, particularly for those staff members operating mowing or cutting equipment that, however simple, demands concentration and care. Indifference and a lack of enthusiasm can also stifle creativity, which is essential if improved and/or less costly maintenance techniques are to be honed from existing ones. Finally, experience has shown that the vegetated, "living" character of most structural BMPs requires a certain interest and concern on the part of maintenance staff (qualities that are evident in most successful gardeners) if proper maintenance, performance, and aesthetic levels are to be achieved.

Therefore, it is essential for maintenance staff to have an interest in the overall success of the BMP. One way that this may be accomplished is by having the long-term maintenance of a given BMP performed by the same maintenance crew, which then becomes the sole group responsible for its success or failure. Such "ownership" of the BMP helps promote more direct interest in its condition and a greater effort to maintain it.

In addition, competent BMP inspection, particularly of larger, more complex structures and dams, requires a high degree of skill, experience, and knowledge. Often, such levels require that some of the inspections be conducted by a licensed professional engineer who has a background in geotechnical and structural engineering. Other necessary skills may include biology or plant sciences, particularly if the BMP includes diverse vegetation and habitats. Obviously, the training required for such inspection personnel is more rigorous and the number of qualified personnel available to the program will be less. Finally, the training provided to maintenance workers should, in part, be directed at making them informal inspectors as well. When maintenance workers are trained and motivated to spot and report such problems as sloughing or settling of embankments, surface erosion, animal burrows, and structural cracks, repairs can be performed more promptly and with less expense and effort.

Regular Performance of Routine Maintenance Tasks

The essence or core of any facility maintenance program is the regular, consistent performance of the actual maintenance tasks that the remainder of the program has identified, planned, and scheduled, and for which staff, equipment, and funding have been provided. The competent and consistent performance of these routine tasks is the single greatest factor in determining the success of the overall BMP inspection and maintenance program. These routine tasks normally include grass mowing and trimming, trash and debris removal, soil fertilization, and sediment removal. Experience has shown that the regular, frequent (e.g., monthly or less) performance of these tasks often requires less overall time and effort on an annual basis than if the tasks are performed only a few times a year.

In addition, a flexible and informed definition of "regular" should be adopted when scheduling routine maintenance tasks. For example, while it will be easier to schedule maintenance at a given BMP for the first week of every month, the actual performance of the work should instead be based on weather conditions and maintenance need. This is particularly true of turf grass, which may be damaged by a regularly scheduled mowing during dry or drought conditions. During wet conditions, attempts to perform maintenance tasks may result in rutting and other ground disturbances, causing more facility damage. The ability to perform "regular" maintenance tasks on a somewhat "irregular" basis is one of the greatest challenges of a comprehensive inspection and maintenance program.

Timely Performance of Emergency Maintenance Tasks

Despite the best efforts of any inspection and maintenance program, emergency maintenance measures may be necessary at a structural BMP from time to time for a variety of causes, ranging from excessive rainfall to vandalism. As a result, the successful inspection and maintenance program must be ready to respond to this need in a timely and comprehensive manner. To do so, it is best to plan ahead for emergencies by developing an emergency response plan that identifies potential emergency problems and ways to address them. This may include the preparation of a list of typical repair materials, which then can be either stockpiled in house or quickly acquired through designated suppliers. The plan may also identify individuals and organizations that can provide technical input or services on short notice to assist in the emergency repair effort. Finally, a designated number of staff personnel should be available on a 24-hour basis to respond to maintenance emergencies.

Regular, Competent Inspections

One of the keys to program efficiency and overall BMP safety is the performance of competent BMP inspection on a regular basis. In view of the increasingly complex nature of structural BMPs and the wide range of technical aspects inherent in each, the need for competent inspectors should be obvious. In fact, a team of inspectors may be necessary to adequately review the geotechnical, environmental performance, structural, hydraulic, and biological aspects of many BMPs. Inspections must be performed on a regular basis to identify problems and special maintenance needs quickly and efficiently. This allows repairs to be performed promptly without the need for major remedial or emergency action.

The frequency of inspections varies with the size and complexity of a given BMP. Regular inspections by qualified personnel may range from once a year for large facilities with high damage potential to every 2 to 5 years for smaller, less complex sites. Additional inspections should also be performed as appropriate following major rain storms and other extreme climatological events such as droughts, extreme snowfalls, or high winds. It should also be noted that the growing complexity and technical range of structural BMPs is expected to require more frequent inspections covering a wider range of BMP features.

Finally, the formal inspections described above should be supplemented by informal inspections conducted by maintenance personnel during each of their site visits. This further enhances the program's ability to quickly identify and respond to special maintenance needs before they can become costly emergencies. As noted above, such informal inspections require further training of maintenance personnel.

Performance Guarantees and Defaults

In many BMP inspection and maintenance programs, the owners of the property on which the BMP is located are responsible for performing maintenance tasks. Such properties may range from single-family residences to major industrial or commercial complexes. Under such conditions, the governmental agency responsible for the overall success of the program must obtain some form of guarantee that the maintenance will in fact be performed. This guarantee is acquired through several steps. First, the property owner's responsibilities should be specified in a written agreement between the owner and the agency. This agreement should also grant the agency the right to enter the property and inspect the BMP to ensure that the stipulated maintenance is, in fact, being performed satisfactorily. In addition, the agreement should also provide a method by which the agency can perform both emergency and regular maintenance tasks in the event of default by the owner, including a provision to charge the owner for the cost. Finally, such an agreement should be binding on all future owners of the property to ensure continuity.

Accurate Recordkeeping

In view of the large number of tasks, equipment, and materials that may be involved in a comprehensive BMP inspection and maintenance program, accurate records of the maintenance effort should be kept. This includes logs of time and manpower, records of material quantities and costs, and the type and frequency of the various maintenance tasks performed. In addition, accurate records should also be kept of any complaints received from community residents regarding the adequacy and/or frequency of the various maintenance tasks as well as all reports of potentially hazardous conditions. The time and expense of such recordkeeping, including the need for staff training in the proper procedures, can be quickly offset if the recorded information is used to improve scheduling, task performance, and purchasing practices. Additional details of such use is described below.

Productive Self-Evaluation and Interaction

To achieve improved levels of efficiency, a BMP inspection and maintenance program should conduct regular reviews and self-evaluations. The availability of thorough program records is of great assistance in this effort. The program review should include input from all program personnel and should address such aspects as maintenance frequency, the sequence of facility visits, equipment suitability, staffing levels, and training needs. In addition, establishing a positive dialogue with stormwater regulators, designers, and contractors is highly desirable because all of these people are responsible for creating the structural BMPs that the inspection and maintenance program must ultimately (and forever) maintain. Studies and experience have shown that many of the problems encountered during BMP maintenance are actually the result of poor or misinformed regulations, designs, or construction efforts. Therefore, maintenance personnel need to identify such problems and be given a means to inform those responsible. Such interaction can be achieved through conferences and meetings with professional societies, industry groups, and governmental agencies and departments. Public input should also be sought through individual contacts (using the complaint records noted above) and community meetings.

The Growing Need for BMP Performance Monitoring

More than just grass mowing, BMP inspection and maintenance represent a broad range of integrated technical activities. In fact, this can also be said for the entire field of modern stormwater management, which requires technical interaction between regulators, designers, contractors, maintenance personnel, and the public to truly achieve the goal of comprehensive runoff management. Unfortunately, due to the random and, at times, unpredictable behavior of storm events and the inherent complexity of the rainfall-runoff process, it is often difficult to determine how well our runoff goals are being met, regardless of the proficiency of design, construction, and maintenance efforts. For this reason, BMP performance monitoring should also be included in any stormwater management program.

By closely and accurately monitoring BMP performance through field monitoring, sampling, and laboratory analysis, BMP monitoring can enable us to better define the "problem" of runoff pollution and allow regulators and designers to gain a better understanding of both BMP function and performance. This information can be used more conclusively to identify those runoff goals and management functions that either can or cannot be realistically achieved by structural BMPs. This will further allow regulators and designers to improve those functions that are viable and to develop alternatives to those that are not, both through enhanced design standards and techniques and updated regulations. BMP performance monitoring can also provide information regarding construction and maintenance practices that may have an effect on facility performance, which can in turn lead to improved or new practices or equipment.

In overview, BMP performance monitoring can be seen as a means of achieving greater return on the time, materials, and property invested now and in the future in our stormwater management programs. And because these amounts are expected to grow considerably as we expand our programs to address more complex stormwater problems, the importance of such improved returns will certainly increase.

In addition, BMP performance monitoring can also be seen as a way to help ensure overall program credibility and achieve stronger community acceptance. In recent years, much attention has focused on the need to expand traditional stormwater management programs beyond structural measures to also include nonstructural measures in order to achieve more comprehensive results. To do so, we must achieve greater community involvement in our stormwater management efforts, both through lifestyle changes (involving a wide scope of activities, from pet care to car washing to home landscaping) and through participation in various nonstructural stormwater programs (ranging from household waste disposal to carpooling to resource preservation). With the real data obtained through BMP performance monitoring, it will be easier to convince the community of both the need for and the promise of stormwater management.

Such data will also lend greater credibility to our concerns over runoff pollution and will enable us to credibly demonstrate the value of both structural and nonstructural measures. Such credibility is vital if we are to expect the public to make the changes and sacrifices demanded by both the structural and nonstructural BMPs we now have or hope to implement in their communities (and even their backyards) in the future. Finally, BMP performance monitoring will help us to more closely monitor our progress and more quickly identify program problems and shortcomings. This will help us to develop and implement program modifications and improvements in a manner that will not threaten community acceptance. As noted earlier, we will not be able to rely on public support for nor participation in vital nonstructural stormwater programs if we are unable to create and maintain aesthetically pleasing structural BMPs. We can also expect similar results if we discover that those same BMPs simply do not work.

Summary

- To achieve comprehensive success in our stormwater management efforts, it is vital that inspection, maintenance, and monitoring be considered as equal in importance to structural BMP planning, design, and maintenance.
- The neglect of BMP inspection and maintenance can actually result in worse environmental impacts to a community than the ones that the BMP was intended to prevent. This result can threaten the viability of the entire stormwater management program.
- BMP inspection and maintenance must be an official component of a comprehensive stormwater management program, with adequate staffing, equipment, and funds.
- Self-evaluation and interaction with regulators, designers, constructors, and members of the community are vital to reducing overall maintenance needs, efforts, and costs.
- BMP performance monitoring is increasingly important to the continued effectiveness and growth of stormwater management programs.

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Guidance Specifying Management Measures for Sources of Nonpoint Pollution in Coastal Waters

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Abstract

This paper describes the technology-based management measures developed under Section 6217(g) of the Coastal Zone Act Reauthorization Amendments to control sources of nonpoint pollution in the coastal zone. The implementation of state coastal nonpoint source control programs, including the development of enforceable policies and mechanisms, is the subject of other papers. The management measures, and the various practices that can be implemented cost-effectively to achieve conformity with the management measures, are the subjects of this paper. The U.S. Environmental Protection Agency document *Guidance Specifying Management Measures for Sources of Nonpoint Pollution in Coastal Waters* (1) contains most technical information available on the effectiveness of practices to control nonpoint source pollutants and the costs of these practices. Nonpoint sources addressed in the document include agriculture, forestry, urban areas, marinas, and hydromodification (dams, shorelines, and channels). Practices include nonstructural methods such as planning, pollution prevention, and source reduction alternatives in addition to structural methods such as detention ponds and composting facilities. A separate chapter of the document contains information on the protection and restoration of wetlands with nonpoint source pollution abatement functions and the use of vegetated treatment systems in nonpoint source control programs.

Introduction

Section 6217 of the Coastal Zone Reauthorization Amendments of 1990 (CZARA) requires the development of coastal nonpoint source (NPS) control programs to protect and restore coastal waters. States with coastal zone management plans that the National Oceanic and Atmospheric Administration (NOAA) has already approved will develop the new NPS control programs by implementing management measures found in the U.S. Environmental Protection Agency (EPA) document *Guidance Specifying Management Measures for Sources of Nonpoint Pollution in Coastal Waters* (1). The development process, including determination of program content, use of alternative management measures, and development of additional management measures to meet water quality standards, is described in a separate document (2) and is the subject of other papers. This paper focuses on the development of the management measures and their basis—the structural and nonstructural practices that can be used to cost-effectively control NPS pollution and achieve conformity with the management measures. The value of the management measures guidance as a comprehensive technical reference should not be underestimated because it was developed as guidance for coastal state programs; the management measures guidance contains detailed information on the cost and effectiveness of a wide variety of methodologies and technologies that have proven effective in controlling nonpoint sources of pollution in both coastal and noncoastal areas.

Legislative Background

Congress enacted CZARA on November 5, 1990. A major focus of this law is the control of NPS pollution to avoid impacts on coastal waters. Congress showed concern in section 6202(a) that growing populations in the coastal zone are endangering wetlands and marine resources. Section 6217 addresses this concern by requiring that each state with an approved coastal zone management program develop a coastal NPS control program and submit it to NOAA and EPA for approval. The purpose of the coastal NPS control program is to develop and implement management measures for NPS pollution to restore and protect coastal waters, working closely with other state and local agencies. Simply stated, EPA develops the management measures and publishes them as guidance, and the states develop and implement programs in conformity with the management measures and program guidance.

Section 6217(g) of CZARA defines management measures as the best available controls that can be economically achieved to reduce pollutants from existing and new categories and classes of NPS pollution. The charge is clearly to develop technology-based controls to reduce pollution from nonpoint sources. In addition, Section 6217(b) of CZARA requires the implementation of additional water-quality-based management measures to protect impaired and critical coastal areas if implementation of the measures developed under Section 6217(g) is not effective at improving water quality.

Guidance Development

To develop the guidance, EPA formed work groups composed of more than 250 people recognized as knowledgeable in the control of NPS pollution. The work groups corresponded to the six technical chapters of the management measures guidance and were cochaired by EPA staff and a combination of staff from NOAA, the U.S. Department of Agriculture (USDA) and the U.S. Forest Service. Other work group members included staff from state agencies, interstate agencies, research agencies, universities, and other federal agencies including the Bureau of Land Management, Fish and Wildlife Service, Army Corps of Engineers, Federal Highway Administration, National Park Service, and Geological Survey.

Work group members provided references, literature reviews, and advice as EPA worked with its own contractors and experts to pull together, analyze, and summarize information on management practices and their effectiveness. EPA released the proposed management measures guidance in May 1991. EPA and NOAA also published a proposed program implementation guidance in October 1991.

Input on the proposed management measures guidance was solicited from the public during a 7-month comment period. The major problems identified in the public comments on the technical chapters were a lack of cost information and a perceived "East Coast bias" in the practices identified. There were, however, many positive comments on the usefulness of the guidance as a compendium of structural and nonstructural control alternatives for NPS pollution in all areas of the country.

The final management measures guidance was released in January 1993. That document incorporated most suggested improvements and additional information received from the public comments, as well as 1) a more thorough literature review; 2) additional focus on regional differences in climate, weather, and geomorphology; 3) additional cost information; and 4) information on economic achievability. The final management measures guidance is more than twice the size of the May 1991 proposed guidance and, hopefully, twice as useful. There are more alternative practices, better descriptions, additional source reduction and pollution prevention programs, and examples of successful implementation of cost-effective practices under a variety of site conditions. Based on the favorable response to date on the final management measures guidance, the guidance is a valuable technical reference for identifying NPS problems and cost-effective solutions.

Description of the Final Management Measures Guidance

Problem Identification

Each chapter contains a discussion of NPS pollutants and problems as a rationale for the management measures and controls to be implemented as part of state coastal NPS control programs.

Agricultural Runoff

Coastal waters are affected by NPS pollution resulting from the erosion of crop land; from the manure and other wastes produced in confined animal facilities; from the application of nutrients, pesticides, and irrigation water to crop land; and from physical disturbances caused by livestock and equipment, particularly in and along streambanks.

Urban Runoff

Urbanization in the form of new development changes the natural hydrology of an area and increases runoff volumes, erosion, sediment loadings to surface waters, and loadings of sediment, nutrients, oxygen-demanding substances, pathogens, metals, hydrocarbons, and other pollutants. These changes and increases can impair water quality, alter habitats, close and destroy fisheries and shellfish beds, and close recreational areas such as beaches. Decreases in base flows caused by impervious areas can also adversely alter habitat and impair water quality. Existing urban activities such as the use of onsite disposal systems, improper disposal of household wastes, turf and lawn management, pets wastes, and road maintenance can also cause water quality problems.

Silvicultural (Forestry) Operations

Forestry operations can degrade water quality in water bodies receiving drainage from forest lands. Sediment concentrations can increase because of accelerated erosion; water temperatures can increase because of removal of the overstory riparian shade; slash and other debris can deplete dissolved oxygen; and organic and inorganic chemical concentrations can increase due to harvesting and the use of fertilizers and pesticides. Increased stream flow can also result from the removal of trees and vegetation.

Marinas and Recreational Boating

Because marinas are located at the water's edge, a variety of nonpoint effects are associated with poor flushing of boat basins, spills from refueling areas, bilge pumping, and wastes produced by the cleaning and repair of boats.

Hydromodification

Hydromodification activities have been separated into three categories:

- *Channelization and channel modification* frequently diminish the suitability of instream and streamside habitat for fish and wildlife, and alter instream patterns of water temperature and sediment transport. Hardening of banks, in particular, can increase the speed of movement of NPS pollutants from the upper reaches of watersheds into coastal waters.
- *Dams* can affect the hydraulic regime, the quality of surface waters, and the suitability of instream and streamside habitat for fish and wildlife.
- *Shoreline and streambank erosion* is a natural process that can have either beneficial or adverse impacts on surface water quality and on the creation and maintenance of coastal habitat. Eroded shoreline sediments help maintain beaches and replenish the substrate in tidal flats and wetlands. Excessively high sediment loads, however, can smother submerged aquatic vegetation, cover shellfish beds, fill in riffle pools, and contribute to increased levels of turbidity and nutrients.

Wetlands and Vegetated Treatment Systems

Wetlands and riparian areas reduce NPS pollution by filtering pollutants—especially sediment, nitrogen, and phosphorus—from surface waters. Wetlands and riparian areas can also attenuate flows from higher-than-average storm events, thereby protecting receiving waters from peak flow hydraulic impacts such as channel scour, streambank erosion, and fluctuations in temperature. Degraded wetlands lose this important set of NPS control functions. Also, degradation of wetlands and riparian areas can cause these areas to become sources of nonpoint pollution because they will then deliver increased amounts of sediment, nutrients, and other pollutants to adjoining water bodies.

Management Measures and Practices

The management measures are major subheadings within each chapter. The coastal NPS control programs that states are to develop must be in conformity with these measures. An applicability section for each measure contains information on the activities and locations to which each measure applies. A description section is included for each measure to illustrate goals and objectives and provide more detail on what the measures mean. The selection section provides the rationale used in selecting the management measure. Usually, selection is based on widespread use of a management practice or combination of practices that can be used to achieve the management measure. The economic achievability of the management measures was evaluated separately (3). If this evaluation affected the selection of a measure, the effect is described in the selection section.

Management practices are described in a separate section under each management measure for illustrative purposes. State programs do not have to specify or require the implementation of any of these management practices. EPA does expect, however, that one or a combination of these practices appropriate to local conditions can be used to achieve conformity with the management measures. For example, the management measure for runoff from new development calls for 80 percent reduction in the average annual total suspended solid (TSS) loadings. Several management practices such as sand filters or extended detention wet ponds can be used to achieve the required TSS removal. If local conditions are not appropriate for one of those practices, however, a combination of vegetated filter strips, grass swales, wet ponds, or constructed wetlands could also be used to achieve the measure. The costs and effectiveness of the management practices are usually included within the description of each practice or in a separate summary section at the end of each management measure chapter. An economic impacts study (3) was prepared based on representative practices and combinations of practices and their costs.

Management Measures by Chapter

Presented below are brief synopses of the major management measures presented in each of the technical chapters. The discussion below is not comprehensive, and the management measures guidance should be consulted to establish the exact requirements and applicability of the management measures.

Agriculture

- *Sediment and erosion control:* Rely on USDA's conservation management system to promote practices such as conservation tillage and strip-cropping.
- *Animal facilities (large units):* Contain runoff and animal waste in storage structures.
- *Animal facilities (small units):* Use less-stringent requirements for economic reasons.
- *Nutrient management:* Develop and implement comprehensive nutrient management plans that involve fertilizer application rates, timing, and use efficiency.

- *Pesticide management:* Evaluate the problem and site, use integrated pest management (IPM) where possible, and apply pesticides properly and safely.
- *Livestock grazing:* Protect sensitive areas through appropriate grazing management techniques (e.g., providing alternative water, salt, and shade sources away from sensitive areas and providing livestock crossing areas).
- *Irrigation:* Optimize water use and use chemigation safely.

Forestry

- *Preharvest planning:* Consider the timing, location, and design of harvest activities.
- *Streamside management areas (SMAs):* Establish SMAs to protect against soil disturbance and delivery of sediment and nutrients from upslope activities; retain canopy species to moderate water temperature.
- *Road construction/reconstruction and road management:* Reduce the generation and delivery of sediment.
- *Timber harvesting:* Protect waters during harvesting, yarding, and hauling.
- *Site preparation and forest regeneration:* Confine onsite potential NPS pollution and erosion resulting from these activities.
- *Management of fire, chemicals, and forested wetland areas:* Reduce NPS pollution of surface waters.
- *Revegetation of disturbed areas:* Prevent sedimentation from harvest units or road systems.

Urban

- *Runoff control for new development:* Reduce runoff levels of TSS by 80 percent, and maintain natural hydrology.
- *Watershed protection/site development:* Use comprehensive planning to protect areas that are ecologically sensitive, provide water quality benefits, or are prone to erosion.
- *Construction erosion/sediment and chemical control:* Reduce construction-related erosion, retain sediment onsite, and properly manage chemical use.
- *Runoff management for existing development:* Identify and implement runoff quality controls as appropriate and feasible.
- *New and operating onsite disposal systems (OSDSs):* Select, site, and operate OSDSs to reduce OSDS impacts on coastal waters.
- *Pollution prevention for urban areas:* Target and implement NPS reduction and public education programs.
- *Roads, highways, and bridges:* Site, construct, operate, and maintain roads, highways, and bridges properly.

Marinas

- *Marina siting and design:*
  - Allow for maximum flushing of the marina basin.
  - Perform water quality and habitat assessments to protect against adverse impacts on shellfish resources, wetlands, and submerged aquatic vegetation.
  - Control stormwater runoff (additional controls exist for hull maintenance areas).
- *Fueling station design:* Design to allow for ease of cleanup, and develop spill contingency plans.
- *Sewage facilities:* Ensure availability of pumpouts and pump stations, and develop maintenance procedures.
- *Operation and maintenance:* Establish marina operation and maintenance programs to control and to provide for proper disposal of solid waste, fish waste, liquid materials, petroleum products, and boat cleaning byproducts.
- *Public education:* Develop public education programs for marina users.

Hydromodification

- *Channelization and channel modification:* Evaluate effects of new projects on physical and chemical characteristics of surface waters and on instream and riparian habitats
- *Dams:* Control erosion/sediment and chemicals during and after construction; develop and implement an operation and maintenance plan to protect surface water quality and instream and riparian habitat.
- *Eroding shorelines and streambanks:* Stabilize streambanks and shorelines where erosion is a nonpoint problem; vegetative methods are strongly preferred over engineering structures where vegetation will be cost-effective. Protect streambanks and shorelines from erosion from the use of the shore and adjacent waters.

Wetlands, Riparian Areas, and Vegetated Treatment Systems

- *Protection:* Protect wetlands and riparian areas serving a NPS pollution abatement function to maintain water quality benefits and ensure that they do not become a source of nonpoint pollution.
- *Restoration:* Promote the restoration of damaged and destroyed wetlands and riparian systems where they will have a significant NPS pollution abatement function.

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- *Vegetated treatment systems:* Promote the use of constructed wetlands and filter strips where they will serve a significant NPS pollution abatement function.

Next Steps

1993

NOAA and EPA began meeting with states and other interested parties to assist in program development and determine their needs for future technical assistance. Activities included:

- Regional workshops with state coastal zone management and NPS control agencies.
- Briefings of other federal agencies and interest groups (e.g., trade associations and environmental groups).
- Presentations at meetings of other interested parties (e.g., International Marina Institute, National Association of Conservation Districts, Water Environment Federation, and Coastal State Organization).

1994

NOAA and EPA formulated and implemented a technical assistance program using information on needs obtained from state and local government, industry, trade organizations, and others. Elements of this program include:

- Publishing several guidance documents, including *State and Local Government Guide to Environmental Program Funding Alternatives* and *Developing Successful Runoff Control Programs for Urbanized Areas* (4, 5).
- Providing funds to help produce additional technical guidance, including *Urbanization and Water Quality, Watershed Protection Techniques*, and *Fundamentals of Urban Runoff Management* (6-8).
- Conducting workshops on such topics as stream restoration, NPS monitoring, and marina NPS controls.
- Developing educational curricula and sponsoring train-the-teacher programs on runoff NPS pollution.
- Developing an expert system for identifying and selecting agricultural NPS controls.

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Biotechnical Streambank Protection

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Abstract

Streams in areas of intense residential and commercial development have high rates of surface water runoff, so bank erosion and downstream flooding become more common and severe. Throughout the greater Chicago area, this has resulted in destabilized streams lacking habitat for fish, wildlife, and people. The Illinois Environmental Protection Agency and the U.S. Environmental Protection Agency funded the urban stream restoration projects on Glen Crest Stream and the Waukegan River. During the spring and summer of 1992, stabilization sites were completed on Glen Crest Stream, in Glen Ellyn, and in Washington Park of the Waukegan Park District. The lunker technique was chosen for its low cost of installation and ability to resist the high-velocity runoff while increasing instream habitat for gamefish and the stream side habitat for the urban population. At Glen Ellyn, lunkers were constructed of recycled plastic lumber for increased longevity. Low-cost vegetative stabilization incorporated an initial matrix of grasses and willows, plus rooted stock of redosier dogwood near the water's edge, followed by appropriate riparian trees on the upper bank that the landowner chose. Both projects trained senior members and staff personnel of the park district and the city in the application of lunkers and vegetative stabilization.

Introduction

This paper describes methods of biotechnical stabilization and instream habitat enhancement that have been field trialed in Illinois. These practices have been authorized and funded by the U.S. Fish and Wildlife Service, the Soil Conservation Service, the U.S. Environmental Protection Agency, and all Illinois state agencies responsible for stream modification permits. The following methods are described: willow post bank stabilization, lunker instream habitat enhancement with vegetative bank stabilization, and A-jack structural and vegetative bank stabilization (Figures 1, 2, and 3).

In rural Illinois areas, bank erosion is not addressed because of limited financial resources. In agricultural states, U.S. Army Corp of Engineers district offices receive many requests for assistance on bank erosion protection. Within recent years, the need for bank erosion control has been coupled with the need for environmental protection of the stream habitat and riparian areas for wildlife and fisheries. Keeping costs low while considering various environmental issues has made bank erosion control a difficult challenge for the Corps.

In Illinois, stream channel erosion increased when prairies were converted to rowcrop agriculture and residential development, thereby increasing surface water runoff rates. Man has become a dominant geomorphic factor in the watershed hydrology of both rural and urban watersheds. In most urban and agricultural areas, streams were channelized to move floodwaters away from valued lands, to maximize the size and uniformity of land holdings, even to decrease channel erosion (1). One result of increased water runoff rates and poorly designed channelization efforts has been massive bank erosion in the floodplains of Illinois streams.

Watershed studies by the Illinois State Water Survey have documented the channel erosion damages to floodplain fields and the consequent increased sediment yield. Channel erosion contributed 40 to 60 percent of the sediment yield in two monitored Illinois watersheds (2). Within these watersheds, increased runoff rates and stream channelizations caused the streambed to be downcut at first and then erode laterally to regain a meander shape (Figure 4). This process was hastened by channel incision into extremely unstable glacials and gravel deposits below an 8- to 20-ft layer of loess clays. The Crow Creek watershed study demonstrates both the bridge damages from channel incision and the field damages from bank erosion (3).

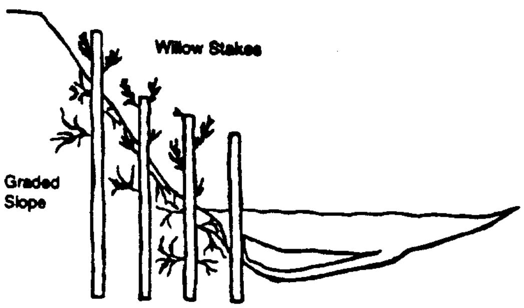

Figure 1. Willow posts installed below depth of streambed scour.

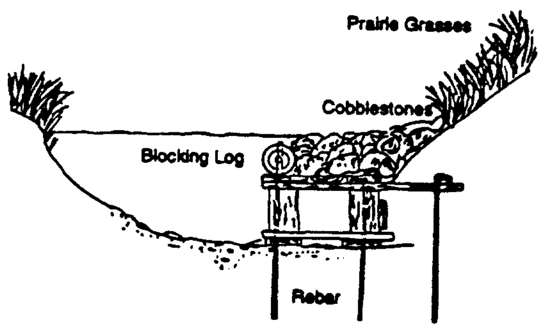

Figure 2. Lunker with riprap below baseflow stage. Rebar is driven below bed scour depth.

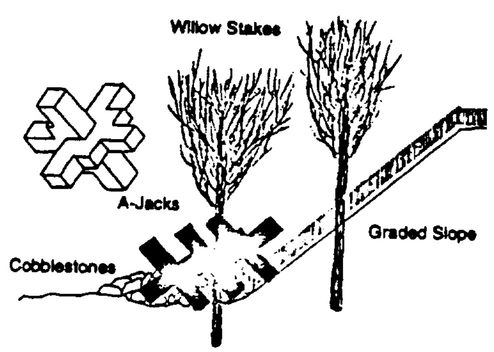

Figure 3. A-jack bank structures.

Willow Post Bank Stabilization

The willow post method differs from most European bioengineering techniques (4, 5) in that individual willows are positioned vertically below the depth of channel scour. Most biotechnical bank stabilization techniques have used vegetation with a riprap mentality. Layers of horizontally bundled woody vegetation are entrenched in the bed and bank. This type of earth

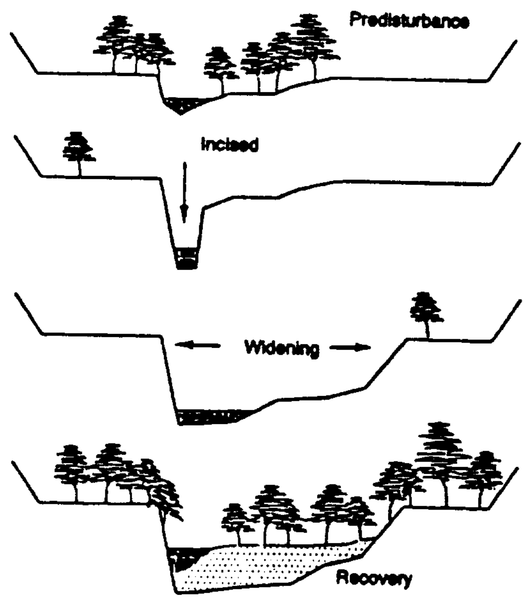

Figure 4. Incision and recovery process. Vegetative bank stabilization can be applied during the widening phase.

moving and hand labor often doubles installation costs and installation times.

Willows and most woody riparian vegetation do not naturally extend root systems very deeply below the water table. The posts are implanted much deeper than native seedlings would grow. Lateral root growth rapidly binds adjacent posts together in the bank soil. Lateral branch growth also interlocks adjacent posts to slow flow velocity near the bank.

The willow post method was mentioned by Scheichtl (4) as a method of ravine stabilization in Germany during the 1800s. Both the Corps of Engineers and the Soil Conservation Service used large willow poles in the 1930s (6, 7). In most cases, the posts or poles were laid as a layer along the sloped bank. York (8) placed willow posts in vertical holes to protect the base of levees in Arizona.

Willows are cut into 10- to 14-ft posts when the leaves have fallen and the tree is dormant. At this time, growth hormones and carbohydrates are stored in the root system and lower trunk. Dense stands of 4- to 6-year-old willows make the best harvesting areas. These stands are commonly found on the stream deltas in lakes or in old stream channel cutoffs. The willow posts are 4 to 6 in. in diameter and may be stored up to 1 month if kept wet.

The eroding streambank is shaped to a 1:1 slope with the spoil placed in a 6-in. deep layer along the top of the bank. In major erosion sites, post holes are formed in the bed and bank so that the end of the post is 2 ft below maximum streambed scour. The posts are placed 4 ft apart in rows up the streambank. The posts in one row are offset from the posts in adjacent rows.

While the steel ram and excavator is more efficient at depths of 6 ft in clay soils, a hydraulic auger and excavator unit forms deeper and longer lasting holes in stony or sand streambeds. Large stone layers of streambed material cause damage to the excavator when the steel ram is used. In fine sand layers, ram holes collapse before the post reaches the bottom of the holes. In highly fluid sands, even auger holes fill but the post can be pushed deeper with the bucket or boom. In streams with sand or gravel beds, the hydraulic auger places posts 9 to 11 ft deep in the bed. Almost all contractors in Illinois currently use an excavator and hydraulic auger unit.

In larger streams with noncohesive sand banks, large cedar trees are cabled to the willow posts along the toe of the bank. The cedars not only reduce bank scour while root systems are growing but also retain moisture during drought periods. In larger streams, such as Illinois's only designated scenic river, the Middle Fork, large rounded boulders were used as additional bank protection with the willow posts.

In Illinois, the contractor slopes 15-ft banks on a 1:1 grade for 80 cents per linear foot. Each post hole is augered 10 ft deep for $2.90. Each willow post costs $1 to $2. With a five-man crew at $10.00 per hour per man, bank sites are estimated to cost between $5 and $8 per linear foot.

Bank Erosion Site Assessment

The following questions should be asked when determining the applicability of willow bank post stabilization:

1. Does sunlight fall directly on the eroding bank? (Willows must have sun.)
2. Is bedrock close to the surface? (Streambed material should be 4 ft deep; check with a tile probe.)
3. Are lenses of fine sand exposed in the eroding bank?
4. Is the stream channel stable upstream of the erosion site? (If the stream cuts behind the upper end of willow posts, the entire bank will erode.)
5. How deep is the stream along the eroding bank? (Willow posts must be 2 ft deeper than the deepest water or the posts will be undercut below the root zone. The length of the willow posts depends on the water depth. In sand or cobble streams, a hydraulic auger forms a deeper and more stable hole.)
6. How wide is the stream channel at the erosion sites compared with stable channels upstream and downstream? (If the channel is wider at the erosion site, vegetation will not choke the stream channel and cause other erosion problems.)
7. Do you have a source of large willows close to the site? (Your costs are small when the willows are close.)
8. Will the site be wet during dry summers? (Willow posts require a lot of water while the roots are regrowing; willow posts should only extend 1 to 2 ft aboveground in dry sites.)
9. Can you keep cattle away from the posts during the first summer? (Willows must be able to produce leaves for photosynthesis and regrowth.)
10. Have debris jams forced floodwater into the eroding bank? (Large debris jams must be removed according to guidelines established by the American Fisheries Society (9).)

The willow post method of bank stabilization is the lowest cost bank stabilization method that provides both wildlife and fisheries benefits. This method has received widespread support by both the agricultural and environmental communities: Farm Bureau, soil and water conservation districts, American Fisheries Society, and Nature Conservancy. The willows serve only as a pioneer plant on the disturbed soils. Succession to wooded or grass banks is speeded by additional trees or grass plantings with active site management if the landowner desires.

Lunker Instream Habitat Structures

Lunkers are constructed of 2-in. oak planks (10). The planks form upper and bottom layers so that the interior is open to water flow at both ends and on the stream side of the structure (Figure 2). A series of lunkers are placed along the base of the eroding bank. When necessary, the lunkers are placed into an excavated trench, especially on the upper and lower ends of the sites. Each lunker is held with nine lengths of rebar, which are driven 5 ft into the streambed. In the Illinois adaptation, riprap was placed only on lunkers behind the blocking log.

In rural areas and in state parks, the bank above the lunkers was stabilized with willow posts. The bank was steeply sloped to keep the lunkers scoured (11) and to prevent silt deposition in the lunkers. In Court Creek, the upper bank was seeded with prairie grasses. During the second year, the posts were cut down so that only a narrow fringe of willow grew along the water's edge. By the third year, with active burn management, the prairie grasses had become established.

At Franklin Creek State Park, the banks were seeded with cool season grasses because the erosion site was located beside the equestrian corral. Once again, the willow posts were to be cut during the second year. A large population of protected beavers sped up the postcutting schedule. A spray of Ropel, an unpleasant-tasting liquid, mixed with a tackifer (to decrease water solubility) gave protection until the grasses became established. When Ropel applications were discontinued, the large posts were quickly cut down. Even with heavy browsing, however, the willow stubs regrew branches because the root systems were not damaged.

While the cool season grasses became established more quickly than the prairie grasses, the root systems of cool season grasses are shallow and therefore more susceptible to scour during high velocity flows. While damages have been minor after 4 years, two 9 ft^2 areas were seeded with grasses and 18-in. willow cuttings in April 1993. Adult smallmouth bass populations increased over 50 percent. Of more importance to stream bass populations, the yearling bass survival increased 300 percent at the lunker site (12).

Costs of lunker installation were $25 to $35 per linear foot, with prairie grass seeding and maintenance accounting for higher costs at the Court Creek site. Labor was 45 percent of costs, contractual equipment was 30 percent, and materials were 25 percent. A 300-ft site is estimated to cost $8,000 to $10,000.

Urban Lunkers

In northeastern Illinois near Chicago, urban streams respond quickly to rainfall events so that floods are extremely erosive. Damage to homes and the higher cost of lands allow more intensive stream management. Often this has led to concrete or heavily riprapped stream channels with acute environmental damages. While necessary in some urban settings, the value of residential homes and parks can be increased if stream channel stabilization can be made more environmentally sensitive. In the smaller stream, the lunkers were constructed from recycled plastic lumber so that lunkers would not dry rot during lowflow drought periods. In larger stream segments, deeper pools allowed the use of wooden lunkers.

In urban streams, the higher cost of materials, the higher cost of contractual equipment as excavators, and the very high cost of landscape repairs to private lawns substantially increase the cost of lunker installation. The lunker installations are $45 to $55 per linear foot of bank.

Summer scheduling of stream restoration required the use of rooted and therefore smaller willow saplings. Additional rooted stock as redosier dogwood played a greater role in riparian revegetation of urban sites. Tree corridors were preserved as sound barriers to traffic noises and visual privacy barriers between homes. The resulting shade, however, denied the use of willows in some areas. In these shaded areas, redosier dogwood were planted with very good survival.

These urban sites were only 1 year old at the time this paper was presented, but the Chicago area had just undergone an extremely wet fall and spring. Two fall floods and three spring floods did not damage the urban lunkers sites.

A-Jack Structures With Willow and Dogwood Bank Revegetation

A-jacks look like small versions of the World War II tank traps (see Figure 3). The A-jacks can be placed so that each A-jack will interlock within each row and with A-jacks in adjacent rows. The lowest rows of A-jacks are trenched along the base of the eroding bank, with the excavated sediment placed along the top of the bank. In the Glen Crest Stream and the Waukegan River, 2-ft diameter A-jacks were used.

Fibredam, a geotechnical fabric that locks the curled wood fibers in excelsior blankets, was placed between the rows of A-jacks and the bank soils to reduce soil movement through the A-jacks. Fibredam is easily torn apart and molded into crevices between A-jacks.

Willow cuttings were driven into the streambed between A-jacks and behind the last interior rows of A-jacks. The fluid sediment was placed on the rows and allowed to fill the interior spaces. The vertical streambank was then sloped over the A-jacks.

This structure ran $45 to $50 per linear foot of bank when composed of two base rows and one upper row. The cost of materials was $25 per foot. Ease of handling and suitability for transport by small marsh vehicles are advantages of this system. Each A-jack is composed of two halves that lie flat on pallets during transport. A-jacks are assembled at the bank site.

When the willows and dogwood are fully grown, root systems lock the entire structure together while giving a natural appearance to the streambank. Small stone is added to A-jack rows near the waterline to give a more natural appearance.

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The Use of Wetlands for Stormwater Pollution Control

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Abstract

This paper presents the results of a literature review that summarizes the current state of knowledge regarding the use of wetlands for stormwater pollution control. The paper reviews the primary removal mechanisms in wetlands, including sedimentation, adsorption, precipitation and dissolution, filtration, biochemical interactions, volatilization and aerosol formation, and infiltration. The results from 26 wetlands are reviewed and contrasted regarding their ability to remove pollutants from stormwater. The systems range from salt marshes to high-elevation riverine wetlands. The study sites are reviewed in relation to the type of wetlands system, including design features and upstream watershed characteristics. The wetlands receive stormwater from different land uses, including residential, commercial, highway, golf courses, and open. The observed pollutant removal efficiencies are quite variable but generally show good removals of phosphorus (median of 46 percent average removal) and the heavy metals cadmium, copper, lead, and zinc (median of 70, 40, 83, and 42 percent average removal, respectively) from stormwater. Constructed wetlands generally perform better and with greater consistency. In general, larger wetlands perform better than their watershed areas as well. Nevertheless, some carefully planned constructed systems with a small area performed quite well compared with their watershed areas. Because there is little information on noted impacts to biota, these are just briefly reviewed. Finally, the paper suggests collecting additional information in new studies. This would make comparisons among different sites more useful in assessing the factors that affect the abilities of constructed wetlands to remove pollutants from stormwater.

Introduction

Constructed wetlands are receiving increasing attention as attractive systems for removing pollutants from stormwater runoff. Other potential benefits that such systems provide include flood control and habitat. Wetlands have long been used for the treatment of wastewaters from municipal, industrial, and agricultural sources (1). The U.S. Environmental Protection Agency (EPA) encourages the use of constructed wetlands for water pollution control through the innovative and alternative technology provisions of the construction grants program (2).

The purpose of this paper is to assist EPA, state, and local technical personnel in assessing the capabilities and limitations of using wetlands as a control measure to reduce the environmental impacts of stormwater pollution on downstream water bodies. The paper summarizes a report prepared for EPA by Strecker et al. (3) that reviewed published literature and documented reports on aspects of stormwater wetland design, operation, and performance. An appendix that accompanied the published report included a one- to six-page summary of each pertinent study reviewed for the report. The summaries covered influent and effluent water quality, the effectiveness of the system, flows and volumes, wetland and watershed areas, and the biological characteristics of the system.

Table 1 presents a list of selected reports with which researchers have documented the ability of wetland systems to remove pollutants from stormwater. The table includes some general characteristics of the wetland systems. Figure 1 shows the wetlands' geographic locations. The wetlands differed widely in location and wetland type (e.g., Florida's southern swamplands, Minnesota's northern peatlands, California's brackish marshlands, and Puget Sound's palustrine wetlands). Each of these locations differs in climate, vegetation, and soil types.

Wetland Stormwater Pollutant Removal Mechanisms

Wetlands can combine various actions to remove pollutants from stormwater:

- Incorporation into or attachment to wetland sediments or biota.
- Degradation.

Table 1. Literature Researched To Investigate Performance Characteristics of Wetlands

Study/ Reference	Year of Publication	Location	Name/I.D.	Detention Pond/Wetland	Constructed/ Natural	Wetland Classification
Martin and Smoot (4)	1986	Orange County, FL	Orange County Treatment System	Detention pond and wetland	Constructed	Hardwood cypress dome
Harper et al. (5)	1986	FL	Hidden Lake	Wetland	Natural	Hardwood swampland
Reddy et al. (6)	1982	Orange County, FL	Lake Apopka	Wetland	Constructed	Cattail marsh
Blackburn et al. (7)	1986	Palm Beach, FL	Palm Beach PGA Treatment System	Wetland	Constructed and natural	Southern marshland
Esry and Cairns (8)	1988	Tallahassee, FL	Jackson Lake	Detention pond and wetland	Constructed	Southern marshland
Brown, R. (9)	1985	Twin Cities Metro Area, MN	Twin Cities Metro	Wetlands	Natural and constructed	Northern peatland
Wotzka and Oberts (10)	1988	Roseville, MN	McCarrons Treatment System	Detention pond and wetland	Constructed	Cattail marsh
Hickok et al. (11)	1977	MN	Weyzata	Wetland	Natural	Northern peatland
Barten (12)	1987	Waseca, MN	Clear Lake	Wetland	Constructed	Cattail marsh
Meiorin (13)	1986	Fremont, CA	DUST Marsh	Wetland	Constructed	Brackish marsh
Morris et al. (14)	1981	Tahoe Basin, CA	Tahoe Basin Meadowland	Wetland	Natural	High elevation riverine
Scherger and Davis (15)	1982	Ann Arbor, MI	Pittsfield-Ann Arbor Swift Run	Detention pond and wetland	Constructed and natural	Northern peatland
ABAG (16)	1979	Palo Alto, CA	Palo Alto Marsh	Wetland	Natural	Brackish marsh
Jolly (17)	1990	St. Agatha, ME	Long Lake Wetland-Pond Treatment System	Detention pond and wetland	Constructed	Cattail marsh
Oberts et al. (18)	1989	Ramsey-Washington Metro Area, MN	Tanners Lake, McKnight Lake, Lake Ridge, and Carver Ravine	Detention pond and wetland	Constructed	Cattail marsh
Reinelt and Horner (19, 20)	1990	King County, WA	B3I and PC12	Wetland	Natural	Palustrine
Rushton and Dye (21)	1990	Tampa, FL	Tampa Office Pond	Wetland	Constructed	Cattail marsh
Hey and Barrett (22)	1991	Wadsworth, IL	Des Plaines River Wetland Demonstration Project	Wetland	Constructed	Freshwater riverine

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Figure 1. Location of wetlands researched for their ability to treat stormwater runoff.

- Export of pollutants to the atmosphere or ground water.

Both physical and chemical pollutant removal mechanisms probably occur in wetlands. These mechanisms include sedimentation, adsorption, precipitation and dissolution, filtration, biochemical interactions, volatilization and aerosol formation, and infiltration. Because of the many interactions between the physical, chemical, and biological processes in wetlands, these mechanisms are generally not independent. Sedimentation is usually the most dominant removal mechanism. The large variation in wetland characteristics (e.g., hydrology, biota) may cause the dominant removal mechanisms to vary from wetland to wetland. Variations in wetland characteristics can also help explain why wetlands differ so widely in their pollutant removal efficiencies. Following is a brief description of the principal removal mechanisms.

Sedimentation

Sedimentation is a solid-liquid separation process using gravitational settling to remove suspended solids. It is considered the predominant mechanism for the removal of many pollutants from the water column in wetland and other flow detention systems. Sedimentation of suspended material, along with pollutants that are highly adsorbed, has been documented as the primary removal mechanism in wetlands by many study authors, including Martin and Smoot (4) and Oberts (23). The most significant factors affecting settling of suspended material pertain to the hydraulic characteristics of the wetland system, including the detention time, inlet-outlet conditions, turbulence, and depth. The opposite of sedimentation is flotation. Floatable pollutants such as oil and grease, litter, and other pollutants can accumulate in the surface microlayer. These pollutants can be removed by adsorption.

Adsorption

Adsorption of pollutants onto the surfaces of suspended particulates, sediments, vegetation, and organic matter is a principal mechanism for removing dissolved or floatable pollutants. The literature suggests that these processes remove pollutants such as phosphorus, dissolved metals, and other adsorbents (including colloidal pollutants) (5, 11, 16). Adsorption occurs through three main processes:

- Electrostatic attractions.
- Physical attractions (e.g., Van der Waals forces and hydrogen bonding).
- Reactions.

The rates by which these processes occur are thought to be inversely related to the particle size and directly related to the organic content of the particles in the wetland soils (5). Increasing the contact of stormwater with the underlying soils and organic matter can enhance adsorption processes. In addition, high residence times, shallow water depths, and even distribution of influent enhance the interactions of water with soil and plant substances, thereby increasing the adsorption potential.

Precipitation and Dissolution

Many ionic species (e.g., metals) dissolve or precipitate in response to changes in the solution chemistry of the wetland environment. Metals such as cadmium, copper, lead, mercury, silver, and zinc can form insoluble sulfides under the reduced conditions commonly found in wetlands (24). Decaying organic matter releases fulvic and humic acids that can form complexes with metal ions. In addition, decreased pH can promote the dissolution of metals, thereby making them available for bonding to inorganic and organic molecules (25).

Filtration

Filtration occurs in most wetlands simply because vegetation acts like a sieve to remove pollutants and sediments from the water column. Dense vegetation can be very effective at removing floatables (including oil and grease) and litter from stormwater. Filtration can also take place in the soil matrix when infiltration occurs. Brown (9) and Wotzka and Oberts (10) also noted that increased density of vegetation slows the velocity and wave action, thereby allowing increased settling of suspended material.

Biochemical Interactions

Vegetative systems possess a variety of biochemical interaction processes that can remove nutrients and other material from the water column. In general, these processes are:

- High plant productivity and associated nutrient uptake
- Decomposition of organic matter
- Adsorption
- Bacterially aerobic or anaerobic mediated processes

Through interactions with the soil, water, and air, plants can increase the assimilation of pollutants within a wetland system. Plants provide surfaces for bacterial growth and adsorption, filtration, nutrient assimilation, and the uptake of heavy metals (26).

Volatilization and Aerosol Formation

Volatilization (or evaporation) can remove volatile pollutants from wetlands. Air and water temperature, wind speed, subsurface agitation, and surface films can affect the rate of volatilization. Surface films may act as a barrier for the volatilization of some substances. Alternatively, evaporation may be a key mechanism for exporting substances such as chlorinated hydrocarbons or oils, which are often found in the surface films of water bodies receiving urban stormwater runoff (26). Aerosol formation may play only a minor role in removing pollutants in wetlands and occurs only during strong winds (26).

Infiltration

For wetlands with underlying permeable soils, infiltration can remove pollutants. Stormwater percolates through the soil, eventually reaching ground water. Passage through the soil matrix can provide physical, chemical, and biological treatment depending on the matrix thickness, particle size, degree of saturation, and organic content. Infiltration is also dependent on the ground-water level at a site. In some instances, seasonal fluctuations in ground-water levels may cause some wetlands to discharge ground water during part of the year and recharge to ground water during other times of the year. The potential of pollutants to migrate to ground water depends highly on the type of pollutant, the soil type and properties, the hydrology, and the characteristics of the aquifer. Contamination of unconfined aquifers by stormwater is likely to be more significant from upland infiltration than from recharge through wetlands because of the high filtering action of typical wetland soils (27).

Wetland Stormwater Pollutant Removal Efficiencies

Only a limited number of studies have investigated the effectiveness of wetlands to treat stormwater runoff (Figure 1), and those have primarily focused on a few geographical locations (e.g., Florida, Minnesota, and California). The studies that this paper summarizes represent a wide diversity of wetland types, ranging from southern cypress swamplands and northern peatlands to brackish marshlands and high-elevation meadowlands. This section presents a discussion of wetland stormwater pollutant removal efficiencies found in the literature.

Table 2 summarizes reported removal efficiencies for total suspended solids (TSS) and selected nutrients and metals. The broad ranges of pollutant removal efficiencies were not surprising because wetlands vary in their hydraulic conditions, climate, and vegetation, and because the studies employed various monitoring and reporting procedures. Figure 2 presents histograms of pollutant removal efficiencies reported for TSS, total phosphorus (TP), ammonia (NH_3), and lead (Pb).

Table 2. Average Removal Efficiencies for Total Suspended Solids and Nutrients in Wetlands Reported in the Literature

Study	System Name	System Type	Pollutant Removal Efficiency (Percent)[a]							Lead		Zinc		Copper		Chromium	
			TSS	NH_3	NO_3	TP	Dis. P	COD	BOD	Total	Dissolved	Total	Dissolved	Total	Dissolved	Total	Dissolved
Martin and Smoot (4)	Orange County Treatment System	Detention pond*	65	60	-17	33	78	7		39	29	15	-17				
		Wetland*	66	54	40	17	-30	18		73	54	56	75				
		Entire system	89	61	9	43	21	17		83	70	70	65				
Harper et al. (5)	Hidden Lake	Wetland	83	62	80	7			81	55	58	41	57	40	29	73	75
Reddy et al. (6)	Lake Apopka	Reservoirs		57.5	68.1	80.9	75.1										
		Flooded fields		51.9	64.2	7.3	16.7										
Blackburn et al. (7)	Palm Beach PGA Treatment System	System	50	17	33	62			35								
Esry and Cairns (8)	Jackson Lake	System	98	37	70	90	78										
Brown (9)	Fish Lake	Wetland/pond	95	0		37	28										
	Lake Elmo	Wetland	88	50		27	25										
	Lake Riley	Wetland	-20	25		-43	-30										
	Spring Lake	Wetland	-300	-88		-7	-10										
Wotzka and Oberts (10)	McCarrons Wetland Treatment System	Detention pond*	91		80	78	57	90		85							
		Wetland*	87		22	38	25	79		68							
		System	94		63	78	53	93		90							
Hickock et al. (11)	Wayzata Wetland	Wetland	94	-44		78				94		82		80			
Barten (12)	Clear Lake	Wetland	76	55		54	40										
Meiorin (13)	DUST Marsh																
	Basin A	Wetland*	63	-8	32	46			-25	30		42		-20		55	
	Basin B	Wetland*	40	-5	2	-4			-46	27		24		-60		47	
	Basin C	Wetland	51	18	12	38			-18	83		-29		17		13	
	System	Wetland*	78	16	29	58			-57	88		42		-19		66	
Morris et al. (14)	Angora Creek	Wetland	54	20	50	5											
	Tallac Creek	Wetland	36	33	35	-120											

Table 2. Average Removal Efficiencies for Total Suspended Solids and Nutrients in Wetlands Reported in the Literature (continued)

Study	System Name	System Type	Pollutant Removal Efficiency (Percent)[a] TSS	NH_3	NO_3	TP	Dis. P	COD	BOD	Lead Total	Lead Dissolved	Zinc Total	Zinc Dissolved	Copper Total	Copper Dissolved	Chromium Total	Chromium Dissolved
Scherger and Davis (15)	Pittsfield-Ann Arbor Swift Run	Detention pond*	39			23				61							
		Wetland	76			49				83							
ABAG (16)	Palo Alto Marsh	Wetland	87			-6			54								
Jolly (17)	Long Lake Wetland-Pond Treatment System	Entire system	95			92											
Oberts et al. (18)	Tanners Lake	Detention pond*	63		1	7	-14			59							
	McKnight Lake	Detention ponds*	85		11	34	12			83							
	Lake Ridge	Wetland	85		17	37	8			52							
	Carver Ravine	Wetland-pond system	20		9	1	1			6							
Reinelt and Horner (19, 20)	B3I	Wetland	14		4	-2											
	PC12	Wetland	56		20	-2											
Rushton and Dye (21)	Tampa Office Pond	Wetland	64			55						34					
Hey and Barrett (22)	Des Plaines River Wetland																
	EWA 3	Wetland	72		70	59											
	EWA 4	Wetland	76		42	55											
	EWA 5	Wetland	89		70	69											
	EWA 6	Wetland	98		95	97											
Median pollutant efficiency for wetland systems (without *)			76	33	46	46	23	55	45	83	83	42	61	40	29	70	75

[a]Negative removal efficiencies indicate net export in pollutant loads.
COD = chemical oxygen demand
BOD = biochemical oxygen demand

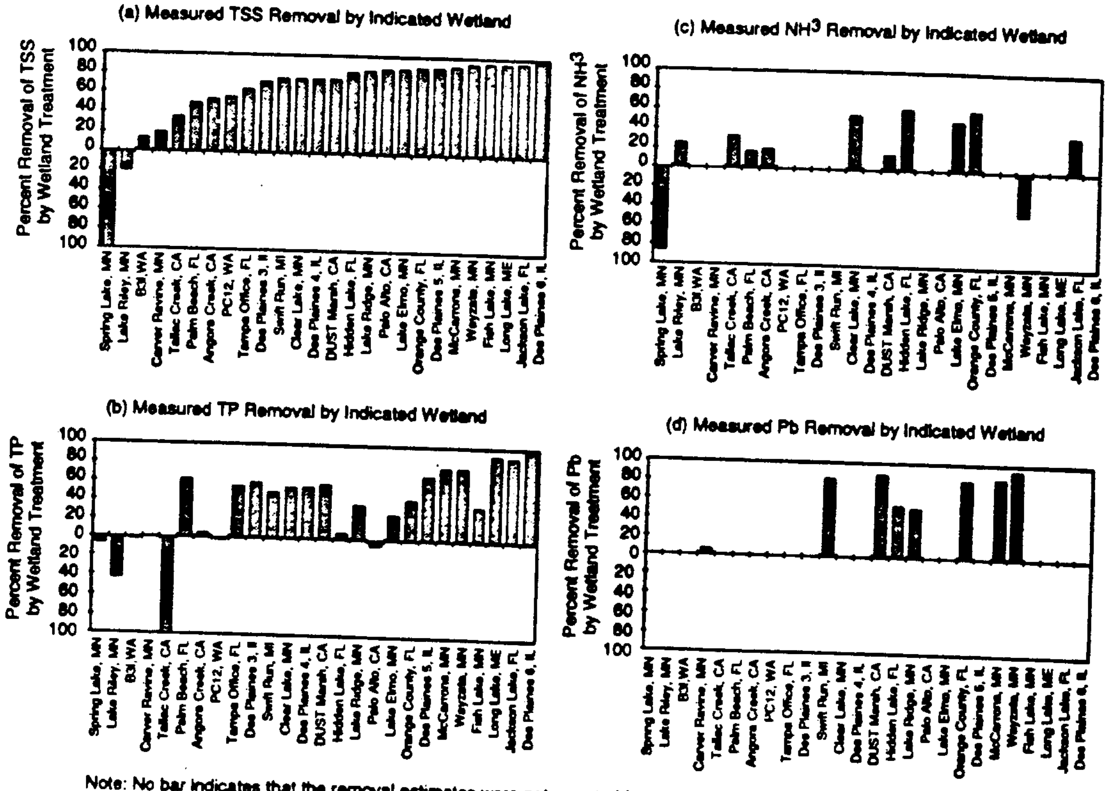

Figure 2. Pollutant removal rates for a) TSS, b) TP, c) NH_3, and d) Pb.

Despite the variability observed in pollutant removal efficiencies, some similarities exist among the wetlands. The following observations can be made:

- Suspended solids and total lead (TPb), followed by total zinc and chromium, show the greatest consistency with pollutant removal efficiencies.
- Suspended solid removal efficiencies tend to be more consistent and larger in constructed wetlands than in natural systems. This is likely due to the design and management of the constructed systems.
- In some cases, concentrations of dissolved Pb, zinc, and copper appear to be reduced significantly.
- Nutrient removal efficiencies vary widely among wetlands. The variations appear to be a function of the season, vegetation type, and wetland systems management methods.
- Total phosphorus and nitrate show the greatest consistency for nutrient removal efficiencies. Total phosphorus removal efficiencies tend to be more variable for the natural wetlands and less variable for detention basins and constructed wetlands.

Probable Causes of Variations and Dissimilarities of Reported Wetland Pollutant Removal Effectiveness

In addition to the efficiencies that the authors tabulated, several reports presented conclusions to help explain the effectiveness of wetland treatment and variations. Hydrology is reportedly the most critical parameter influencing wetland performance. Variations in local hydrology, detention times, rates of runoff, water level fluctuations, and seasonality all reportedly affect the function of wetlands and thus their effectiveness at removing pollutants (25). Table 3 presents geographic, hydrologic, and hydraulic characteristics for each of the wetlands reviewed.

The size and volume of a wetland system can greatly affect both the actual removal efficiencies and the ability to estimate these efficiencies. EPA (26) reported difficulties in estimating pollutant removal efficiencies due to the volume of the wetland basin. The volume of the Demonstration Urban Stormwater Treatment (DUST) marsh is large enough that the treatment cycle spans several storms; therefore, no one storm provided a complete picture of pollutant efficiencies. The DUST marsh accu-

Table 3. Wetland Geographic and Hydraulic Characteristics

Study	System Name	Watershed Land Use	% Land Use	System Type	Constructed/ Natural	Wetland Size (acres)	Watershed Size (acres)	Wetland/ Watershed Ratio	Average Flows (ft^3/sec)	Basin Volume (acre-ft)	Detention Time (hr)	Depth (ft)	Inlet Condition	Comments
Martin and Smoot (4)	Orange County Treatment System	Residential	33	Detention pond	Constructed	0.2	41.6	0.5%	2.5	1.2-1.9	7.5	8-11	Discrete	a
		Highway	27	Wetland	Constructed	0.78	NA	1.9%	NA	0.5-2.8	8	0-5	Discrete	
		Forest	40	System	Constructed	0.98		2.4%						
Harper et al. (5)	Hidden Lake	Residential	NA	Wetland	Natural	2.5	55.2	4.5%	0.22	NA	NA	NA	Diffuse	b
Reddy et al. (6)	Lake Apopka	Agriculture	100	Reservoirs	Constructed	0.9	NA	NA	0.56	2.6	9.4 days	3.3	Diffuse	c
				Flooded fields	Constructed	0.9	NA	NA	0.23	0.6	4.8 days	0.7	Diffuse	
Blackburne et al. (7)	Palm Beach PGA Treatment System	Residential	NA	Wetland	Constructed	89	2,350	3.8%	NA	NA	NA	NA	Diffuse	c
		Golf course	NA	Wetland	Constructed + natural	298	2,350	12.6%	NA	NA	NA	NA	Diffuse	d
Esry and Cairns (8)	Jackson Lake	Urban	NA	Detention pond	Constructed	20	2,230	0.9%	NA	150	NA	7.5	Diffuse	c
			NA	Wetland	Constructed	9	2,230	0.4%	NA	13.5	NA	1.5	Diffuse	
Brown (9)	Fish Lake	Residential	30	Wetland	Natural	16	700	2.3%	0.001–0.01	64	NA	4	Discrete	e
		Commercial	5											
		Agricultural	12											
		Open	53											f
	Lake Elmo	Residential	12	Wetland	Natural	225	2,080	10.9%	0.001-0.65	900	NA	4	Discrete	g
		Commercial	1											
		Agricultural	34											
		Open	53											
	Lake Riley	Residential	13	Wetland	Natural	77	2,475	3.1%	0.004-1.35	231	NA	3	Discrete	
		Commercial	2											
		Agricultural	30											
		Open	55											
	Spring Lake	Residential	5	Wetland	Constructed	64	5,570	1.1%	0.008-4	258	NA	4	Discrete	
		Commercial	1											
		Agricultural	57											
		Open	37											

Table 3. Wetland Geographic and Hydraulic Characteristics (continued)

Study	System Name	Watershed Land Use	% Land Use	System Type	Constructed/ Natural	Wetland Size (acres)	Watershed Size (acres)	Wetland/ Watershed Ratio	Average Flows (ft^3/sec)	Basin Volume (acre-ft)	Detention Time (hr)	Depth (ft)	Inlet Condition	Comments
Wotzka and Oberts (10)	McCarrons Wetland Treatment System	Urban	NA	Detention pond	Constructed	29.7	600	5.0%	0.05-0.2	2.3-9.7	24 days	2.5	Diffuse	h
				Wetland	Constructed	6.2	600	1.0%						
				System	Constructed	35.9		6.0%						
Hickok et al. (11)	Wayzata Wetland	Residential Commercial	NA	Wetland	Natural	7.6	65.1	11.7%	0.08	NA	NA	NA	Discrete	i
Barten (12)	Clear Lake	Urban	NA	Wetland	Constructed	52.9	1,070	4.9%	1.5	10	3-5 days	0.5	Diffuse	
Melorin (13)	DUST Marsh	Urban	93	Wetland:										
		Agricultural	7	A	Constructed	5	—	—	10-250	150	4-40 days	4.7	Diffuse	j
				B	Constructed	6	—	—						
				C	Constructed	21	2,960	0.7%						
				System	Constructed	32	2,960	1.1%						
Morris et al. (14)	Angora Creek	Residential Forest	NA NA	Wetland	Natural	NA	2,816	NA	8.46	NA	NA	NA	Diffuse	k
	Tallac Creek	NA	NA	Wetland	Natural	NA	2,781	NA	6.68	NA	NA	NA	Diffuse	
Scherger and Davis (15)	Pittsfield-Ann Arbor Swift Run	Residential	45	Detention pond	Constructed	25.3	4,872	0.5%	0-2,916	21-176	4-105	0-6	Discrete	f
		Commercial	19	Wetland	Natural	25.5	1,207	2.1%	0-166	15-60	12-82	0-3	Discrete	
		Agriculture	13											
		Open	23											
ABAG (16)	Palo Alto Marsh	Residential Commercial Open	62 12 26	Wetland	Natural	613	17,600	3.5%	150-320	400-750	30	1-6	Discrete	l m
Jolly (17)	Long lake Wetland-Pond Treatment System	Agriculture	100	Wetland/ pond	Constructed	1.5	18	8.3%	0.01	1.5	NA	0.5-8	Diffuse	n
Oberts et al. (18)	Tanners Lake	Residential	NA	Pond	Constructed	0.07	1,134	Neg.	NA	0.1	NA	3.0	Discrete	o
	McKnight Lake	Residential	NA	Pond	Constructed	5.53	5,217	0.1%	NA	13.2	NA	4.9	Discrete	
	Lake Ridge	Residential	NA	Wetland	Constructed	0.94	531	0.2%	NA	2.0	NA	4.8	Discrete	

Table 3. Wetland Geographic and Hydraulic Characteristics (continued)

Study	System Name	Watershed Land Use	% Land Use	System Type	Constructed/ Natural	Wetland Size (acres)	Watershed Size (acres)	Wetland/ Watershed Ratio	Average Flows (ft^3/sec)	Basin Volume (acre-ft)	Detention Time (hr)	Depth (ft)	Inlet Condition	Comments
	Carver Ravine	Residential	NA	Wetland/ pond	Constructed	0.37	170	0.2%	NA	1.0	NA	2.0	Discrete	
Reinelt and Horner (19, 20)	B31	Urban	NA	Wetland	Natural	4.9	461.7	1.1%	1.5	0.03–0.43	3.3	NA	Discrete	p
	PC12	Rural	NA	Wetland	Natural	3.7	214.8	1.7%	0.7	0.05-0.80	2.0	NA	Discrete	q
Rushton and Dye (21)	Tampa Office Pond	Commercial	100	Wetland	Constructed	0.35	6.3	5.6%	NA	0.32	NA	0-1.5	Discrete	r
Hey and Barrett (22)	Des Plaines River Wetland Demonstration Project	Agriculture	80	Wetland:										
		Urban	20	3	Constructed	5.6	—	—	5	NA	NA	1	Discrete	s
				4	Constructed	5.6	—	—	0.8	NA	NA	1	Discrete	
				5	Constructed	4.5	—	—	4	NA	NA	1	Discrete	
				6	Constructed	8.3	—	—	1	NA	NA	1	Discrete	

NA = Not available

System = summary information

a Short-circuiting was observed during several storms.
b The wetland is not a basin but similar to a grassy swale.
c Design configuration suggests little short-circuiting occurred.
d Generally sheet flow exists within the artificial wetland.
e The major influent to these natural wetlands is discrete channelized flow.
f The schematic suggests large areas of dead storage exist.
g Short-circuiting was not discussed by the author.
h Three discrete inlets help to minimize short-circuiting and dissipate surface water energy.
i Design configuration suggests minimal short-circuiting existed regardless of a single discrete inlet.
j Design configuration suggests little short-circuiting occurred due to long and narrow wetland basins.
k Flow occurs as channelized flow until the storm volume is large enough to force sheet flow through the meadowlands.
l Water level and volume are controlled by the tidal cycle.
m Channelized flow exists until the tide increases, causing the surrounding marsh to become inundated.
n Entire system consists of a sedimentation basin, grass filter strip, constructed wetland, and deep pond.
o Monitoring occurred during a dry period.
p Storm flows reduce detention times.
q Channelization reduced effective area in wetland.
r Overflow from adjacent wetlands occurred during extremely high water; leak and breach problems occurred during study.
s Water is pumped to the system from the river (drainage area of 210 square miles) for 20 hr/wk.

mulates stormwater flows within the system and discharges effluent slowly over days or weeks, depending on the interval between storms. Thus, the water collected at the discharge from the DUST marsh is probably a mixture of water that entered from the previous storms.

The type of inlet structure and the flow patterns through wetland areas also can significantly affect pollutant removal efficiencies. Morris et al. (14) found that sheet flow (as opposed to channelized flow) was the most critical factor in the effectiveness of meadowland treatment. This finding is consistent with the theory that shallow, vegetative overland flow decreases velocities and increases sedimentation. In addition, close contact with the soil matrix was found to increase assimilation of nutrients and bacteria. Brown (9) found that an undefined inflow (multiple input locations) to the wetland, which results in better dispersion of incoming load, was critical in the effectiveness of the wetland. An undefined inflow reduced short-circuiting and increased mixing and contact of the stormwater with the soil and plant substrates.

The change in seasons has been considered another important factor in the effectiveness of wetland treatment of storm runoff. Typical factors of seasonality are evapotranspiration rates and seasonal productivity and decay of plant and animal life. Removal efficiencies in wetlands located in areas with strong seasonal variation may vary significantly between seasons. For example, Meiorin (13) reported that high summer evapotranspiration rates caused a 200- to 300-percent increase in the total dissolved solids concentrations within the DUST marsh. Furthermore, high productivity during warm periods can lead to decreases in nutrients and increases in biochemical oxygen demand (BOD) and suspended solids. Morris et al. (14) reported that flushing and leaching effects of spring snowmelt caused an increase in total Kjeldahl nitrogen and organic carbon in flows leaving the Tahoe Basin meadowland. Harper et al. (5) reported that detention times greater than 2 days caused an increase in the export of orthophosphorus from the Hidden Lake wetland.

Hickok et al. (11) described microbial activity as the most important factor affecting phosphorus removal. Other factors that probably cause variations in the reported pollutant removal effectiveness include maturity of the wetland, the buildup of nutrients and heavy metals in a wetland system, particle-size distribution (which affects the settling of suspended sediments), and maintenance practices performed at a wetland.

Comparison of Factors Affecting Reported Treatment Efficiencies

This study reviewed data on removal efficiencies for 26 different wetland systems. The study evaluated the following factors regarding their effects on wetlands pollutant removal performance:

- Constructed versus natural systems.
- Vegetation types found in the wetland.
- Land-use types draining to the wetland.
- Area of the wetland system compared with the contributing watershed.
- Estimated average storm-flow quantities draining to the wetland.
- Inlet types.

These factors affected only a few meaningful direct relationships. This was because of the limited amount

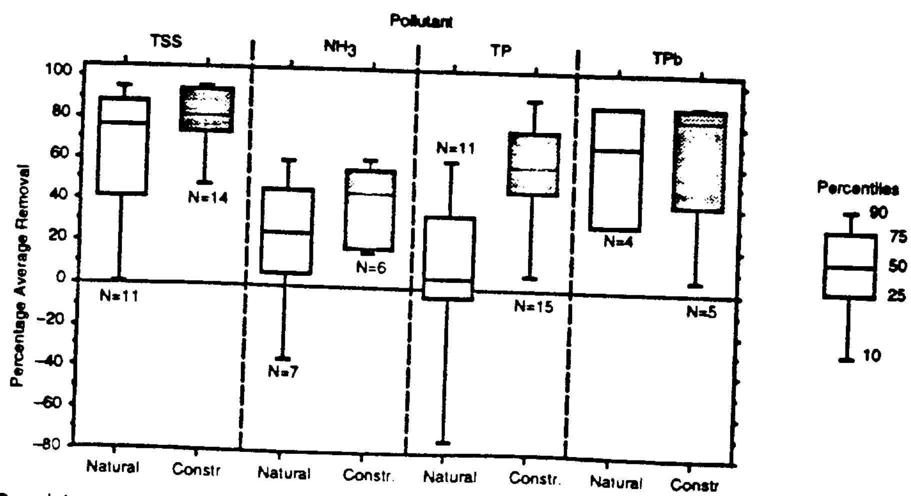

Figure 3. Box plot percentiles comparison of site average pollutant removals for natural and constructed wetland systems: TSS = total suspended solids, NH_3 = ammonia, TP = total phosphorus, TPb = total lead, and N = number of wetland sites.

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of data available to determine these relationships as well as the multiple factors that affect performance. Without a large database, a meaningful multiple regression analysis was not possible.

Several trends, however, were noted. First, constructed systems generally had a higher average removal performance than natural systems, with less variability. Second, larger wetlands compared with their tributary watershed areas also showed the same trend: a higher average removal performance, with less variability. Figure 3 presents TSS, TP, NH_3, and TPb in a percentile box plot for the constructed and natural systems. Note that, in all cases for the pollutants summarized, constructed systems showed a higher average and median performance level. More significant, however, is the difference in variability between the two types of wetlands. Constructed sites were much less variable. This is not a surprising finding, given that constructed systems have generally been designed to handle expected incoming flows and to minimize short-circuiting. They should generally show a higher performance level with more consistency.

Investigators also looked at the area of the wetland system compared with the size of its contributing watershed. Regression of the wetland to watershed area ratio

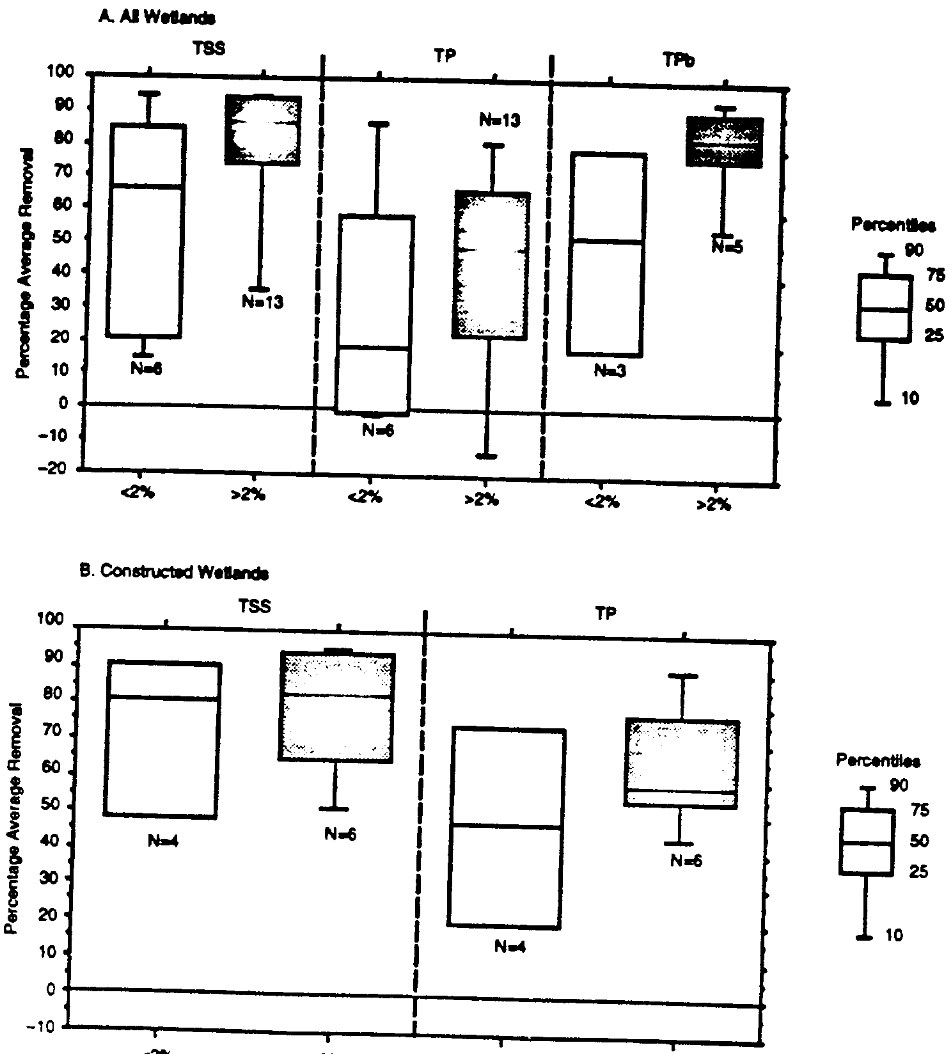

Figure 4. Average site percentile box plots for TSS, TP, and TPb pollutant removals for wetlands with less than 2 percent and greater than 2 percent wetland-to-watershed size ratios (WWAR): N = number of wetland sites, TSS = total suspended solids, TP = total phosphorus, and TPb = total lead.

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(DAR) to pollutant removal performance did not reveal good direct relationships. Grouping sites according to a greater than or less than 2 percent DAR, however, did result in some general trends. Figure 4 presents performance results for all wetland systems with reported tributary watershed areas. In general, the larger DAR wetlands had higher performance levels, with less variability. This analysis included all wetland sites, natural and constructed. To separate out the effects of natural versus constructed systems, Figure 4 also presents a similar analysis for constructed sites only. Generally, for constructed sites the trends are the same, although the differences in performance levels and variability in performance are much less. The data indicate that carefully constructed systems can probably mitigate the importance of DAR as a factor in determining performance. Therefore, at this time we are not suggesting that 2 percent minimum DAR is a proper design criteria for constructed wetlands.

The Jackson Lake wetland is an example of a wetland with a small DAR that still achieved excellent performance (85 percent TSS removal). The DUST marsh and the Lake Ridge wetlands also showed high performance levels (76 and 85 percent TSS removals, respectively). One factor that explains the DUST marsh performance is that it is an "off-line" device: it only receives flow volumes up to a certain flow rate, then bypasses high flows. This type of design is particularly appropriate for wetlands receiving stormwater from larger catchments relative to wetland size.

To better measure the capacity of a wetland to treat runoff from a given watershed would entail evaluating average storm runoff volumes of wetland tributary areas with wetland storage volumes and/or contact surface areas. The data from the studies, however, did not consistently include data on rainfall statistics, percent impervious for land uses, specific percentages for land uses in a catchment, flow volumes to the wetland, capacity of the wetland system, and surface areas for contact with stormwater (including soils and plants). Therefore, we were not able to analyze the wetland systems using this approach. The summary of this paper contains some recommendations regarding reporting information for future studies, so that such analyses can be completed.

Finally, no good studies or documentation exists regarding maintenance activities in wetlands that are treating stormwater. In addition, the need for maintenance and level of maintenance are not well understood or documented. These activities could affect performance characteristics of wetlands, particularly over the long term.

Assessment of the Reliability of Wetland Data

There are various difficulties in comparing one wetland study to another. Table 4 presents a list of the selected literature, including information on the sampling characteristics that each study employed. The table shows that the studies identified generally lasted a year or less. There was quite a variation in the number of samples collected (from 3 to about 150), as well as in the sampling methods used (i.e., grab sample or samples versus composite sample for an event). These factors all contribute to the difficulty of comparing results from the different studies. Another complication in comparing the performance of wetlands involves the method of quantifying their effectiveness.

Noted Impacts of Stormwater Runoff on Wetland Biota

Many researchers have expressed concern over the impact of the quantity and quality of stormwater runoff on wetland biota, especially in natural wetlands (27, 28). The quantity of stormwater runoff determines the hydrologic characteristics of a wetland, including the average and extreme water levels and duration and frequency of flooding. Stormwater runoff also contains pollutants that can adversely affect wetland biota if accumulated in high concentrations. The hydrology of a wetland is one of the most important factors in establishing and maintaining specific types of wetlands and wetland processes (29). Hydrology is a key factor in wetland productivity, vegetation composition, nutrient imports, salinity balance, organic accumulation, sedimentation transport, and soil anaerobiosis.

Few of the reports reviewed indicated concern regarding the effects of contaminants in urban stormwater on wetland systems. Many of the reports referenced studies performed in wetlands receiving sewage effluents or industrial discharges of some type. Urban runoff, especially from residential watersheds, frequently has much lower concentrations of pollutants than do sewage effluents or industrial discharges.

Sediments typically constitute the most significant store of toxic substances available to organisms in a wetland (29). Plants can take up metals and toxic organic compounds from the sediments, thus introducing them into the food web (30-32). Both metals and organics tend to be adsorbed to finely divided solids, depending on conditions such as pH, oxidation-reduction potential, and salinity (33). The way a metal is complexed determines its availability to plants (33).

Water resides longer in wetlands compared with more swiftly moving waters because of the flatness of wetlands and the filtering action of the vegetation. This longer residence time allows suspended solids to drop out and be retained (32, 33). Woodward-Clyde Consultants (34) found that the greatest concentration of metals in sediments occurred at the location nearest the stormwater inlet and declined with distance from the inlet. They found the sediment concentration and bioavailabil-

Table 4. Sampling Characteristics From the Wetlands Reviewed

Study	Location	Time of Study	Length of Study	Type of Sample	Number of Storms Monitored	Method of Computing Efficiencies
Martin and Smoot (4)	Orange County, FL	1982–1984	2 years	7 multigrab, 6 composite	13	ROL
Harper et al. (5)	FL	1984–1985	1 year	Composite	18	ER
Reddy et al. (6)	Orange County, FL	1977–1979	2 years	Single grab	Approx. 150	MC
Blackburn et al. (7)	Palm Beach, FL	1985	1 year	Single grab	36	MC
Esry and Cairns (8)	Tallahassee, FL	1985	NA	NA	1	NA
Brown (9)	Twin Cities Metro Area, MN	1982	1 year	Composite	5–7	SOL
Wotzka and Oberts (10)	Roseville, MN	1984–1988	2 years	Composite	25	ROL
Hickok et al. (11)	MN	1974–1975	10 months	NA	NA	SOL
Barten (12)	Waseca, MN	1982–1985	3 years	Composite	27	ER
Meiorin (13)	Coyote Hills, Fremont, CA	1984–1986	2 years	Composite	11	SOL
Morris et al. (14)	Tahoe Basin, CA	1977–1978	1 year	Single grab	Approx. 75	MC
Scherger and Davis (15)	Ann Arbor, MI	1979–1980	8 months	Composite	7	SOL
ABAG (16)	Palo Alto, CA	1979	3 months	Composite	8	ER
Jolly (17)	St. Agatha, ME	1989	5 months	Composite	11	SOL
Oberts et al. (18)	Ramsey–Washington Metro Area, MN	1987–1989	2 years	Composite	7–22	SOL
Reinelt and Horner (19, 20)	King County, WA	1988–1990	2 years	Composite	13	SOL
Rushton and Dye (21)	Tampa, FL	1989–1990	12 months	Composite	3–8	ER
Hey and Barrett (22)	Wadsworth, IL	1990	8 months	Discrete	Continuous	SOL

ER = event mean concentration
MC = mean concentration
NA = not available
ROL = regression of event loads
SOL = sum of event loads

ity of copper, lead, and zinc to be at or near background levels in the downstream marsh area.

Plants take more metals from the sediment than from the water column. Phytoplankton, however, can remove metals directly from the water, releasing them to the sediments or to the water upon death (35). In general, far greater amounts of metals remain in the sediment than are taken up by plants (36-39). Some plants are apparently able to exclude toxic metals selectively. Organic compounds undergo many of the same processes in wetlands as metals, including adsorption to sediments and plant uptake. In addition, they can be biodegraded.

The uptake of toxic materials by plants can introduce these materials into the grazing and detrital food chains, with potentially deleterious effect. Metals from sewage effluents introduced to wetlands tend to accumulate in the food chain (32). Finally, the relative responses of plants and animals to toxic metals and organic compounds indicate that these contaminants are more likely to affect animals negatively.

Comparison of Wetland and Detention Basin Performance

Detention facilities have traditionally been constructed to control stormwater runoff quantities. These facilities temporarily store stormwater runoff and later release the water at a lower flow rate. Design of detention basins and ponds can provide for water quality enhancement by including a permanent pool of water and inlet and outlet structures to maximize detention. Quiescent velocities within the basins allow sediments to settle out of the stormwater and undergo chemical and biological removal processes. Detention basins usually do not have vegetation within the permanent pool, but the banks may be planted with grasses for erosion control.

Detention basin/constructed wetland treatment systems have been recommended for stormwater treatment (4, 10, 40). Typically in these systems, stormwater runoff discharges to the detention basin, which then releases the water to the wetland for additional treatment. The detention basin can provide pretreatment for the wetland, reducing the sediment and pollutant loads to the wetland. In other instances, detention basins and constructed wetlands are competing alternatives under consideration for stormwater treatment. To make a decision, the designer or planner requires knowledge of the relative pollutant removal efficiencies, environmental impacts, maintenance requirements, and costs of the two alternatives.

To further illustrate how those systems compare, the following discussion focuses on the results from a case study of the McCarrons treatment facility system, which compared the performance of wetlands with that of detention basins through simultaneous monitoring of both systems. Wotzka and Oberts (10) presented a paper discussing the combined detention-wetland stormwater treatment facility. The McCarrons treatment facility consisted of a 30-acre detention basin with an average depth of 1.2 ft and a 6.2-acre constructed wetland with an average depth of 2.5 ft. The detention basin received stormwater and then discharged to the wetland. The contributing watershed consisted of 600 acres of primarily urban land use. The predominant vegetation in the wetland consisted of cattails with other emergent plant species.

Overall, the system produced very good results. The detention basin proved to be more effective than the wetland in reducing several pollutants. For example, Table 5 lists removal efficiencies for the detention basin and wetland.

Wotzka and Oberts (10) discussed some of the possible explanations for the good results of the detention basin and for its differences from the wetland. In general, they believed that the treatment efficiencies were lower in the wetland due to pretreatment by the detention basin. They stated that the inflows into the detention basin spread equally around the perimeter of the detention basin, thus dissipating the entry velocities of the storm runoff. Dissipation of inflow energy probably promoted settling and minimized short-circuiting.

Table 5. Removal Efficiencies (%) for Detention Basin and Wetland

Parameter	Detention Basin	Wetland
TSS	91	87
TP	78	36
TN	85	24
TPb	85	68

Wotzka and Oberts (10) suggested that the percentage of phosphorus in the dissolved and particulate phases affected the reduction potential. They found that more than 80 percent of the phosphorus was in the particulate form, resulting in high removal efficiencies due to settling. Apparently, the wetland did not perform as well as the detention basin because of the periodic release of nutrients from decaying vegetation and the fact that significant pretreatment had occurred. The authors also suggested that the high removal of phosphorus was due in part to the newly exposed soils on the bottom of the detention basin. They explained that the newly exposed soils probably had more adsorption capacity available than the soils in the wetland further downstream. They also suggested that saturated soil conditions could lead to a reduction in phosphorus removal.

In conclusion, this study indicated that the detention basin performed better than the wetland system. This may be misleading, however, because the wetland received pretreated waters from the detention basin. The detention basin removed the fraction of pollutants that were more readily settled and treated, leaving the wetland with the more difficult-to-treat, finer particulates and dissolved pollutants.

Summary

Wetlands have a good capability for removing pollutants from stormwater runoff. Several factors contribute to and influence removal efficiencies, including sedimentation, adsorption, precipitation and dissolution, filtration, biochemical interactions, volatilization and aerosol formation, and infiltration. The reported removal efficiencies are, as expected, quite variable. For the wetlands systems reviewed, removal efficiencies for TSS had a median of 76 percent. TSS removal is a good indicator of pollutant removal potential for heavy metals and phosphorus, as well as other pollutants associated with fine particulate matter. Constructed wetlands tended to be more consistent than natural wetlands in their removal of TSS and the other analyzed parameters. Wetlands have also shown the ability to remove dissolved metals. Nutrient removal in wetlands is variable, depending on both wetlands characteristics and seasonal effects.

Because many dissimilarities exist between the wetlands studied, wetlands stormwater pollutant removal efficiencies vary widely. Properly designed, constructed, and maintained wetlands, however, can be effective pollution control measures. Examining additional wetlands in a variety of geographical areas, as well as long-term pollutant removal efficiencies, is definitely necessary.

A significant issue, however, involves whether stormwater control measures should include natural wetland systems. In general, natural wetlands have been found to be somewhat less predictable than constructed wetlands in terms of pollutant removal efficiency. This difference may be due to the fact that constructed wetlands have generally been engineered specifically to provide favorable flow capacity and routing patterns. As a result, they tend to detain inflows for longer periods and have less short-circuiting than many natural systems.

People often question the appropriateness of using a natural, healthy wetland for such purposes. Their concern is whether the modified flow regime and the accumulation of pollutants will result in undesirable environmental effects. There are many situations where natural wetlands have been receiving urban runoff for years. Some of these wetlands reflect significant degradation because of many factors, including urban runoff, whereas others have been less affected. A general consensus from the literature is to discourage the use of a healthy natural wetland for stormwater pollution control. In the case of rehabilitating a natural but degraded wetland, modifications should ensure that the applied runoff receives sufficient pretreatment. One pretreatment technique would be to use pond areas to provide an opportunity for suspended materials to settle out before the flows enter the wetland. Other possible options include routing inflows to the wetlands through upstream grass swales, oil/water separators, heavily vegetated areas (e.g., thick, shallow cattail areas), and overland flow areas.

These techniques would not only act on solids but also on floatables such as oil and water. Although little evidence exists of problems in wetlands that have been receiving stormwater runoff, the available data are quite limited, and developing additional information on impacts is critical. Additional studies on the impacts to biota should be undertaken.

In addition, the maintenance needs of wetland systems that treat stormwater merit further study. Such maintenance activities could include sediment removal and plant harvesting. Further studies should address the need for and the frequency and appropriateness of maintenance.

Gathering more information on wetland effectiveness would benefit design development procedures for sizing wetland treatment facilities. There is currently not enough information in the existing literature to develop design guidelines for constructed wetland treatment systems. Additional studies are needed to broaden the type of wetland systems reviewed, develop information on long-term performance, and evaluate seasonal characteristics of wetland performance.

A review of the data available on wetland stormwater treatment effectiveness revealed that most studies did not contain enough information on study and wetland characteristics to analyze in detail the factors affecting treatment performance among different wetlands. Table 6 presents a summary of the information that would hopefully provide a better means to compare wetland

Table 6. Suggested Reporting Information for Studies That Assess the Ability of Wetlands To Treat Stormwater Pollution

Wetland classification
- Constructed or natural or combination wetland?

Vegetation species

Vegetation density (percentage open and vegetated)

Vegetation types (submerged, emergent, floating)

Wetland size

Wetland aspect (length-to-width ratio)

Side slopes

Soil type and depths

Watershed size (acres)

Watershed land use (percent residential, industrial, agricultural, undeveloped, etc.)

Watershed percent impervious (percent impervious area)

Rainfall data/statistics
- Average rainfall during study (in./year)
- Average number of storms per year
- Average storm intensity (in./hr)
- Average storm duration (hr)
- Average time between storms (days)

Low flow inflow rate(s)

Ground-water interaction?

Total flow from average storm

Wetland volume (maximum storage volume)

Average detention time for average storm (hours)

Water depth (minimum, maximum, average)

Inflow condition (discrete or diffuse inlets)

Pretreatment of inflow (settling forebays, overland flow, detention basin, grassed swales, etc.)

Maintenance practices (including frequency)
- Plant harvesting?
- Flushing?
- Sediment removal?
- Chemical treatment?
- Other maintenance?

Provide hydrology and water quality data for all storms monitored

Type of samples (grab or composite)

Number of storms monitored

Method used to compute pollutant removal efficiencies

Dominant removal mechanisms (sedimentation, adsorption, filtration, biochemical, etc.)

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designs and treatment effectiveness from different wetland systems. This type of information could be useful when comparing watershed to wetland characteristics regarding performance.

This paper compared watershed to wetland size ratios. A comparison of average storm volume to wetland volume would have made a better analysis of the effect of wetland "sizes" on treatment abilities. The currently available data, which predominantly present areas of wetlands and watersheds, did not allow for this kind of comparison. Percent impervious factors and therefore runoff volumes could be very different in different watersheds. Data such as percent imperviousness, land use information, and rainfall statistics, along with wetland volume information, would have allowed us to compare average runoff volumes, wetland volumes, and resulting performance characteristics.

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Constructed Wetlands for Urban Runoff Water Quality Control

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Abstract

Like all options for urban runoff water quality control, constructed wetlands have their advantages, disadvantages, and limitations. To realize their advantages, avoid problems, and use them appropriately requires recognition and adherence to certain principles. A hallmark of true constructed wetlands is their structural diversity, which yields the substantial advantages of breadth in treatment capabilities and potential for ancillary benefits as well as the disadvantage of larger land requirements for equivalent service than alternative measures. Prerequisites for success are functional objectives for the project to achieve and a corresponding design concept based on the structural characteristics of natural wetlands that are responsible for effective performance of the identified functions. Critical implementation considerations are proper siting, sizing, configuring of design features, construction, and various aspects of operations. Careful site-specific hydrologic analysis must be performed to ensure a sufficient water supply to sustain a wetland. The basis for sizing is limited at present, but application of climatological statistics and existing knowledge of needed hydraulic residence times for given treatment objectives provide some foundation. Equal in importance to planning, siting, and sizing are shaping, contouring, vegetating, and following up with short- and long-term maintenance, for which specific guidance is offered.

Background

Scope

Wetlands specifically constructed to capture pollutants from stormwater runoff draining urban and agricultural areas are gaining attention as versatile treatment options. Several recent major pieces of work have covered constructed wetland treatment, including those by Hammer (1), Strecker et al. (2), Olson (3), and Schueler (4). This paper draws on these resources and is intended to offer a concise summary of the current state of stormwater treatment using constructed wetlands and the methods for developing projects. The paper was derived from a 1-day continuing education course on the subject at the University of Washington, for which a course manual is available (5). In particular, this paper emphasizes the fundamental concepts on which successful application is based.

More than 150 wetlands have been constructed in the United States to treat municipal and industrial, especially mining, wastewaters (2). No complete accounting of stormwater constructed wetlands exists, but their number is certainly fewer.

The two basic types of municipal and industrial systems are both forms of attached growth biological reactors: free water surface (FWS) and subsurface flow (SF), or vegetated submerged bed (VSB) (6). The first type is similar to natural wetlands, with a soil base, emergent vegetation, and water exposed to air. The second type has a soil base overlain by media, emergent vegetation, and a water level below the media surface. The majority of municipal and industrial applications, most of small scale, are of this type. The advantages of a submerged system in these applications are reduced odor, insect problems, and land requirements because of the greater surface area for biological growth offered by the media. The FWS type is generally more appropriate for stormwater applications, where usually no odor problem exists, flows vary widely, and often there is a desire to integrate the treatment system with the landscape and to provide ancillary benefits. This paper covers only the FWS type of system.

Legal and Regulatory Considerations

From a legal and regulatory standpoint, "constructed wetlands" are designed, built, and continually maintained for the purpose of waste treatment. In this status, they are not regarded under the Clean Water Act as "waters of the United States." Accordingly, no regulations apply to water quality within, but the discharge is regulated in the same way as any treatment system.

This designation is in contrast to wetlands built for such purposes as mitigation of wetland losses under Clean Water Act Section 404 or to develop waterfowl habitat, known as "created wetlands." These systems have the same legal protections as natural wetlands, including prohibition on using them for the conveyance or treatment of waste. They usually have multiple functions, with any water quality improvement benefit being only incidental; entering water must be managed to prevent damage to any intended function. A constructed wetland also differs in purpose and legal status from a wetland "restoration," the purpose of which is to return a degraded system with reduced acreage or functional ability to the condition preceding degradation. If the wetland is not completely restored but one or more functions are increased, it is termed an "enhanced wetland." Restored and enhanced wetlands also have the same legal protections as natural wetlands.

A somewhat fuzzy issue with respect to constructed wetlands is their regulatory status if the principal purpose is waste treatment but ancillary benefits (e.g., wildlife habitat) are gained by design or incidentally. This situation is subject to interpretation by state and federal agencies. Such benefits are often among the objectives of project developers and are certainly possible to attain along with stormwater treatment in many circumstances; this paper provides advice on pursuing these objectives in a judicious way.

Constructed Wetlands in Relation to Alternative Methods

Alternatives to constructed wetlands for general-purpose stormwater treatment include wet ponds, extended-detention dry ponds, infiltration basins and other devices that drain into ground water, filtration, and "biofiltration" through terrestrial or hydrophytic plants in swales or on broad surface areas. Constructed wetlands have both advantages and disadvantages relative to these other options. Principal advantages are:

- More diversity in structure than any alternative, which offers the potential for relatively effective control of most types of pollutants.
- Wider range of potential side benefits than any alternative.
- Relatively low maintenance costs.
- Wider applicability and more reliable service than infiltration.

Disadvantages of constructed wetlands include:

- Larger land requirements for equivalent service than wet ponds and other systems, especially if intended to serve quantity as well as quality control purposes.
- Relatively high construction costs.
- Delayed efficiency until plants are well established.
- Uncertainty in design, construction, and operating criteria, a drawback also hampering competitive methods.
- Public concern about nuisances that can develop with stormwater constructed wetlands without care in siting, design, construction, and operation.

Functioning of Constructed Wetlands

Pollutant Removal Mechanisms

Numerous physical, chemical, and biological mechanisms can potentially operate in constructed wetlands to trap and transform entering pollutants. Understanding these mechanisms is the basis for determining effective treatment systems. That understanding can inform the entire process, from conception of the project, through preliminary planning and all phases of implementation, and, finally, to the long-term operation of the system. Table 1 summarizes the various mechanisms, the pollutants that they affect, and features that can promote their operation.

Some beneficial features are controllable through choices made during the project development process, while others are largely outside of the designer's influence, especially in a stormwater application. As can be seen in Table 1, some features are helpful in achieving multiple treatment objectives, but others are more specialized. Features that are largely under the project developer's control and help achieve any objective are 1) increasing hydraulic residence time (HRT); 2) providing an environment that creates flow at a low level of turbulence; 3) propagating fine, dense, herbaceous plants; and 4) establishing the wetland on a medium-fine textured soil, or amending soils to attain that condition.

Somewhat more specialized features, still mostly controllable, include 1) circumneutral Ph, which advances microbially mediated processes such as decomposition and nitrification-denitrification and avoids the mobility of certain pollutants at extreme pH; 2) a relatively low level of toxic substances in the site soils and entering flow, also needed for microbes; and (3) high soil organic content, which advances adsorption and decomposition and can be attained by site selection or soil amendment. Even more specialized are measures that can aid phosphorus capture, one of the most difficult treatment objectives to achieve. High soil exchangeable aluminum and iron contents have been found to enhance phosphorus reduction (7) but would require special soil amendments where naturally lacking, which thus far is an undemonstrated option in a full-scale wetland system. Addition of precipitating agents is an active treatment measure that is difficult to apply in passive

Table 1. Constructed Wetland Pollutant Removal Mechanisms

Mechanism	Pollutants Affected	Promoted By
Physical		
Sedimentation	Solids, BOD, pathogens; particulate COD, P, N, metals, synthetic organics	Low turbulence
Filtration	Solids, BOD, pathogens; particulate COD, P, N, metals, synthetic organics	Fine, dense herbaceous plants
Soil incorporation	All	Medium-fine textured soil
Chemical		
Precipitation	Dissolved P, metals	High alkalinity
Adsorption	Dissolved P, metals, synthetic organics	High soil Al, Fe (P); high soil organics (met.); circumneutral pH
Ion exchange	Dissolved metals	High soil cation exchange capacity
Oxidation	COD, petroleum hydrocarbons, synthetic organics	Aerobic conditions
Photolysis	COD, petroleum hydrocarbons, synthetic organics	High light
Volatilization	Volatile petroleum hydrocarbons and synthetic organics	High temperature and air movement
Biological		
Microbial decomposition	BOD, COD, petroleum hydrocarbons, synthetic organics	High plant surface area and soil organics
Plant uptake	P, N, metals	High plant activity and metabolism and surface area
Natural die-off	Pathogens	Plant excretions
Nitrification	NH_3-N	Dissolved oxygen >2 mg/L, low toxics temperature >5-7°C circumneutral pH
Denitrification	$NO_3 + NO_2$-N	Anaerobic, low toxics, temperature >15°C

Al = aluminum, BOD = biochemical oxygen demand, COD = chemical oxygen demand, Fe = iron, N = nitrogen, NH_3 = ammonia, NO_2 = nitrite, NO_3 = nitrate, P = phosphorus.

stormwater treatment systems subject to unpredictable and variable flow conditions.

Also outside the control of the designer and operator in a stormwater wetland is exploitation of the nitrification-denitrification processes to achieve nitrogen removal ultimately through evolution of nitrogen gas to the atmosphere. Full operation of the several steps in the bacterially driven processes requires alternating aerobic and anaerobic conditions at favorable temperatures, the first condition to permit oxidation to nitrate and the second to allow nitrate reduction to free N_2 gas. While these processes can be brought under some control in municipal and industrial treatment applications through timing of flow introduction, that degree of management is usually not possible in stormwater cases.

Expected Performance of Constructed Wetlands

Strecker et al. (2) conducted a full literature review of the use of both natural and constructed wetlands for controlling stormwater pollution. This review considered more than 140 papers and reports and assembled detailed information on 18 locations throughout the United States. Median pollutant removals in constructed wetlands were 80.5 percent for total suspended solids (TSS), 44.5 percent for NH_3-N, 58.0 percent for total phosphorus (TP), 83.0 percent for lead (Pb), and 42.0 percent for zinc (Zn). Coefficients of variation (standard deviation/mean) for these contaminants ranged from 27.7 to 56.1 percent, pointing out that both substantially higher and lower performances than median levels were reported. Pollutant reductions in constructed wetlands were overall higher than in natural wetlands, which was attributed to the specific design features and more intensive management of the constructed systems.

Schueler (4) estimated the performance potential of wetlands designed as he recommended based on the overall literature (Table 2). He considered these efficiencies to be provisional pending monitoring of the new systems.

Table 2. Projected Long-Term Pollutant Removal Rates for Wetlands Constructed as Recommended by Schueler (4)

Pollutant	Removal Rate (percent)[a]
TSS	75
TP	45[b]
Total nitrogen (TN)	25[c]
BOC, COD, total organic carbon	15
Pb	75
Zn	50
FC	Two orders of magnitude

[a] Lower by an unknown amount for pocket wetlands (see below for description of wetland types).
[b] 65 percent in pond/marsh system.
[c] 40 percent in pond/marsh system.

The Constructed Wetland Design and Implementation Process

Developing a constructed wetland treatment system should proceed carefully through a number of steps, as follows:

1. Planning the project.

2. Selecting the site.
3. Sizing the facility.
4. Configuring the facility, and incorporating design features that promote pollution control.
5. Designing for ancillary benefits.
6. Selecting vegetation and developing a planting plan.
7. Constructing the facility and establishing vegetation.
8. Developing and implementing an operation and maintenance plan.

The remainder of this paper explains these steps.

Project development for a constructed wetland must be a team effort, with a number of skills and specialties represented, including:

- Hydrology
- Water quality
- Soils
- Botany
- Wildlife ecology
- Landscape architecture
- Design engineering
- Construction engineering
- Stormwater facility maintenance

It bears emphasizing that a high level of hydrologic expertise should be employed to ensure that the most essential need—water supply—is met.

Planning and Site Selection

Preliminary Planning Considerations

Constructed wetland projects should be planned systematically and on a watershed scale as much as possible. This comprehensive analysis should start with consideration of management and source control practices that can prevent pollutant release. Another general consideration that should receive attention is the overall place of constructed wetlands and how they can best be used in conjunction with other treatment practices.

If the constructed wetland option is pursued, project objectives should be stated in functional terms, for example:

- The type of protection to be provided to the receiving water, pollutants to be controlled, and levels of control to be achieved (if possible).
- Benefits to be provided in the areas of, for example, open space, aesthetics, and recreation.
- Animals and life stages for which habitat is to be provided.

The potential for constructed wetlands to play a key role in stormwater management has developed from the understanding of natural wetland functioning gained during the past 20 years. Natural wetlands serve their recognized functions, which include providing flood flow control, water quality improvement, and ecological benefits, as a consequence of their structure and the interactions among their component parts. Mimicking these functions in an engineered system can best be done with reference to natural models. Therefore, using nearby natural wetlands as reference models for the configuration and planting of the wetland to be designed is strongly recommended. The reference system(s) should be characterized through formal observations and measurements of its hydrology, water quality, soils, vegetation, and, if appropriate, animal habitat and species. It is not necessary to mimic the reference plant community entirely, but studying it provides an idea of how the constructed system is likely to evolve.

With the natural model(s) in mind, a design concept can be developed. Schueler (4) proposed four basic stormwater wetland designs:

- *Shallow marsh:* A system with a relatively large land requirement that generally is used in larger drainage basins.
- *Pond/Marsh:* A two (or more) cell arrangement with a land requirement that is reduced by a relatively large deep pool.
- *Extended-detention wetland:* A more highly fluctuating hydrologic system in which the land requirement is reduced by adding high marsh to the shallow marsh zone.
- *Pocket wetland:* A design for smaller drainage basins (0.4 to 4 hectares) that may provide insufficient baseflow for permanent pool maintenance and cause greater water level fluctuations.

Figure 1 illustrates the pond/marsh type design. For diagrams of the other designs, see Schueler (4). Table 3 summarizes some of the principal selection criteria for the respective wetland types.

To complete preliminary planning, the design process and its aftermath should be organized. The following list of general principles for project design and implementation, derived from the various comprehensive references cited earlier, provides guidance for these steps:

- Design and implement with designated objectives constantly and clearly in mind.
- Design more for function than for form. Many forms can probably meet the objectives, and the form to which the system evolves may not be the planned one.

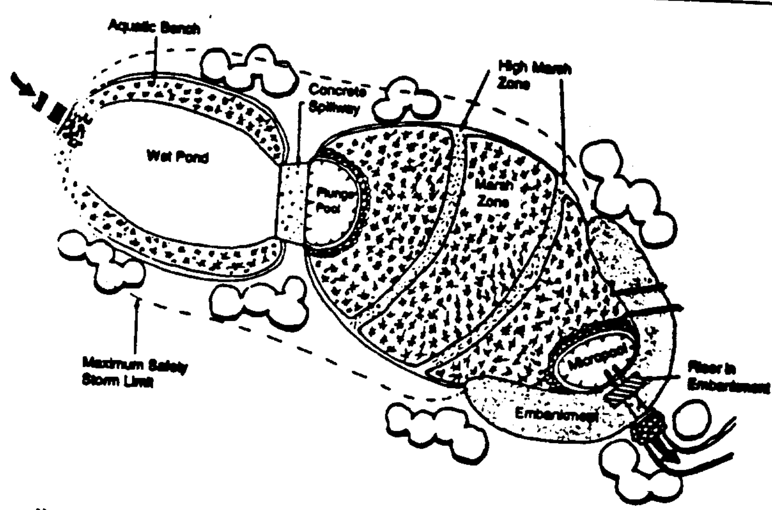

Figure 1. Two-cell pond/marsh design concept (4).

Table 3. Design Concept Selection Criteria (adapted from Schueler [4])

Attribute	Shallow Marsh	Pond/ Marsh	Extended-Detention Wetland	Pocket Wetland
Minimum wetland-to-watershed area ratio	0.02	0.01	0.01	0.01
Minimum watershed area (hectares)	10	10	4	0.4
Dry weather baseflow	Yes	Yes	Not necessarily	Not necessarily
Relative potential for ecological benefits	High	High	Moderate	Low to moderate

- Design relative to the natural reference system(s), and do not over-engineer.
- Design with the landscape, not against it (e.g., take advantage of natural topography, drainage patterns).
- Design the wetland as an ecotone. Incorporate as much "edge" as possible, and design in conjunction with a buffer and the surrounding land and aquatic systems.
- Design in structural complexity for beneficial distribution of water (e.g., its contact with vegetation and soils) and for biological advantages, as appropriate to objectives.
- Design to protect the wetland from potential high flows and sediment loads.
- Design to avoid secondary environmental and community impacts.
- Plan on sufficient time for the system to develop before it must satisfy objectives. Attempts to short-circuit ecological processes by overmanagement usually fail.
- Design for self-sustainability and to minimize maintenance.

Constructed Wetland Site Selection

Prospective constructed wetland sites should be evaluated carefully and a selection made after analyzing a number of conditions. Brodie (8) presented a generalized site screening procedure, which is reproduced in Figure 2. Table 4 summarizes the major considerations that should enter into this analysis. Application of these recommendations implies a significant data-gathering effort, which is essential at this sensitive stage in project development.

The need for a sufficient water supply to sustain a wetland is an especially important consideration; neglect of this consideration has led to constructed and created wetlands that are not viable. Thus, a water balance should be carefully established using the following formula to ensure that water availability and inputs at least balance outputs at all periods throughout the year:

$$I + P + D + S > O + E + R$$

where

I = surface inflow
P = precipitation
D = ground-water discharge

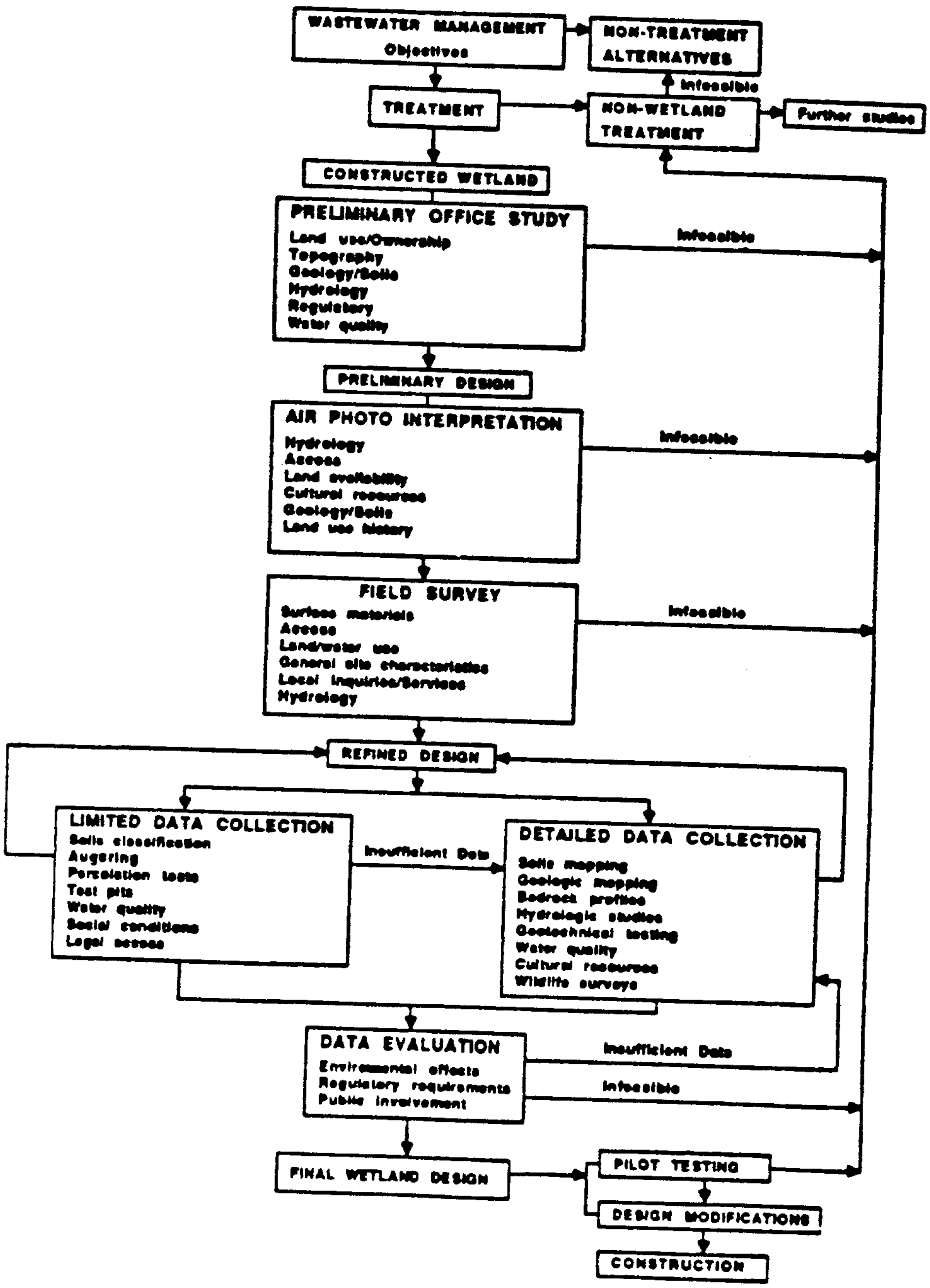

Figure 2. A generalized methodology for screening sites for constructed wetlands (8).

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Table 4. Considerations in Constructed Wetland Site Selection

Category	Considerations
Land-use and general factors	Land availability Existing site use and value Site problems (e.g., previous dumping, utility lines) Adjacent land use and value Connection to wildlife corridors and potential for adjacent areas to be biological donors Public opinion Accessibility for construction and maintenance Ability to control public access according to project objectives
Environmental and regulatory factors	Federal, state, and local laws and regulations Avoidance of archaeological and cultural resources Avoidance of critical wildlife habitat areas
Hydrology and water quality factors	Water supply reliability Low potential for disruptive flooding Water supply of adequate quality to sustain biota Low potential for the project to adversely affect downstream water bodies and adjacent properties and their water supplies Need for lining to retain water or avoid ground-water contamination
Geology factors	Preferably flat or gently sloped topography Adequate soil development Sufficient depth to bedrock Soil characteristics consistent with pollution control objectives Suitability of site materials for use in construction

S = wetland storage at beginning of calculation period
O = surface outflow
E = evapotranspiration
R = ground-water recharge

All units are expressed in terms of volume or water depth over the wetland surface.

The water balance should be estimated during site selection and checked after preliminary design. In areas with pronounced seasonal drought (e.g., most of the western United States), the calculation should definitely be performed for this period. Ground-water terms are difficult to establish with assurance, but they should at least be estimated as closely as possible by a hydrogeologist familiar with the location. As demonstrated by the fact that natural wetlands often dry below the soil surface, permanent standing water is not required for a wetland to be viable. Research on natural wetlands in Washington State has found that plant community richness declines substantially when drying extends longer than 2 months, compared to wetlands with shorter dry periods (9). Hence, the water balance should at least demonstrate that drying will never extend longer than 2 months.

Brodie (8) and Mitsch (10) have discussed positioning constructed wetlands in watersheds. Brodie (8) listed advantages and disadvantages of locating wetlands in upper reaches, on slopes, and in lowlands. No single setting is clearly optimal; thus, location from this standpoint depends on project objectives and the relative importance of the advantages and disadvantages at the specific site under consideration. Some possibilities for locating constructed wetlands in the overall landscape include:

- Just off stream channels, for baseflow supply by diversion.
- In stream floodplains, separated from the low-flow channel by a natural levee, with periodic water supplied to the wetland when the levee is topped.
- Several small wetlands in upper reaches of the watershed.
- One large wetland in lower reaches.
- Several small wetlands in lower reaches.
- Terracing into the landscape in steep terrain.

Constructing several small wetlands in the upper watershed provides some advantages relative to locating one large wetland in the lower reaches, such as better survival of extreme events, closer proximity to pollutant sources, and local flood protection. In contrast, the single large lowland wetland can provide overall greater flood reduction capability, if that is an objective. An alternative is the multiple lowland wetland plan, under which each can take a portion of high flows with less vulnerability to any one.

Sizing Constructed Wetlands

Establishing Volume

Possible arrangements of a constructed wetland in relation to runoff quantity and quality control requirements are:

- Place a runoff quantity control device "on line" and a constructed wetland "off line" to treat all runoff up to a certain volume.
- Construct a wetland with a permanent pool ("dead storage") zone for treatment and a "live storage" zone and discharge control sized for peak runoff rate control.
- Construct a wetland only for treatment (for situations where quantity control is not required).

The first arrangement takes advantage of the fact that most of the pollutant mass loading over time is transported by runoff from the more frequent, smaller storms and the "first flush" from the less frequent, larger storms. This is the recommended arrangement where runoff quantity control is required because 1) the relatively shallow depths needed to maintain wetlands are somewhat inconsistent with the large storage volume needed for quantity control and 2) large surges of water can damage the wetland.

Basic sizing decisions involve the dead storage volume, surface area, depth contouring, and live storage volume, if runoff quantity control will be provided. There are three fundamental ways to calculate the treatment volume of a constructed wetland:

- Compute the volume needed to provide the required HRT for achieving a desired effluent concentration of the limiting pollutant (the hardest to remove), given a certain influent concentration, by using a mechanistic equation.
- Compute according to maximum allowable loading rates of water or specific pollutants established empirically from measurements on operating systems.
- Compute on the basis of a hydrologic criterion.

The first two approaches are employed in municipal and mining industry wastewater applications, where parameterized mechanistic equations or allowable loading rates exist for BOD and nitrogen in sewage and iron and manganese in mining effluents (6). Similar relationships do not exist for stormwater and will be difficult to develop, given the variability of flows and pollutant concentrations.

Therefore, stormwater wetland sizing must be determined using some form of the third approach. One version calls for choosing a volume sufficient to hold all runoff from a set percentage of the annual storms (e.g., 90 percent) or to hold a set depth of runoff generated by the contributing catchment (e.g., the first 2.5 cm = 1 in.). Schueler (4) presents several sizing rules of this type. Equivalent to this version is an approach for using a "water quality design storm" of a selected recurrence frequency and duration. The Washington State Department of Ecology (11) has taken this approach, selecting the 6-month, 24-hour rainfall event, which in Seattle is approximately equivalent to the first 3 cm of runoff, for stormwater treatment design in the Puget Sound basin.

A third version of the hydrologic basis is the method developed from wet pond performance data collected during the Nationwide Urban Runoff Program by the U.S. Environmental Protection Agency (EPA) (12). Using this method implicitly assumes that constructed wetlands will perform at least as well as wet ponds of equivalent treatment volume, which seems to be a safe assumption given the treatment advantages offered by a more structurally complex, vegetated system. The data exhibited an association between treatment efficiency and the ratio of permanent pool volume to runoff volume associated with the mean storm, termed the "volume ratio." The mean storm is the average rainfall quantity over all storms in a long-term record at a gaging station. TSS loading reduction is typically around 75 percent at a volume ratio of 2.5, which is a common design basis. Obtaining increasingly better performance levels requires exponentially increasing basin size because the contaminants hardest to capture are those still in suspension or solution.

With this means of sizing constructed wetlands, the task almost entirely involves hydrologic analysis. This is another point at which hydrologic expertise is important to the design effort. Unless actual data are available from gaging the catchment that will contribute to the constructed wetland, the hydrologic analysis must be performed using a model. Modeling options include, in order of preference, a well-calibrated continuous simulation computer model, such as EPA's SWMM and HSPF, an event-based model such as the Soil Conservation Service's curve number method, and, where adequate data exist, a locally derived empirical model of the rational method type.

Once the hydrologic analysis is complete, the permanent pool volume (VP) calculation can be made very simply by using the equation:

$$VP = C \cdot VR \cdot AC$$

where

C = unit conversion factor
VR = runoff volume from hydrologic analysis
AC = contributing catchment area

Schueler (4) recommended a minimum VP of 1.6 cm/ha of contributing catchment area, which will increase the wetland size over that calculated by the equation in small catchments.

This procedure is used for general runoff pollution control purposes. Knowledge is inadequate at present to perform detailed sizing calculations for such specific purposes as control of metals and nutrients. These special objectives can be advanced in part by installing appropriate design features (addressed later in this paper). It is known that the maximum potential to remove dissolved pollutants, which include certain nitrogen and phosphorus forms and some metals, is reached with a long HRT in the dead storage (2 to 3 weeks) (13, 14). The average residence time can be checked as follows: 1) perform the hydrologic analysis to determine the rate of flow to the wetland associated with the mean storm (Q), and 2) calculate HRT = VP/Q. If HRT is less than 2 to 3 weeks and dissolved pollutant removal is an objective, increase VP to obtain HRT in that range.

If the wetland has live storage for peak runoff rate control, the volume of that zone and the discharge orifice size will also have to be calculated. These calcula-

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tions require hydrograph simulation and routing analysis and are beyond the scope of this paper. They should be performed by a qualified hydrologist.

Permanent Pool Surface Area and Depth Contouring

A larger surface area for the same volume provides better treatment by allowing more light penetration for photosynthetic activity by plants and algae, more aeration for aerobic chemical and biological processes, and a shorter settling distance for particles. A straightforward way of establishing the wetland surface area (AW) is to start by selecting a trial mean depth (D) from the following approximate ranges (after Schueler [4]):

Shallow marsh:	0.30 to 0.45 m
Pond/marsh:	0.60 to 0.85 m
Extended-detention wetland:	0.25 to 0.30 m (permanent pool) 1.0 m (extended-detention zone)
Pocket wetland:	0.15 to 0.40 m

Using the trial mean depth, calculate surface area by AW = VP/D. Determine the wetland to contributing catchment area ratio (AW/AC), and compare it with the guidelines in Table 3.

Once satisfactory basic dimensions are determined, allocate depths to the different wetland zones according to the design concept. Schueler (4) recommended the following zones to obtain diversity in structure and treatment capabilities:

- Deep areas (30 to 180 cm deep, no emergent vegetation)—forebay, micropools, deep water pools, and channels.
- Low marsh (15 to 30 cm below normal pool).
- High marsh (0 to 15 cm below normal pool).
- Irregularly inundated zone (above normal pool).

Schueler went on to supply approximate depth allocations for the various zones and design concepts, and the reader is referred to his guidelines for these details. For example, he recommended allocating 40 percent of the surface area to the high marsh and 40 percent to the low marsh in the shallow marsh design, with 5 percent each given to the forebay, micropools, deep water, and irregularly inundated zones.

Recommended Constructed Wetland Design Features

Adequate size is a necessary but not sufficient condition for good treatment performance. The theoretical HRT provided by the volume will not be achieved in practice if the layout permits water to traverse the wetland faster. Many of the features presented in this section are recommended to reduce the tendency of flow to short-circuit the wetland and fail to achieve an actual HRT as long as the theoretical HRT. Given that natural wetlands generally exhibit the recommended features, the selected reference system(s) should be employed as a model for designing these features. The recommendations are presented here in an abbreviated list format; consult the comprehensive sources referenced earlier for more detail.

Shaping the Wetland

Create a complex microtopography to lengthen the edge and flow path by using high marsh peninsulas and islands. Create at least two distinct cells by restricting the flow to a narrow passageway using the following features:

- Make the wetland relatively wide at the inlet to facilitate distribution of the flow well.
- Maximize the distance between the inlet and outlet.

The effective length to width ratio should be 5:1, preferably, and at least 3:1.

Slopes

The longitudinal slope (parallel to the flow path) should be less than 1 percent.

The wetland should be carefully constructed to have no lateral slope (perpendicular to the flow path) to avoid concentration of the flow in preferred channels, which reduces actual HRT and risks erosion.

Side slopes should be gradual (e.g., 5:1 to 12:1 horizontal to vertical), as in natural wetlands. Nowhere should the side slope be greater than 3:1.

Forebay

A forebay is a relatively deep zone placed where influent water discharges. It traps coarse sediments, reduces incoming velocity, and helps to distribute runoff evenly over the marsh.

Install a forebay in shallow marsh and extended-detention wetlands. In the case of a pond/marsh system, the pond serves this purpose. The restricted size of pocket wetlands generally does not allow for a forebay. Make the forebay 1.2 to 1.8 m deep. The forebay should be a separate cell set aside by high marsh features.

Provide maintenance access for heavy equipment (4.5 m wide and a maximum 5:1 slope) directly to the forebay. The forebay bed should be hardened to prevent disturbance during cleanout.

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Flow Channeling

Create sheet flow to the maximum extent possible. Where flow must be channeled, use multiple, meandering channels rather than a single straight one. Intersperse open water areas with marsh, rather than connecting along the flow path. Minimize velocity in channels to prevent erosion and expand habitat opportunities.

Outlet Design

Place a micropool 1.2 to 1.8 m deep at the outlet. Install a reverse-sloped pipe 30 cm below the permanent pool elevation. This outlet design has been found to avoid clogging, to which constructed wetland outlets are prone (4).

Install a drain capable of dewatering the wetland in 24 hours to allow for maintenance. Control the drain with a lockable, adjustable gate valve. Place an upward-facing, inverted elbow on the end of the drain to extend above the bottom sediments.

Soils

Medium-fine textures, such as loams and silt loams, are optimal for establishing plants, capturing pollutants, retaining surface water, and permitting ground-water discharge. Circumneutral pH (approximately 6 to 8) is best for supporting microorganisms, insects, and other aquatic animals.

A relatively high content of highly decomposed organics ("muck") is favorable for plant and microorganism growth and the adsorption of metals and organic pollutants. Muck soils are preferred to peats (less decomposed organics), which tend to produce somewhat acidic conditions, to be low in plant nutrients, and to offer relatively poor anchoring support to plants.

Vegetation becomes established more quickly and effectively in constructed wetlands when soils contain seed banks or rhizomes of obligate and facultative wetland plants. Attempt to obtain any available soils that offer these resources.

Soil characteristics recommended for specific pollution control objectives are:

- High cation exchange capacity—for control of metals.
- High exchangeable aluminum and/or iron—for control of phosphorus.

Liner

An impermeable liner is required when infiltration is too rapid to sustain permanent soil saturation, when there is a substantial potential of ground water being contaminated by percolating stormwater, or both. Infiltration losses are insignificant at most sites with Soil Conservation Service Class B, C, and D soils. Also, sediment deposition is likely to seal the bottoms of constructed wetlands. Generally, therefore, a liner is likely to be needed only in Class A soils.

Emergency Spillway

An emergency spillway is required when the wetland will be used for runoff quantity control (and any other situation in which it would be possible for runoff to enter from a larger storm than the largest storm the facility is sized to handle).

Buffer

A buffer should be provided around the wetland both to separate the treatment area from the human community and, if development habitat is an objective, to reduce the exposure of animals to light, humans, and pets. The buffer requirement can be waived for pocket wetlands without wildlife habitat objectives and adjacent structures. The minimum buffer width should be 8 m, measured from the maximum water surface elevation, plus 5 m to the nearest structure. The buffer should be increased to at least 16 m when developing wildlife habitat is an objective. It should be sloped no more than 5:1 (horizontal to vertical).

Preserve existing forest in the buffer area if at all possible. At least 75 percent of the buffer should be forested to avoid attracting geese and to provide better protection and habitat for other wildlife.

Pretreatment

The constructed wetland is expected to serve as the primary treatment device. Nevertheless, some pretreatment can prevent problems in the wetland, produce a more self-sustaining system, and increase the potential for ancillary benefits. Pretreatment mechanisms that should be considered include:

- Catch basins, for trapping the largest solids.
- A presettling basin or biofilter, when the watershed produces relatively high solids loadings.
- Oil-water separators.

Designing for Ancillary Benefits and Avoidance of Problems

Ancillary Benefits

Potential ancillary benefits of constructed wetlands include:

- Wildlife habitat.
- Aquaculture for harvest.
- Primary production for food-chain support.

- Biological diversity.
- Open space for recreational, educational, and other human uses.

This paper focuses on creating wildlife habitat, which also helps achieve the latter three benefits. The preceding recommendations on configuring the wetland were also designed in part to contribute to these benefits.

An issue, of course, is the attraction of wildlife to a wastewater treatment area that might be contaminated. It is thought, but not proven, that levels of contamination hazardous to wildlife are a relatively rare problem restricted to watersheds with very high vehicle traffic, proportions of impervious surface, and/or population densities. It is also thought that such problems can be addressed at least partially by reversing the recommendations to attract wildlife; that is, install features that discourage wildlife colonization. In either case, a qualified wildlife biologist is needed to design the features. For now, the best course seems to be using and studying constructed wetlands for many applications, but avoiding their use in areas with a high potential for toxic contamination.

The main factor in designing for wildlife habitat is complex structure that provides a variety of possible niches to support feeding, nesting, breeding, and refuge requirements of desired species. Fortunately, many features that promote pollution control also enhance wildlife habitat. Figure 3 illustrates several suggested features for habitat development, and the comprehensive references provide other illustrations.

Following is a summary of features that enhance wildlife habitat drawn from Figure 3 and the references:

- Irregular shorelines.
- A wide range of depth zones—deep zones provide habitat for invertebrates, amphibians, and possibly fish; higher marsh areas offer feeding grounds to birds; and various nesting opportunities are provided in the different zones.
- Perimeter forest buffer at least 16 m wide.
- Connect wetland to corridors (e.g., streams and passages to forests and other wetlands) that allow wildlife movement.
- Increase wetland size if very small—research has shown that wildlife use is not strongly correlated to the size of natural wetlands of 0.5 to several hectares in area (15), but is low in very small natural and constructed wetlands (less than 0.1 hectares).
- Select plants that offer refuge, nesting, feeding, and breeding habitat.
- Install other features providing for nesting and refuge, such as:
  - Islands (protection for ground-nesters) (minimum 3 m^2 for a waterfowl pair, above maximum water surface elevation, densely vegetated, positively drained).

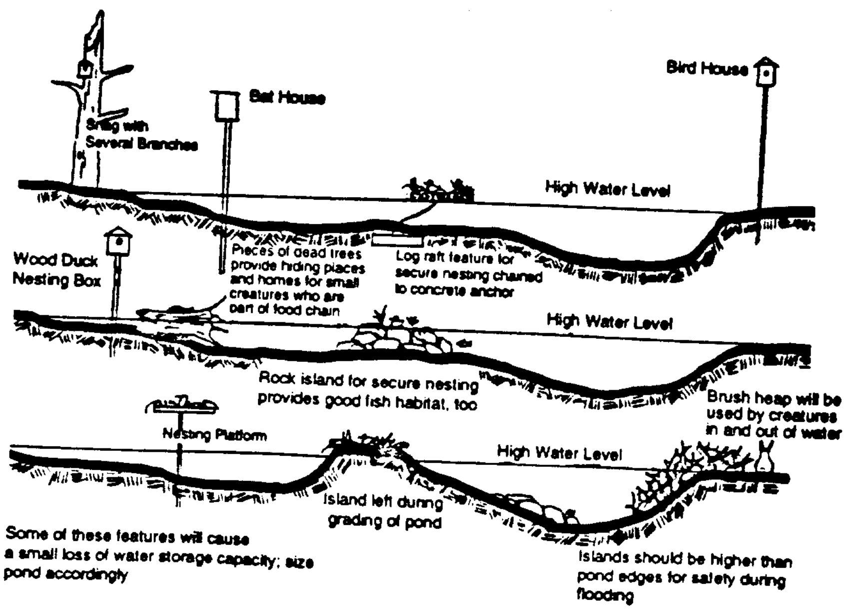

Figure 3. Suggested constructed wetland habitat features (11).

- Snags (dead tree trunks installed for cavity-nesters).
- Nest boxes and platforms (unique designs for cavity-nesters).
- Buffer trees (for foliage-nesters).
- Logs, stumps, and brush (for bird perches and small-mammal refuge).

• Avoiding significant water level fluctuations—this is an inherent disadvantage of stormwater wetlands relative to wildlife. The best remedy is to precede the wetland with runoff quantity control. Otherwise, the configuring recommendations stated earlier provide the best situation obtainable in stormwater applications.

Avoidance of Problems

Potential problems associated with constructed wetlands include:

- Mosquito breeding.
- Aesthetic drawbacks.
- Safety concerns.
- Attraction of geese and ducks, which can constitute a nuisance.
- Development of a monoculture of undesirable vegetation.
- Accumulation of toxicants.

The extent of actual occurrence of these problems and managing to avoid or minimize them is addressed briefly in this paper.

Mosquitoes are actually rarely a problem in well-designed and operated constructed wetlands; thus, education of the concerned public is part of the solution. A problem with mosquitoes can best be prevented by providing diverse habitats that support predatory insects. Mosquito fish *(Gambusia)* have been used successfully to control mosquitoes in permanent ponds, but the introduction of the fish in areas to which they are not native must be carefully assessed.

Aesthetic problems can be avoided with careful attention to construction and vegetation establishment. The buffer and tall emergent vegetation can be used to conceal such wetland characteristics as water level fluctuation and films on the water.

Constructed wetlands are inherently safer than deeper ponds, but some degree of potential hazard to children is associated with deep zones. Hazards can be avoided by establishing gradual side slopes and a shallow marsh safety bench (5 m wide) where the toe of the side slope meets any deep pool, by concealing outlet piping, and by providing lockable access. In general, fencing should only be needed on the embankment above large outfalls, where they exist.

Nuisance waterfowl can be discouraged in several ways. Maintain the buffer largely with forestland (at least 75 percent), and avoid the growth of turf grass around the wetland. Also, maintain a variety of depths, especially high marsh not favored by geese and mallards. Another important measure is to educate citizens and place signs to discourage feeding.

The tendency for wetlands to develop undesirable plant monocultures can be limited by maintaining structural diversity and a range of depths, especially shallower areas. A diverse selection of native flora should be planted shortly after the wetland is constructed.

Regarding toxicant accumulations, evidence suggests that metals and organics are tightly bound in sediments and do not tend to become mobilized over long periods. When maintenance is performed, disposal of spoils becomes an issue. Current knowledge indicates that spoils pass hazardous waste tests and can be safely land applied or landfilled (4). Plan an onsite application area if possible to save costs of disposal.

Vegetation Selection and Establishment

As experience with wetland creation, restoration, and construction projects accumulates, it is becoming increasingly clear that the plant community develops best when the soils harbor substantial vegetative roots, rhizomes, and seed banks. Its development is also enhanced by the opportunity for volunteer species to enter from nearby donor sites; however, volunteers cannot be relied on for vegetation establishment. Transplants may be supplanted by more vigorous resident and volunteer stock under these circumstances and may actually constitute a minor component of the eventual community. Nevertheless, transplanting is generally a wise strategy, and most of the specific guidance available for establishing wetlands concerns this source; thus, it is fully covered below.

Hydric soils containing vegetative plant material collected for establishing new wetlands are becoming known as "wetland mulch." It appears that ample use of this mulch enhances diversity and the speed of vegetation establishment, but the mulch content is somewhat unpredictable and donor sites are limited. Also, guidelines for extracting, handling, and storing the material are limited. A danger with the use of mulch is the possible presence of exotic, opportunistic species that will out-compete more desirable natives. Therefore, at least the donor sites that obviously support such plant species should be avoided in obtaining material. Preferred donor material includes wetland soils removed during maintenance of highway ditches, swales, sedimentation ponds, retention/detention ponds, and clogged infiltration basins and during dredging, or from natural wetlands that are going to be filled under permit (although these soils are best used for mitigating the loss). It is recommended that the upper 15 cm of donor soils be obtained at the end of the growing season, if possible. The best way to hold soils until installation is somewhat uncertain but must include keeping soils moist in conditions that will maintain vital dormancy. Efforts are under way to establish repositories for mulch reclaimed in maintenance operations.

The reliability of transplanting and the instant partial cover it provides make it necessary regardless of the potentials offered by wetland mulch and volunteer species recruitment. Commercial wetland plant nurseries now operate in many places in the nation to provide material. The following list of general vegetation selection principles was compiled from Garbisch's (16) recommendations for creating wetlands and from the comprehensive constructed wetland works:

- Base selections more on the prospects for successful establishment than on specific pollutant uptake capabilities (plant uptake is a highly important mechanism only for nutrients, much of which are released upon the plant's death; nutrient removal is more the result of chemical and microbial processes than of plant uptake).
- Select native species, and generally avoid natives that invade vigorously.
- Use a minimum of species adaptable to the various elevation zones; diversification will occur naturally.
- Select mostly perennial species, and give priority to those that establish rapidly.
- Select species that are adaptable to the broadest ranges of depth, frequency, and duration of inundation (hydroperiod).
- Match the environmental requirements of plant selections to the conditions to be offered by the site. Consider especially hydroperiod and light requirements.
- Give priority to species that have been used successfully in constructed wetlands in the past and to commercially available species.
- Avoid specifying only species that are foraged by wildlife expected to utilize the site.
- Phase the establishment of woody species to follow herbaceous ones.
- Consider planting needs to achieve designated objectives other than pollution control.

Although excessive emphasis on vegetation selection based on pollution control capabilities should be avoided, considerable information on that subject has been compiled. Kulzer (17) prepared a summary of the demonstrated capabilities of plants for the various common classes of pollutants. The most versatile genera that have species representatives in most parts of the nation are *Carex*, *Scirpus*, *Juncus*, *Lemna*, and *Typha*.

Schueler (4) and Garbisch (16) have assembled a considerable amount of specific guidance on the construction and vegetation establishment process for constructed wetlands and created wetlands, respectively. The course manual by Horner (5) also incorporates this guidance. Given the available literature, these topics are not addressed in this paper.

Operating Constructed Wetlands

Relative to retention/detention ponds, constructed wetlands pose a relatively significant routine operating burden. Operated properly, however, they should not require periodic expensive sediment cleanouts. From the outset, the project should include a formal operation and maintenance plan that covers the following elements: 1) inspection, 2) sediment management, 3) water management, and 4) vegetation management.

There are two levels of inspection: routine and comprehensive. Rapid, routine inspections should be made by a qualified observer to identify and take action on any problems that would damage the wetland's function. Recommended scheduling for these inspections is monthly and after each storm totaling more than 1.25 cm (0.5 in.) of precipitation. Comprehensive inspections should take place twice yearly the first 3 years, once in the growing season and again in the nongrowing season. Conditions that should be noted during these inspections include:

- Dominant plants and their distributions in each zone.
- Relative presence of intentionally planted and volunteer invasive and noninvasive species.
- Plant condition—look for signs of disease (yellowing, browning, wilting), pest infestations, and stunted growth.
- Depth zones and microtopographic features compared with the original plan.
- Normal pool elevation compared with the original plan.
- Sediment accumulations (locations and approximate quantities).
- Outlet clogging.
- Buffer condition.

The objective of sediment management is to trap—and when necessary remove—sediments before they reach the shallow zones. Forebays will probably have to be drained and dredged every 2 to 5 years. The pond in a pond/marsh system is, in part, a large forebay and should not need dredging as frequently.

If water levels do no conform to plans, or there is another reason to change them, regulation can be accomplished by installing a flash board at the desired height at the outlet weir or by adjusting the gate valves (if provided). Remove clogging debris from around the outlet as necessary.

In vegetation management, provide extra care during the first 3 years to plantings, especially trees, including watering, supporting, mulching, and removing weeds. Reinforcement plantings will probably be required after 1 or 2 years and should be added as necessary. Manually remove undesirable species with a high potential to invade and dominate, if they will subvert achievement of the designated objectives. Cut or dig out woody, unwanted species in marsh zones before they cause damage and become too difficult to remove.

Harvesting the wetland for nutrient control can be performed but has many drawbacks, including cost, disposal, and damage to the system. It is generally only possible to cut aboveground biomass, which will not adequately control the release of nutrients.

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Stormwater Pond and Wetland Options for Stormwater Quality Control

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Abstract

In this paper, 10 designs for stormwater wetland and pond systems used for effective urban runoff quality control are surveyed. Each design is based on a different allocation of deep-pool, marsh, and extended detention storage. The comparative pollutant removal capability of the 10 designs are reviewed based on a national survey of 58 performance monitoring studies. In addition, the reported longevity, maintenance requirements, and environmental constraints of each design is assessed.

A team approach for selecting the most appropriate design at the individual development site is strongly recommended. Key selection factors, such as space, drainage area, and permitability, are discussed. A seven-stage design/construction process is outlined to ensure the team selects and builds the most appropriate and effective design.

The paper points out that the uncertain regulatory status of pond/wetland systems should be resolved so that this effective runoff control technology can be appropriately used.

Introduction

The use of stormwater ponds to control the quality of urban stormwater runoff has become more widespread in recent years. At the same time, designs have become more sophisticated to meet many environmental objectives at the development site. Today, the term stormwater pond can refer to any design alternatives in a continuum that allocates different portions of runoff treatment volume to deep pools, shallow wetland areas, and temporary extended detention storage. This paper provides a broad review of the comparative capabilities of pond and wetland systems.

In an operational sense, these systems can be classified into one of ten categories:

1. Conventional dry ponds (quantity control only)
2. Dry extended detention (ED) ponds
3. Micropool dry ED ponds
4. Wet ponds
5. Wet ED ponds
6. Shallow marsh systems
7. ED wetlands
8. Pocket wetlands
9. Pocket ponds
10. Pond/marsh systems

Table 1. Comparative Storage Allocations for the 10 Stormwater Pond/Wetland Options (% of Total Treatment Volume)

Pond/Wetland Alternative	Deep Pool	Marsh	ED
1. Conventional dry ponds (quantity control only)	0	0	0
2. Dry ED ponds	0	10 (ls)	90
3. Micropool dry ED ponds	30 (f, m)	0	70
4. Wet ponds	80	20 (b)	0
5. Wet ED ponds	50	10 (b)	40
6. Shallow marsh systems	40 (f, m, c)	60	0
7. ED wetlands	20 (f, m)	30	50
8. Pocket wetlands	20 (f)	80	0
9. Pocket ponds	80	20 (b)	0
10. Pond/marsh systems	70	30 (b, m)	0

Note: The storage allocations shown are approximate targets only.
ls = lower stage of ED pond often assumes marsh characteristics
f = forebay
m = micropool
c = channels
b = aquatic bench

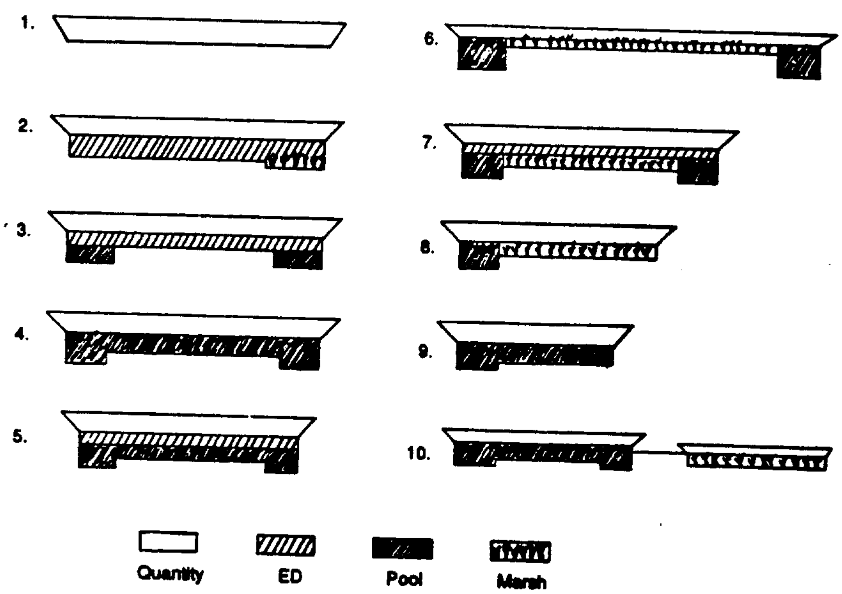

Figure 1. Stormwater pond options.

Each of these designs (shown in cross-sectional view in Figure 1) can be distinguished by how it allocates the total treatment volume to deep pools, shallow wetlands, and temporary extended detention storage. As can be seen, most designs incorporate two and sometimes three runoff treatment pathways. Comparative storage allocations are shown in quantitative terms in Table 1. It is important to note that these allocation targets are approximate and relative, and individual systems may not always conform to the target.

Stormwater pond systems can also be configured in many different ways, as shown in Figure 2. Ponds can be located "on-line" or "off-line" and can be arranged in multiple cells. On-line ponds are located directly on streams or drainage channels. Off-line ponds are constructed away from the stream corridor. Runoff flow is split from the stream and diverted into off-line ponds by a flow splitter or smart box.

The total treatment volume need not be provided within only one cell. Stormwater ponds can contain multiple storage cells, and these often enhance the performance, longevity, and redundancy of the entire system.

All pond designs provide additional storage to control the increased quantity of stormwater produced as a consequence of urban development. This "quantity control" storage is usually defined as the storage needed to keep postdevelopment peak discharge rates equivalent to predevelopment levels for the 2-year storm. The quantity control storage is in addition to, and literally on top of, the quality control runoff storage.

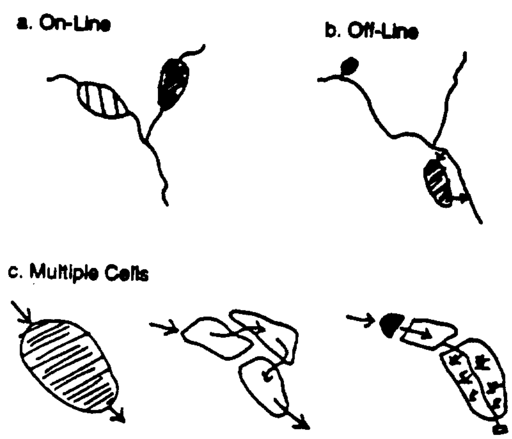

Figure 2. Stormwater pond configurations.

Comparative Pollutant Removal of Stormwater Pond Designs

Each of the three basic treatment volume allocations (pool, marsh, and ED) use different pollutant removal pathways. Therefore, it is not surprising to find considerable variability in the projected removal rates for each of the 10 stormwater pond designs (Table 2). The table is based

Table 2. Comparative Pollutant Removal Capability of Stormwater Pond/Wetland Alternatives

	Pollutant Removal Rate			
Pond/Wetland Alternative	TSS	TP	TN	Reliability
1. Conventional dry ponds	10	0	0	Moderate
2. Dry ED ponds	30	10	10	Low
3. Micropool dry ED ponds	70	30	15	Moderate (projected)
4. Wet ponds	70	60	40	High
5. Wet ED ponds	75	65	40	High
6. Shallow marsh systems	75	45	25	High
7. ED wetlands	70	40	20	Moderate
8. Pocket wetlands	60	25	15	Moderate (projected)
9. Pocket ponds	60	30	20	Moderate (projected)
10. Pond/marsh systems	60	70	45	High

TSS = total suspended solids
TP = total phosphorus
TN = total nitrogen

on a review of 58 pond and wetland performance studies conducted across the United States and Canada (1).

While seven of the ten pond designs have been monitored in the field, the performance of three designs (pocket ponds, pocket wetlands, and micropool dry ED ponds) can only be projected based on design inferences and field experience.

Two of the pond designs possess limited capability to remove pollutants—the conventional dry pond and the dry ED pond. These pond systems seldom have been observed to reliably remove sediment and have shown virtually no capability to remove nutrients. The performance of dry ED ponds is expected to improve if micropools are added at the inlet and the outlet. Micropools help to pretreat incoming runoff, prevent resuspension, and reduce clogging.

When properly sized and designed, wet ponds can reliably remove sediments and nutrients at relatively high rates. The deep pool of the wet pond allows for gravitational settling. Removal rates for wet ponds can be incrementally improved if the deep pool is combined with extended detention, as in the wet ED pond system.

The removal capability of wetland systems (designs 6, 7, and 8) is generally comparable to that of wet ponds of similar size. Sediment removal often is slightly higher in wetland systems, but nutrient removal appears to be somewhat lower and less reliable. Shallow marsh systems exhibit slightly higher removal rates than either the ED wetland or the pocket wetland systems, which may be explained by the greater surface area and complexity of shallow marsh systems (2).

Ponds and wetlands that do not have a reliable source of base flow, and that have a water level that frequently fluctuates, are termed pocket ponds and wetlands. These systems typically serve very small drainage areas and are excavated to the local water table. Consequently, pocket facilities are often less than a quarter acre in size and possess few of the design features of their larger counterparts. Therefore, pocket wetlands are thought to have lower pollutant removal capability, especially for nutrients.

Pond-marsh systems appear to possess the greatest overall pollutant removal capability of all the designs monitored. The permanent pool and the shallow wetland provide complementary and redundant removal pathways, and reduce remobilization of pollutants.

It should be noted that while differences in removal capability do exist among the 10 designs, other key design factors also must be present if these rates are to be achieved. First, the system must be capable of capturing at least 90 percent of the annual runoff volume delivered. Second, incoming runoff must be pretreated in a forebay or deep pool. Third, the system must meet minimum criteria for internal geometry (flow path, microtopography, surface-area-to-volume ratio). Clearly, a poorly conceived or designed pond system will not achieve the rates shown in Table 2.

Comparative Ability To Protect Downstream Channels

Pond systems that combine ED storage with stormwater quantity storage appear to provide the best measure of protection for downstream channels exposed to the erosive potential of bankfull and subbankfull floods. Recent field research has demonstrated that control of the 2-year storm quantity exacerbates, rather than reduces, downstream channel erosion problems. Modeling studies suggest that extended detention (e.g., 6 to 24 hours) of relatively small treatment volumes may have some potential to alleviate downstream channel erosion problems. Additional field research is needed to confirm the value of ED in protecting channels.

Comparative Physical, Environmental, and Maintenance Constraints

Each of the 10 pond systems are subject to many different constraints that may limit their use at a particular site. Some of the more common constraints are outlined in Table 3.

Physical constraints include available space, climate, dry weather base flow, and contributing drainage area. Maintenance constraints may involve susceptibility to clogging and the frequency and difficulty of sediment cleanout.

Table 3. Comparative Capability of 10 Pond/Wetland Alternatives—Physical, Environmental, and Maintenance Constraints

Pond/Wetland Alternative	Minimum Drainage Area[a]	Space Index[b]	Water Balance	Clogging Risk	Sediment Cleanout	Waters of U.S. (404)	Stream Warming	Safety Risk
1. Conventional dry ponds	5	0.5	No restrictions	Moderate	Basin (10-20 yr)	?	Low	Low
2. Dry ED ponds	10	1.0	No restrictions	High	Basin (10-20 yr)	Yes	Moderate	Low
3. Micropool dry ED ponds	15	1.0	May require base flow	Low	Forebay (2-5 yr)	Yes	Moderate	Low
4. Wet ponds	25+	1.0	Climate	Low	Forebay (2-5 yr)	Yes	High	High
5. Wet ED ponds	25+	1.0	Climate	Low	Forebay (2-5 yr)	Yes	High	High
6. Shallow marsh systems	25+	2.5	Climate, base flow	Low	Forebay (2-5 yr)	Yes	High	Moderate
7. ED wetlands	10+	1.5	Climate, base flow	Low	Forebay (2-5 yr)	?	High	Moderate
8. Pocket wetlands	1-5	2.0	Climate, ground water	Moderate	Basin (5-10 yr)	No	Moderate	Moderate
9. Pocket ponds	1-5	1.0	Climate, ground water	Moderate	Basin (5-10 yr)	No	Moderate	Moderate
10. Pond/marsh systems	25+	1.5	Climate, base flow	Low	Pool (10-15 yr)	Yes	High	High

[a]Maximum of 400 acres in most cases.
[b]Space consumption index (1 = space required for wet pond).

Perhaps the most restrictive constraints, however, are of an environmental nature. Recent research has indicated that on-line pond and wetland systems can have serious impacts on the local and downstream environment, if they are not properly located and designed (2). The most serious include the modification or destruction of high-quality forests and wetlands as a consequence of construction, and downstream warming. Consequently, the siting of ponds and wetlands in the mid-Atlantic region has become a major focus of federal and state regulatory agencies. Presently, both a Section 404 (wetlands) and a Section 401 water quality certification permit must be obtained for the construction of any on-line stormwater pond or wetland.

A Team Approach for Selecting the Most Appropriate System

Selecting and designing a pond system has become a complex and lengthy process. An effective approach is to assemble a design team consisting of a stormwater engineer, landscape architect, environmental consultant, and the construction contractor. The combined expertise of the design team, along with early and frequent coordination with local plan reviewers, is an essential ingredient for implementing the most appropriate system for the development site and the downstream community.

The design team works together throughout the planning, design, approval, and construction process, which can take as long as 2 years. Building an effective and appropriate pond system consists of seven general steps, as outlined below:

1. Evaluation of the Feasibility of the Site

The design team has two major tasks. The first task is to define, in consultation with local planning and resource protection agencies, the primary watershed protection objectives for the particular site and stream. The objectives may include specific targets for pollutant reduction, flood control, channel protection, wetland creation, habitat protection, protection of indicator species (e.g., trout), or preservation of stream corridors. Careful identification of realistic and achievable objectives early in the process is critical for allowing the design team to incorporate them into the design and construction process.

The second task is to analyze the physical and environmental features of the development site to determine if a pond system is feasible, appropriate, and can meet the primary watershed protection objectives. This typically involves a thorough delineation of the wetlands, forests, and catchments within the development, as well as the collection of geotechnical data to define soil properties and water balances. The design team also should assess both the site and downstream aquatic conditions during a site visit.

2. Development of the Initial Concept Plan

The task for the design team in this stage is threefold: 1) select the most appropriate pond design option, 2) identify the most environmentally suitable location for it, and 3) compute the size and geometry of the facility. The design team assembles a concept plan and then submits it to the local stormwater review agency and other regulatory agencies for preliminary review and approval. Early input from the permitting agencies is essential, and a joint field visit is often a useful means of securing it.

3. Development of the Final Design

In final design stage, the team adds engineering details to the concept plan and responds to the comments made by the local permitting authorities. The team works together to ensure that all standard pond design features are incorporated into the final design plans (e.g., benches, forebays, buffers, gate valves). (See Schueler [2] for a full list.) In addition, the plan should be thoroughly analyzed to reduce safety risks, allow for easy maintenance access, provide safe and environmentally sensitive conveyance to the pond, and reduce the future maintenance burden. The final plan is then submitted for review and approval by the appropriate local and state regulatory agencies.

4. Preparation of a Pondscaping Plan

This stage of the design process is critical but frequently overlooked. The design team jointly prepares an aquatic and terrestrial landscaping plan for the pond or wetland, known as a pondscape. It specifies the trees, shrubs, ground cover, and wetland plants that will be established to meet specific functional objectives within different moisture zones in and around the pond.

The pondscaping plan is more than a landscaping materials list, it also specifies necessary soil amendments, planting techniques, maintenance schedules, reinforcement plantings, and wildlife habitat elements needed to establish a dense and diverse pondscape over several growing seasons. Although landscape architects take the lead in the development of the pondscape, other members of the team can provide important contributions. For example, the engineer projects soil moisture zones, the contractor provides practical guidance on tree protection during construction and temporary stabilization, and the environmental consultant provides input on native wetland plants and propagation techniques.

5. Construction of the Pond

Appropriate designs only work when they are constructed properly. Therefore, it is essential to conduct a field meeting with the entire construction crew prior to construction. The design team outlines the purpose of the project, the sequence of construction activities, and walks through the no-disturbance limits. Short but regular meetings to inspect progress are helpful during the construction process, especially to modify decisions in the field. After construction is complete and the pond site is stabilized, the engineer performs an as-built survey for submission to local government authorities that verifies that the pond was constructed in accordance with the approved plans.

6. Establishment of the Pondscape

Establishing a functional pondscape requires frequent adjustment of the original pondscaping plan. Initially, the design team modifies the plan to account for actual moisture conditions and water elevations that exist after construction. The design team then reexamines the pondscape after the first growing season to determine if reinforcement plantings are needed.

7. Inspection and Operation of the Pond

The final stage of the process involves the final inspection of the facility, development of the maintenance practices and schedules, and the transfer of maintenance responsibilities to the responsible party.

Resolving the Regulatory Status of Stormwater Ponds

Although pond and wetland systems are attractive options for urban nonpoint source control, their regulatory status has recently become very confused. This is due to the fact the these systems fall under the scope of three often conflicting sections of the Clean Water Act—Section 401 (water quality certification permits), Section 402 (stormwater National Pollutant Discharge Elimination System [NPDES] permits), and Section 404 (wetland permits). Confusion about these systems also stems from a number of particular factors:

First, pond systems often acquire wetland characteristics over time, whether by design or simply with age. At some point, they may become delineated wetlands, subject to the same protection and restrictions as natural wetlands. If a stormwater pond system does evolve into wetland status, then Section 404 wetland permits may be required and all future maintenance activities conducted on the stormwater pond system would likely require a permit. Conversely, it also is possible that a well-designed stormwater wetland would be eligible for a partial mitigation "credit" when it "evolves" into wetland status.

Second, most pond systems are located on waters of the United States (i.e., intermittent or perennial streams or drainage channels) and are thus subject to the Section 404 permit process, even when the system is not located within a delineated wetland. Some regulators have advocated that the prohibition against "instream treatment" should apply to stormwater pond systems, while others have required that an extensive alternatives analysis be undertaken before a permit is issued. In the former interpretation, the use of stormwater pond systems would be limited to off-line or pocket applications. Under the latter interpretation, the design team might have to demonstrate that all upland best management practice (BMP) alternatives are exhausted before a pond system can be constructed. While upland BMPs are an alternative, they do not possess the performance or longevity of pond and wetland systems and may not be adequate to protect streams or meet pollutant reduction targets.

Third, construction of stormwater ponds and wetlands within or adjacent to delineated natural wetlands can radically alter the characteristics of that wetland, either through excavation, fill, pooling, or inundation. In most cases, construction of stormwater ponds in natural wetland areas is strongly discouraged. In other cases, however, it may actually be desirable to convert degraded natural wetlands into stormwater wetlands. The conditions, if any, where these conversions might take place are the subject of considerable controversy. The influence of stormwater ponds on wetlands need not always be negative, however. In many cases, stormwater ponds can help protect downstream wetlands from degradation caused by uncontrolled stormwater flows and construction-stage sediment deposition.

Fourth, stormwater ponds have a dual nature: They can help to meet water quality standards in receiving waters, while at the same time contributing to possible violations of other standards. For example, ponds can help meet sediment, turbidity, nutrient, and toxics limits. At the same time, they may amplify the stream warming associated with urban development and thus lead to violations of temperature standards in some sensitive streams. This creates a great dilemma for regulators that must perform water quality certification on stormwater ponds.

The resolution of the uncertain and confusing regulatory issues relating to stormwater ponds is critical if application of this effective technology is to continue on a widespread basis. The challenge for designers will be to acknowledge and avoid the potential for negative environmental impact, whereas the challenge for the regulatory community will be to recognize the benefits of stormwater ponds and craft a regulatory policy that is practical rather than merely legal. Otherwise, the fifth member of the pond design team may have to be a lawyer. Hopefully, a workable policy can be developed in the near future that sets guidelines on the appropriate use of this effective nonpoint source control technology.

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Practical Aspects of Stormwater Pond Design in Sensitive Areas

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Abstract

This paper's purpose is to provoke thought in establishing some considerations and techniques for the design of stormwater management ponds in sensitive areas, not to describe a step-by-step process for designing stormwater management ponds. The reader should have a basic understanding of the principles of small pond design, urban hydrology, water quality control, and best management practices.

First, practical design requires an inventory of the sensitive resources that need protection and an estimate of the project goals and potential environmental benefits. The next step is to develop a concept plan, which initiates the design process and ensures agency and public involvement in early stages of the project. Several techniques can be used to avoid or minimize negative impacts on sensitive areas, which this paper groups into techniques for either warm water or cool water environments. In addition, the paper covers three new theoretical techniques that combine warm water design practices with cool water mitigation approaches. Maintenance and monitoring issues are also discussed. Coupling a common sense approach with the need for innovative thinking should be a primary goal, and designers must factor into this challenge the goal of reaching a consensus with different interest groups.

Goals and Expectations

Stormwater management ponds are often installed or constructed to fulfill regulations for the control of urban runoff. Controlling urban runoff usually means providing some kind of detention facility that controls the increased runoff frequency and volume in developing areas.

Good, practical stormwater management requires an assessment of what the pond needs to protect and an estimate of how well pond is likely to work. This involves conducting an inventory of existing natural and constructed features, which then becomes a basis for design considerations. For example, stormwater ponds often need to be located in the lower portion of a site to maximize the area and runoff draining toward them. This can create a conflict with existing, sensitive natural features, such as wetlands, seeps, springs, or even intermittent or perennial streams.

A natural resources inventory, which is essential for design, should at a minimum incorporate the following features:

- Topography
- Wetlands (including springs and seeps)
- Soils
- Floodplains
- Forest lands (vegetation)
- Watercourses
- Specimen trees
- Steep slopes, rock outcroppings, etc.
- Historical or archeological features
- Habitat

After a reasonably detailed natural resources inventory has been conducted, design should continue with an analysis of the receiving stream or ground-water aquifers. This may be very detailed and use various habitat analyses or biological indicators, or it can be a general overview. To pursue a sensitive design approach, however, establishing the type of aquatic resource fisheries (cold water versus warm water) is important.

After establishing the natural resources inventory and assessing what level of aquatic resource protection is warranted, a concept plan should be developed.

Concept Plan Development

One of the most important elements in implementing a successful stormwater management plan is the development of a good concept plan. A concept plan allows various agencies and interest groups the opportunity to offer input at a time when change is reasonably inexpensive. Later in a program, change becomes much more difficult. Many resource protection agencies and special interest groups have conflicting goals, which should be resolved as much as possible in the early stages of the concept plan process so that meaningful projects ultimately become a reality.

One of the key elements of working in an environmentally sensitive area is compromise, but ingenuity is equally important. To advance technology and find different and possibly more successful methods of stormwater management pond design, new techniques should be proposed and implemented, even if unproven.

Techniques for Avoiding or Minimizing Impacts to Sensitive Areas

Warm Water Environments

For warm water fisheries, where thermal impacts are not a major consideration, wet ponds (permanent pools of water) represent the most reliable and maintenance-free option for stormwater runoff quality control (1). Several techniques can enhance the pollutant removal efficiency of wet ponds and simultaneously minimize the impact that a large body of water has on surrounding sensitive areas. Some of these techniques are:

- Location of a pond "off-line" from active flowing streams reduces the impact to existing aquatic environment and does not necessarily inhibit fish migration.
- Diversion structures or "flow splitters" provide a technique for conveying both base flow and storm flow away from sensitive areas (see Figure 1).
- Pond grading techniques that provide storage volumes direct impacts away from sensitive areas.
- Pond grading techniques that give curvilinear geometry to the pond can increase flow lengths and decrease ineffective storage areas.
- Pond grading techniques that use shallow aquatic zones, peninsulas and/or islands, and low-lying areas for riparian vegetation provide varied water regimes.
- Incorporating vegetative practices into the design, such as shallow marsh emergent wetlands, submerged aquatic vegetation, and riparian fringe plantings, can create additional wildlife habitats.

Figure 2 depicts a wet pond concept for a warm water environment.

Cool Water Environments

For cool water fisheries, where thermal impacts are a major consideration, a design must attempt to maximize

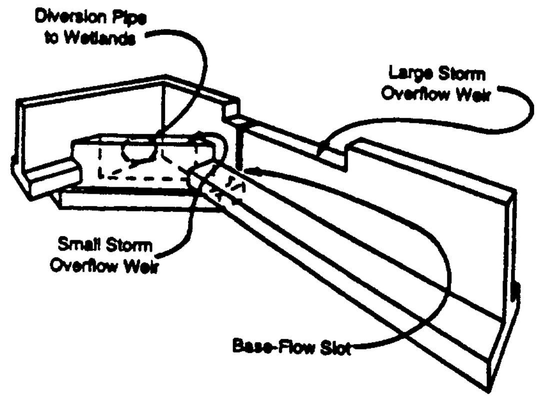

Figure 1. Diversion structure or "flow splitter."

pollutant removal efficiencies but also to reduce and/or offset thermal impacts.

The following are some of the techniques that incorporate these goals:

- The facility should avoid open bodies of water where solar radiation would heat up the water column. Examples in descending order of preference would be infiltration facilities, filtration facilities, dry extended detention ponds, and shallow stormwater wetland ponds (2).
- The location and orientation of the facility should account for the hours of potential solar radiation, such as a north/south dominant orientation.
- Shading of the pool area by maximizing tree canopy can minimize solar penetration.
- Incorporating underdrain and toe drain groundwater collection systems can provide an additional source of cool water release, where available, while implementing an earthen embankment safety consideration.
- Shading and covering a pond's outlet channel helps prevent thermal impacts associated with water running over heated rocks.
- Watershedwide landscaping, including shading of impervious asphalt surfaces, helps reduce thermal loading at the source.

Figure 3 depicts a dry pond concept for a cool water environment.

New Theorized Techniques

New approaches may afford the opportunity to combine the pollutant removal efficiencies of wet ponds with temperature mitigation measures. Three approaches are to:

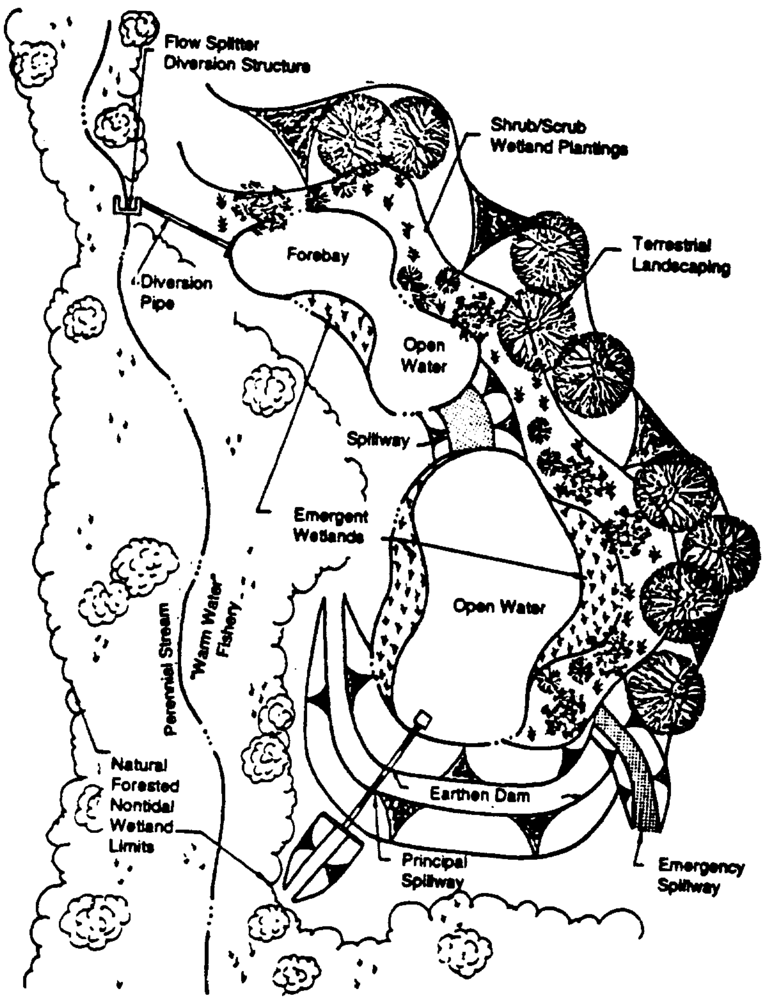

Figure 2. Wet pond concept with diversion structure for warm water environment.

- Incorporate "cooling tower" design practices into the outlet structure of the spillway system (Figure 4) (3).
- Investigate vegetative practices that cover the open water surface of ponds to minimize solar radiation of the water column (4).
- Incorporate a ground-water siphon system into the design of the release structures to siphon ground water as the low flow release (Figure 5) (5).

Maintenance and Monitoring

An effective design cannot become a practical application without a good implementation program, an effective monitoring program, and a maintenance program that keeps a facility functioning at its best. Many of the techniques and considerations previously discussed are new and may not meet expectations. These techniques require short- and long-term monitoring to ensure that they are meeting the expectations of the designer and agency.

In addition, many of the more innovative design approaches require periodic maintenance. It is not practical to assume that these approaches will function without the necessary observations and periodic maintenance. Some of the approaches (e.g., flow splitters) require only periodic trash removal to keep them functioning as designed, while others (e.g., filters and infiltration basins) require a more intensive maintenance program.

Conclusion

In sensitive areas, design approaches need to combine innovative alternatives, common sense, and compromise. Everyone agrees that our sensitive resources

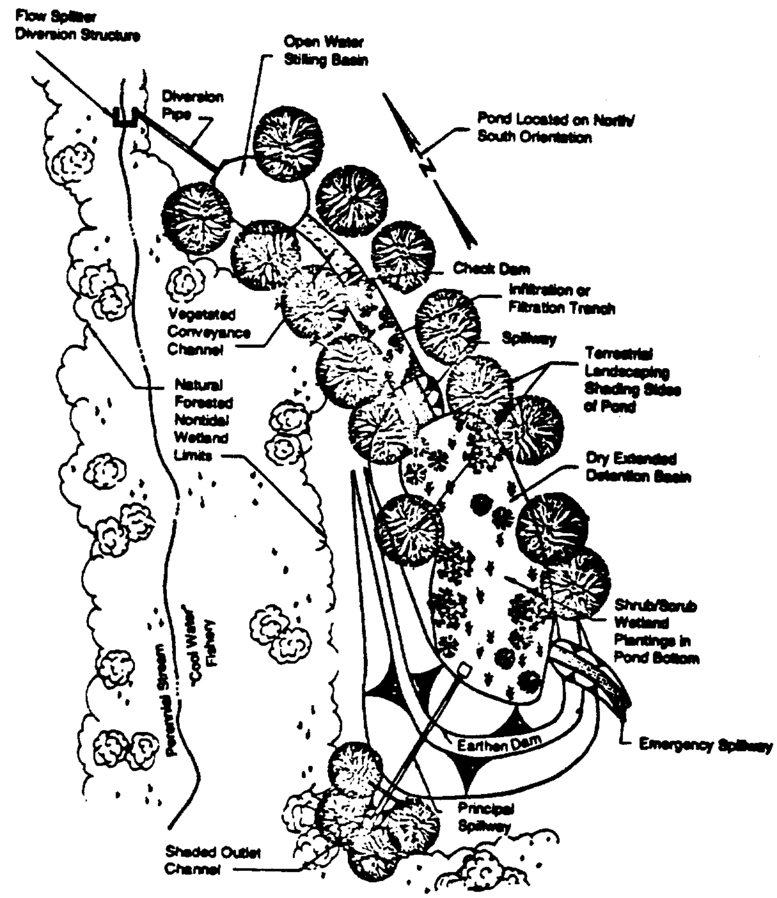

Figure 3. Dry pond concept with diversion structure for cool water environment.

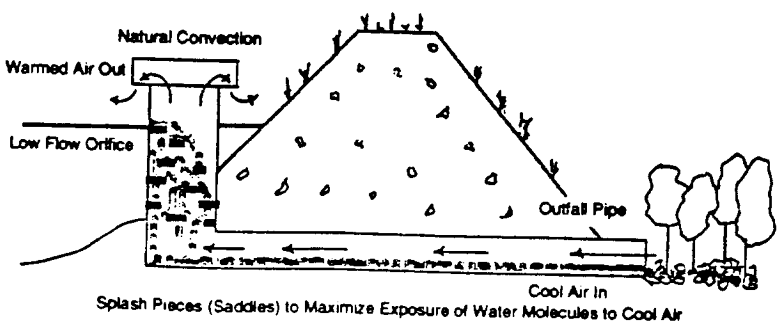

Figure 4. Combination atmospheric and natural draft cooling tower to cool water discharged from a wet pond system (3).

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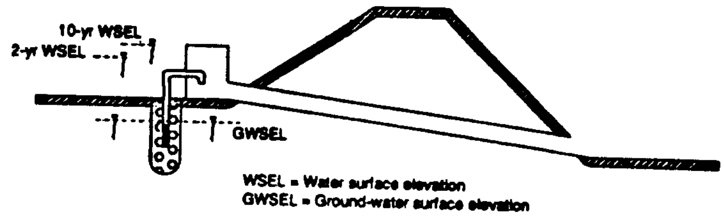

Figure 5. Siphon thermal cooler concept for stormwater management ponds (5).

need special protection and require the utmost care if a disturbance occurs. There is not agreement, however, on the best approaches and on what resources are the most important. Therefore, it is vital to document the existing conditions carefully, prepare flexible concepts and designs, and be prepared to revise plans and design approaches as new information and monitoring results emerge. Practical aspects of stormwater pond design will not remain static but will continue to change as new technologies and techniques advance and older considerations become obsolete.

Acknowledgments

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Infiltration Practices: The Good, the Bad, and the Ugly

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Abstract

Of all the best management practices (BMPs) in the stormwater treatment tool box, infiltration practices are the most effective in removing stormwater pollutants and, equally important, in reducing both stormwater volume and peak discharge rate. This paper explains the concept of on-line and off-line systems, and discusses factors that influence their treatment effectiveness. Design guidelines for infiltration systems, including the importance of the BMP treatment train approach, will be reviewed, focusing on soil types, water table elevation, geology, vegetation, and determination of infiltration rates. Construction considerations will be reviewed. Because of their likelihood for clogging, the importance of regular inspection and maintenance programs is stressed.

Infiltration practices that the paper covers include roadside swales, retention basins, landscape retention, exfiltration systems, infiltration trenches, and porous pavement. For each type of system, information on treatment effectiveness, design criteria, advantages, and disadvantages is presented, along with discussion of the good, the bad, and the ugly. The paper reviews the effect of infiltration practices on ground-water quality and presents recommendations to limit adverse impacts. Special design guidelines for infiltration practices in areas with karst geology, which is characterized by sinkholes, will also be reviewed.

Introduction

To achieve the desired objectives of flood and water quality protection, erosion control, improved aesthetics, and recreation, a stormwater management system must be an integral part of the site planning for every site. Although the basic principles of stormwater management remain the same, each individual site and each specific project presents unique challenges, obstacles, and opportunities. The many variations in climate, soils, geology, ground water, topography, vegetation, and planned land use require site-specific design. Each site contains natural attributes that will influence the type and configuration of the stormwater system.

The variety of features contained on a site suggest which particular combination of best management practices (BMPs) can be successfully integrated into an effective system. Whenever site conditions allow, the stormwater management system should be designed to achieve maximum onsite storage (and even reuse) of stormwater by incorporating infiltration practices throughout the remaining natural and landscaped areas of a site. A stormwater management system should be viewed as a "treatment train" in which the BMPs are the individual cars. Generally, the more BMPs that are incorporated into the system, the better the performance of the treatment train. Inclusion of infiltrative practices as one of the cars should be a primary goal of stormwater system designers.

Infiltration practices are one of the few BMPs that can help to ensure that all four stormwater characteristics (the volume, rate, timing, and pollutant load) after development closely approximate the conditions that occurred before development. This is because infiltration practices help to maintain predevelopment site perviousness and vegetative cover, thereby reducing stormwater volume and discharge rate, which further promotes infiltration and filtering of the runoff.

The benefits of infiltration include:

- Reducing stormwater volume and peak runoff rate.
- Recharging ground water, which helps to replenish wetlands, creeks, rivers, lakes, and estuaries.
- Augmenting base flow in streams, especially during low flow times.
- Aiding in the settling of pollutants.
- Lowering the probability of downstream flooding, stream erosion, and sedimentation.
- Providing water for other beneficial uses.

Another benefit of infiltration practices is their ability to serve multiple uses because they are temporary storage basins. Recreational areas (e.g., ballfields, tennis courts, volleyball courts), greenbelt areas, neighborhood parks, and even parking facilities provide excellent settings for the temporary storage of stormwater. Such areas are not usually in use during periods of precipitation, and the ponding of stormwater for short durations does not seriously impede their primary functions.

Determining Treatment Effectiveness

To design a BMP for water quality enhancement, a pollutant reduction goal must first be established. Stormwater treatment regulatory programs in Florida and Delaware are based on a performance standard of reducing the annual average total suspended solids (pollutant) load by 80 percent for stormwater systems discharging to waters classified as fishable and swimmable. In Florida, stormwater systems discharging to potable supply waters, pristine waters, or highly polluted waters may be required to remove up to 95 percent of the average annual pollutant load. Technology-based performance standards such as these provide water quality goals for nonpoint sources that create equity with the minimum treatment requirements for domestic wastewater point sources (1). Design criteria for various types of stormwater management systems that achieve the desired performance standard (treatment efficiency) are then adopted, thereby providing guidance to the design community and making it relatively easy to obtain a stormwater permit.

The average annual pollutant removal efficiency is calculated by considering the annual mass of pollutants available for discharge and the annual mass removed. The primary removal mechanism for infiltration practices is the volume of stormwater that is infiltrated, because this eliminates the discharge of stormwater and its associated pollutants. As with any type of stormwater management practice, its actual field efficiency depends on many factors. For infiltration practices, these factors include:

- Long-term precipitation characteristics such as mean number of storms per year along with their intensity and volume; average interevent time.
- The occurrence of first flush, which is related to the amount of directly connected impervious area, type of stormwater conveyance system, and the pollutant of interest.
- "On-line" or "off-line" design.

Cumulatively, the above three factors determine the minimum treatment volume and maximum storage recovery time.

The National Weather Service (within the National Oceanic and Atmospheric Administration) has measured weather statistics at many locations around the country. Long-term precipitation records, including information such as day and duration of event, intensity, and volume, are available from either the federal government or private vendors. Statistical analysis of these records can develop probability frequencies for storm characteristics such as the mean storm volume and the mean interevent period between storms.

"First flush" describes the washing action that stormwater has on accumulated pollutants in the watershed. In the early stages of runoff, the land surfaces, especially impervious ones such as streets and parking areas, are flushed clean by the stormwater. This flushing creates a shock loading of pollutants. The occurrence and prevalence of first flush, however, depends largely on precipitation patterns. Studies in Florida have determined that for urban land uses there is a first flush for many pollutants, especially particulates (2, 3). In areas such as Oregon and Washington, however, where rainfall consists of low intensity, long-duration "events," the first flush is not very prevalent. Where it exists, the first-flush effect generally diminishes as the size of the drainage basin increases and the amount of impervious area decreases.

On-line stormwater practices store runoff temporarily before most of the volume is discharged to surface waters. These systems capture all of the runoff from a design storm. This mixes all stormwater within the system, thereby masking first flush and reducing pollutant removal. They primarily provide flood control benefits, with water quality benefits usually secondary, although on-line wet detention systems do provide both benefits.

Off-line practices are designed to divert the more polluted stormwater first flush for water quality treatment, isolating it from the remaining stormwater that is managed for flood control. The diverted first flush is not discharged to surface waters but is stored until it is gradually removed by infiltration, evaporation, and evapotranspiration. Vegetation, such as grass in the bottom and sides of infiltration areas, helps to trap stormwater pollutants and reduce the potential for transfer of these pollutants to ground waters. Off-line retention practices are the most effective for water quality enhancement of stormwater.

Because an off-line retention area primarily provides for stormwater treatment, it must be combined with other BMPs for flood protection to form a comprehensive stormwater management system. Figure 1 is a schematic of an off-line system, commonly referred to as a "dual pond system," in which a smart weir directs the first flush stormwater into the infiltration area until it is filled, with the remaining runoff routed to the detention facility for flood control.

Using the three factors above, design criteria have been developed and implemented in Florida to achieve the

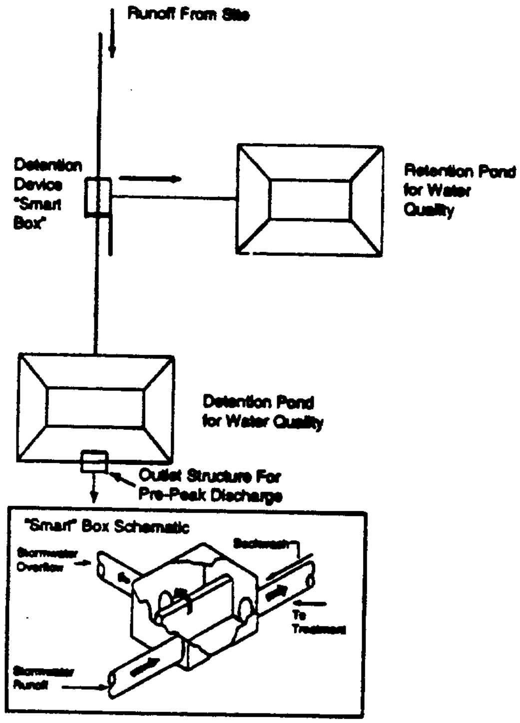

Figure 1. Schematic of an off-line system (4).

desired 80 or 95 percent treatment performance standard (5). The pollutant removal efficiency of an off-line system depends on the annual volume of stormwater that is diverted and infiltrated. For each storm, pollutant removal efficiencies will vary from 100 percent for storms producing less runoff than the diversion design volume to lower efficiencies for much larger storms. If the time between storms is less than the design interevent period, then the design treatment volume will not be available, and more runoff will not be captured and treated. Wanielista (6) developed cumulative frequency distributions for storm-related efficiencies using a simulation model dependent on 20 years of rainfall data and 16 measured storm event runoff quantities and qualities. The results shown in Table 1 are based on Florida rainfall characteristics (90 percent of all annual rainfall events are less than 2.54 cm) and a distinct first flush (up to 90 percent of the pollution load carried in the first 2.54 cm of runoff). An off-line retention system designed to accept at least the first 1.25 cm of runoff (or the volume calculated by 1.25 times the percent imperviousness of the site) will remove more than 80 percent of the average annual pollutant load.

A more recent investigation of the influence of long-term rainfall characteristics on the efficiency of retention practices led to the development of diversion volume curves for interevent dry periods of varying length (7). Figure 2 shows an example diversion volume curve for the Orlando area. It is important to note that first flush is not considered in these curves. If a first-flush effect does exist, the design curves would be conservative in that the percent treatment efficiency of the infiltration system would increase. Furthermore, these curves are based on precipitation interevent frequency (PIF) curves, which also include consideration of the probability that a storm greater than the design storm will occur. The PIF analysis looked at exceedance probabilities for storms with a return period of 2, 3, 4, or 6 months, representing a chance that the storm will exceed the design volume six, four, three, or two times a year.

Table 1. Cumulative Frequency Distributions on Efficiencies per Storm Event as a Function of Storage Volume (Area = 4.6 Ac, 85 percent Impervious, Tc = 20 min)

	Volume of Storage, centimeters (inches)			
Average[a] Efficiency	0.25 (0.1)	0.64 (0.25)	1.27 (0.50)	2.54 (1.0)
100	35.4	66.4	92.9	99.0
>96	42.5	74.3	97.3	100.0
>92	46.0	77.9	97.4	
>88	47.8	81.4	98.2	
>84	50.4	90.3	100.0	
>80	55.6	92.9		
>76	61.1	96.3		
>72	66.4	97.3		
>68	72.6	98.2		
>64	82.3	100.0		

[a] Average efficiency is the average removal of BOD_5, suspended solids, nitrogen, and phosphorus over a 20-year period. Average number of rainfall events producing runoff per year is 116.

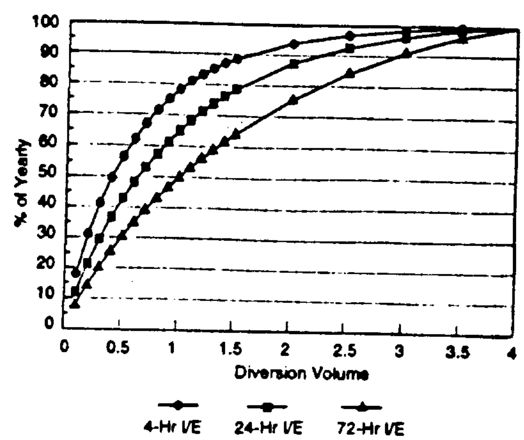

Figure 2. Diversion volume curve for Orlando, Florida.

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Design of Infiltration (Retention) Practices

Infiltration practices also are commonly called retention practices because they retain the runoff on site. They are designed to infiltrate a design volume (treatment volume) of stormwater, and the tool box includes on-line and off-line percolation ponds and trenches, infiltration areas, exfiltration systems, and vegetated swales. Design factors that influence the treatment effectiveness and feasibility of infiltration practices include choice of on-line or off-line system, use of the BMP treatment train concept, and soil type, geology, water table elevation, topography, and vegetation.

Infiltration areas, especially off-line ones, can be incorporated easily into landscaping or open space areas of a site. These can include natural or excavated grassed depressions, recreational areas, and even parking lot landscape islands. If site conditions prevent the exclusive use of infiltration, then off-line retention areas should be used as pretreatment practices in a stormwater treatment train. This is especially true if detention lakes are the primary component of the stormwater system and the lakes are intended to serve as a focal point of the development. Parking lots with their landscape islands offer an excellent opportunity for the use of this concept because even the infiltration of a quarter inch of runoff will greatly reduce sediments, metals, and oils and greases. Placing storm sewer inlets within recessed parking lot landscape areas, raising the inlet a few inches above the bottom, and using curb cuts to allow runoff to enter this area represent a highly effective treatment train.

Siting, Design, and Planning Considerations for Infiltration Practices

The suitability of a site for certain infiltration practices depends on a careful evaluation of the site's natural attributes. Proposed infiltration areas should be evaluated for feasibility on any particular site or project by examining the following.

Soils

Soils must have permeability rates that allow the diverted volume to infiltrate within 72 hours, or within 24 to 36 hours for infiltration areas that are planted with grasses. Soil textures with minimum infiltration rates of 0.43 cm/hr or less are not suitable for infiltration practices (8). These unsuitable soils include soil textures that have at least 30 percent clay content.

Infiltration Rates

One of the most difficult aspects of designing infiltration practices is obtaining reliable information about the actual infiltration rate of the soil where the practice will be constructed. Unfortunately, such information is not easily obtainable. Avellaneda (9) conducted 20 hydrologic studies of vegetated swales constructed on sandy soils with a water table at least 1 ft below the bottom during dry conditions. Infiltration rates were measured using laboratory permeability tests, double-ring infiltrometers, and field mass balance experiments. The field mass balance method measured a minimum infiltration rate of 5 to 7.5 cm/hr. This measured rate was much less than lab permeabilities, rates measured by double-ring infiltrometer tests (12.5 to 51 cm/hr), or rates published in the detailed soil survey. Recommendations for determining the infiltration rate for retention practices include the following:

- Because the infiltration rate is the key to designing any retention practices, conservative estimates should be used and safety factors incorporated into the design to ensure that the design volume will actually be percolated into the soil and not discharged downstream.
- Onsite infiltration measurements must be taken at the locations where retention practices will be located. More importantly, because soil characteristics and infiltration rate change with depth, it is crucial that the measurements be made at the depth of the design elevation of the bottom of the retention practice.
- Infiltration rates should be determined by mass balance field tests if possible. These provide the most realistic estimate of the percolation rate. If field tests are not possible, then infiltrometer tests should be used, with lab permeability tests a third option. In either of these two tests, the design infiltration rate should be half of the lowest measured rate. As a last resort, information from detailed soil surveys can be used to estimated the infiltration rate. The lowest rate should be used, however, as should a safety factor of two.

Water Table

The seasonal high water table should be at least 1 m beneath the bottom of the infiltration area to ensure that stormwater pollutants are removed by the vegetation, soil, and microbes before contacting the ground water. When considering the ground-water elevation, it is important to remember that the retention area can cause a mounding effect on the water table, thereby raising it above the predevelopment level.

Geology

Bedrock should be at least 1 m beneath the bottom of the infiltration area. In those parts of the country where limestone is at or near the land surface, special precautions must be taken when using infiltration practices. The potential for ground-water contamination in such areas is quite high, especially in "karst sensitive areas" (KSAs), where sinkhole formation is common. In KSAs, solution pipe sinkholes may form in the bottom of infiltration areas, creating a direct conduit for stormwater pollutants to enter the ground water. Solution pipes often open in the bottom of retention areas because the natural soil plug capping the solution pipe is thinned by partial excavation to create the retention area and because the stormwater creates hydraulic pressure that can wash out the plug.

In KSAs, a site-specific hydrogeologic investigation should be undertaken that includes geologic borings wherever infiltration areas are proposed and mapping limerock outcroppings and sinkholes on site. Infiltration systems in KSAs should:

- Include several small offsite areas.
- Use swale conveyances for pretreatment.
- Be as shallow as possible.
- Be vegetated with a permanent cover such as sodded grasses.
- Have flat bottoms to keep the stormwater spread out across the entire area.

Topography

Infiltration practices should not be located on areas with slopes over 20 percent to minimize the chance of downstream water seepage from the subgrade. Sloping sites often require extensive cut and fill operations. Infiltration practices should not be sited on fill material because fill areas are very susceptible to slope failure, especially when the interface of the fill/natural soil becomes saturated.

Vegetation

To reduce the potential for stormwater pollutants to enter ground waters and to help maintain the soil's capacity to absorb water, infiltration practices should be vegetated with appropriate native vegetation, especially grasses. This type of vegetation cannot tolerate long-term inundation, however, so the retention area must be capable of infiltrating all of its runoff within a relatively short period (i.e., 24 to 36 hours).

Set Backs

Infiltration areas should be located at least 33 m from any water supply well and at least 3.5 m downgradient from any building foundations. Additionally, they should be set back at least 15 m from onsite wastewater systems, especially drain fields.

Land-Use Restrictions

Certain infiltration practices can only be applied to particular land uses. Some sites are so small or intensively developed that space is insufficient for practices that require a large area (e.g., retention basin). Other practices (e.g., porous pavement) can only be used on sites with parking lots and limited truck traffic.

Sediment Input

Infiltration practices must be protected from large loads of sediment to prevent clogging and subsequent failure. Although sediment loads drop sharply after construction is complete, gradual clogging of infiltration practices can still occur. Pretreatment practices such as swale conveyances or vegetated buffer strips can help to filter out sediments and extend the life of retention practices.

Construction Considerations

To prevent clogging of infiltration areas, special precautions must be taken during the entire construction phase of a project. These are needed to prevent sedimentation during construction, compaction of the soil, and subsequent reduction in its infiltration capacity. Areas with suitable characteristics that are selected for infiltration use should be well marked during site surveying and protected during construction. Heavy equipment, vehicles, and sediment laden runoff should be kept out of infiltration areas to prevent compaction and loss of infiltration capacity.

- Before the development site is graded, the area planned for use as infiltration areas should be well marked during site surveying. Then, the area should be roped off to prevent heavy equipment from compacting the underlying soils.
- Diversion berms should be placed around the perimeter of the infiltration area during all phases of construction. Sediment and erosion control plans for the site should be oriented to keep sediment and runoff completely away from the area. Actual construction of the infiltration practice should not begin until after the site has been stabilized completely.
- Infiltration areas should never be used as a temporary sediment basin during the construction phase. It is somewhat common for infiltration areas, especially basins, to be used as a sediment trap, with initial excavation to within 2 ft of the final design elevation of the basin floor. Sediment that accumulates during the construction phase can then be removed when the basin undergoes final excavation after the development has been completed. Recent experience, however, indicates that even with this type of construction practice infiltration areas used as sediment traps tend to fail.
- Infiltration areas/basins should be excavated using light earth-moving equipment with tracks or oversized tires. Normal rubber tires should be avoided because they compact the subsoil and reduce its infiltration capabilities. For the same reason, the use of bulldozers or front-end loaders should be avoided. Because some

compaction of the underlying soils is still likely to occur during excavation, the floor of the basin should be deeply tilled with a rotary tiller or disc harrow.

- The basin should be stabilized with vegetation within a week after construction. Use of low maintenance, rapid-germinating grasses such as fescues are recommended. The condition of the newly established vegetation should be checked several times over the first 2 months and any necessary remedial actions taken (e.g., reseeding, fertilization, and irrigation).

Maintenance

All infiltration practices require regular and nonroutine maintenance to maintain their ability to infiltrate stormwater. The frequency and need for maintenance depends primarily on the loading of particulates and the use of pretreatment practices. Inspections should be conducted on a regular basis after storm events, and maintenance activities should be conducted whenever stormwater remains in the practice beyond the designed time. Specific maintenance needs are discussed for each of the different types of infiltration practices in the next section.

Discussion of Various Infiltration Practices

Infiltration Basins

An infiltration basin is made by constructing an embankment or by excavating in or down to relatively permeable soils. The basin temporarily stores stormwater until it infiltrates through the bottom and sides of the system. The infiltration "basin" can actually be a landscape depression within open spaces, even parking lot islands or a recreational area such as a soccer field. Infiltration areas generally serve drainage areas ranging from 2 to 20 hectares. Infiltration basins should be designed as off-line systems but they can be on-line, especially if predevelopment stormwater volume is being maintained.

Advantages of infiltration basins are that they preserve the natural water balance of a site, can serve larger developments, and can be integrated into a site's landscaping and open spaces. Disadvantages of infiltration basins can include their land area; fairly high rate of failure due to unsuitable soils, poor construction, or lack of maintenance; the need for frequent maintenance; and possible nuisances such as odors, mosquitos, or soggy ground (all signs of a failing system).

The function of infiltration basins can be improved if the following design tips are followed:

- *Basin floor and sides:* The rate and quantity of infiltration are enhanced by increasing the surface area of the bottom. Large, relatively shallow areas are preferable, especially in KSAs, so that the stormwater spreads evenly over the entire surface area. Therefore, it is very important that the bottom be evenly graded with a zero slope. If the bottom is uneven, these low spots will remain underwater for a longer time and may become chronically wet as the floor clogs and infiltration is reduced. Side slopes should be no steeper than 3:1 to allow for vegetative stabilization, easier mowing and access, and better public safety.
- *Vegetation:* The side slopes and bottoms of infiltration areas should be vegetated with a dense turf of water-tolerant grass immediately after construction. Not only does the vegetation stabilize these areas, but it also helps to filter stormwater pollutants, remove dissolved nutrients and metals, enhance aesthetic qualities, reduce maintenance needs, and even maintain or improve infiltration rates.
- *Reducing incoming water velocities:* Inlets to an infiltration area should be stabilized to prevent inflowing runoff velocities from reaching erosive levels and scouring the bottom. Riprapping inlet channels or pipe outfalls and using bubble-up inflow devices or perimeter swale and berms can address this problem. Because the stormwater should spread evenly over the entire infiltration area, riprap inlets should terminate in a broad apron that serves as a crude level spreader.
- *Construction requirements:* Proper construction and routine maintenance as discussed above are essential for successful infiltration basin implementation. In a recent survey, approximately 40 percent of the infiltration basins had partially or totally clogged within their first few years of operation (10). Many of the systems failed almost immediately after construction or never worked properly from the beginning.
- *Routine maintenance requirements:* Infiltration areas should be inspected following major storms, especially in the first few months after construction. If stormwater remains in the system beyond the design drawdown time (typically 24 to 36 hours if grassed, 48 to 72 hours if not grassed), either the infiltration capacity was overestimated or maintenance is needed. Factors responsible for clogging may include upland erosion and sedimentation, low spots, excessive compaction, or poor soils. Cleaning frequently depends on whether the basin is vegetated or nonvegetated and is a function of storage capacity, sediment and debris load, and land use. Litter, leaves, brush, and other debris should be removed regularly, perhaps during the mowing of vegetation. The buffer, side slopes and bottom of the retention area should be mowed as needed with the grass clippings removed. Eroded or barren areas should be immediately revegetated. Nonvegetated basins can be tilled annually after accumulated sediments are removed. Sediments should be removed only after the basin is thoroughly dry, preferably to the point where the top

layer begins to crack. To reduce soil compaction, only light equipment should be used.

- *Nonroutine maintenance requirements:* Over time, the original infiltration capacity of the bottom will gradually decline. Deep tilling every 5 to 10 years can be used to break up clogged surface layers, followed by regrading, leveling, and revegetation. If the original infiltration rate was overestimated, underdrains may be installed beneath the bottom, or perhaps the system should be converted to a shallow marsh or wet detention system.

Infiltration Trenches

An infiltration trench generally consists of a long, narrow excavation, ranging from 1 to 3 m in depth, that is backfilled with stone aggregate, allowing for the temporary storage of the first-flush stormwater in the voids between the aggregate material. Stored runoff then infiltrates into the surrounding soil. To minimize clogging potential and maximize treatment effectiveness, infiltration trenches should always be designed as off-line systems. Infiltration trenches usually are designed to serve drainage areas of 2 to 4 hectares and are especially appropriate in urban areas where land costs are prohibitive. As with any infiltration practice, the treatment train concept must be employed to capture sediment before it enters the trench to minimize and reduce clogging.

Advantages of infiltration trenches include ground-water recharge, reduced stormwater volume, and the ability to fit into perimeters or other underused areas of a development, even beneath parking areas. Disadvantages include potential clogging, especially if sediment is not kept out during construction, the need for careful design and construction, and maintenance.

Infiltration trenches can be located on the surface or below the ground. Surface trenches receive sheet flow runoff directly from adjacent areas after it has been filtered by a grass buffer. Underground trenches can accept runoff from storm sewers but require use of special pretreatment inlets to prevent coarse sediment, soils, leaves, and greases from clogging the stone reservoir.

Surface trenches typically are used in residential areas where smaller loads of sediment and oil can be trapped by grass filter strips that are at least 6 m wide. While surface trenches may be more susceptible to sediment accumulations, their accessibility makes them easier to maintain. Surface trenches can be used in highway medians, parking lots, and narrow landscape areas.

Underground trenches can be applied in many development situations and are particularly suited to accept concentrated runoff; however, pretreatment is essential. Inlets to underground trenches should include trash racks, catch basins, and baffles to reduce sediment, leaves, debris, and oil and grease. Maintenance of underground trenches can be very difficult and expensive, especially if placed beneath parking areas or pavement.

The most commonly used underground trench is an exfiltration system, in which the stormwater treatment volume is diverted into an oversized perforated pipe placed within an aggregate envelope. The first-flush stormwater is stored in the pipe and exfiltrates out of the holes, through the gravel and filter fabric, and into the surrounding soil. The city of Orlando, Florida, has installed exfiltration systems using perforated corrugated metal pipe and slotted concrete pipe throughout the downtown area to reduce stormwater pollution of its lakes.

Dry wells are used extensively in Maryland to store and infiltrate runoff from rooftops. The downspout from the roof gutter is extended into an underground trench, which is constructed at least 3 m away from the building foundation. Rooftop gutter screens are used to trap particles, leaves, and other debris. Additional design information on dry wells is available from the Maryland Department of the Environment (11).

The following design and construction guidelines are provided for infiltration trenches.

Infiltration Rates

The actual rate at which water leaves the infiltration trench is determined by several factors. Whether infiltration primarily occurs through the trench bottom or sides depends on the elevation of the water table and soil properties. To prevent ground-water contamination, trench bottoms should be at least 4 ft above the seasonal high water table (remember to consider ground-water mounding). This will also ensure infiltration through the bottom. In addition to the infiltration rate of the parent soil, the permeability of the surrounding filter fabric (if used) is crucial and can become a limiting factor. A recent investigation of exfiltration systems (12) provides the following:

- Permeability of the parent soil is not the limiting exfiltration rate.
- The limiting exfiltration rate is set by the geotextile filter fabric, not the soil.
- A maximum rate of 1.27 cm/hr should be used, assuming infiltration through the sides and bottom.
- A maximum rate of 2.54 cm/hr should be used if the geotextile filter fabric is matched correctly to the soil type and only the trench side areas are assumed to exfiltrate.

Construction of Infiltration Trenches

Successful use of infiltration trenches requires thorough site planning and evaluation and proper construction. In addition to the construction recommendations for all

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infiltration practices discussed above, the construction of infiltration trenches should also include the following:

- Excellent erosion and sediment control should be maintained during construction to keep sediments away from the trench. Allowing even an inch or two of soil to get into the trench between the aggregate and the fabric will almost ensure clogging. If constructed before the drainage area is entirely stabilized, then the trench should be covered with heavy plastic to prevent any inflow until stabilization is completed.
- The trench should be excavated using a backhoe or trencher equipped with tracks or oversized tires. Normal rubber tires should be avoided because they compact the subsoil and may reduce infiltration capability. For the same reason, the use of bulldozers or front-end loaders should be avoided. Excavated material should be stored at least 3 m from the trench to avoid backsliding and cave-ins.
- Once the trench is excavated, the bottom and sides should be lined with a geotextile filter fabric to prevent upward piping of underlying soils. The fabric should be placed flush with the sides and bottom, with a generous overlap at the seams. Care should be taken in selecting the proper kind of filter fabric, as available brands differ significantly in their permeability and strength. The geotextile fabric must be handled carefully to prevent holes and tears that allow soil to get into the trench. As an alternative, a 15-cm deep filter of clean, washed sand may be substituted for filter fabric on the bottom of the trench.
- Clean, washed 2.5- to 7.5-cm stone aggregate should be placed in the excavated reservoir in lifts and lightly compacted with plate compactors to form the coarse base. Unwashed stone has enough associated sediment to pose a risk of clogging at the soil/filter cloth interface. Where possible, the use of limestone or bluestone aggregate should be avoided.
- A simple observation well should be installed in every trench. Wells can be made of secure foot plate, perforated polyvinyl chloride pipe, and locking cover. The observation well is needed to monitor the performance of the trench and is also useful in marking its location. The drain time for a trench can be measured by placing a graduated dipstick down the well immediately after a storm and again 24, 48, and 72 hours later.
- Postconstruction sediment control is critical. It is therefore important that 1) sediment and erosion controls be inspected to make sure they still work, 2) vegetated buffer strips are established immediately, preferably by sodding, and 3) if hydroseeding is used, reinforced silt fences are placed between the buffer and trench to prevent sediment entry before the buffer becomes fully established.

Maintenance of Infiltration Trenches

If properly constructed with pretreatment practices to prevent heavy sediment loading, infiltration trenches can provide stormwater benefits without tremendous maintenance needs. Because trenches are "out of sight, out of mind," getting property owners to maintain them can be difficult. Accordingly, a public commitment for regular inspection of privately owned trenches is essential, as is a legally binding maintenance agreement and education of owners about the function and maintenance needs of trenches.

Trenches should be inspected frequently within the first few months of operation and regularly thereafter. Inspections should be done after large storms to check for water ponding, with water levels in the observation well recorded over several days to check drawdown. Grass buffer strips should maintain a dense, vigorous growth of grass and receive regular mowing (with bagging of grass clippings) as needed. Pretreatment devices should be checked periodically and sediment removed when the sediment reduces available capacity by more than 10 percent.

Swales

Swales, or grassed waterways, are one of the oldest stormwater BMPs, having been used along streets and highways and by the farmer for many years. By definition, a swale is a shallow trench that:

- Has side slopes flatter than 3 ft horizontal to 1 ft vertical.
- Contains contiguous areas of standing or flowing water only following a rainfall.
- Is planted with or has stabilized vegetation suitable for soil stabilization, stormwater treatment, and nutrient uptake.
- Is designed to take into account the soil erodability, soil percolation, slope, slope length, and drainage areas so as to prevent erosion and reduce stormwater pollutants.

Traditionally, swales have been and are used primarily for stormwater conveyance; as such, they are considered an on-line practice. The removal of stormwater pollutants by swales can occur by either infiltration or vegetative filtration and uptake. Investigations in Florida (13, 14) have concluded that swale treatment efficiency largely depends on the volume of stormwater that can be infiltrated through the filtering vegetation and into the soil. To achieve Florida's performance standards, swales must be designed to infiltrate the runoff from a 3-yr/1-hr storm (about 7.5 cm) within 72 hours. Investigations in Washington state (15, 16), however, indicate that swales can also act as a biofilter, with removal of particulate pollutants without infiltration of stormwater.

Avellaneda (9) developed the following equation for a triangular shaped swale to estimate the length of swale necessary to infiltrate the design runoff volume:

$$L = \frac{K Q^{5/8} S^{3/16}}{n^{3/8} i} \qquad (1\text{–}1)$$

where:

L = swale length (m)
n = Mannings roughness coefficient
Q = average runoff flow rate (m^3/sec)
i = infiltration rate (cm/hr)
S = longitudinal slope (m/m)
K = constant that is a function of side slope (see Table 2)

For most residential, commercial, and highway projects, the length of swales necessary to percolate the stormwater needed to achieve the 80 percent performance standard was found to be excessive or at least twice the distance available. Thus, some type of swale block (berm) or on-line detention/retention may be more helpful. Swales make excellent pretreatment practices by providing for the infiltration of some stormwater and for some vegetative filtration. By using a raised stormsewer inlet, swales can provide water quality enhancement via retention and still serve as effective conveyances for flood protection. Swales can incorporate retention by using swale blocks, small check dams, or elevated driveway culverts to create storage, thereby reducing runoff velocity, reducing erosion, and promoting infiltration.

Using the runoff from 7.5 cm of rainfall as a design treatment volume, equations have been developed for swale block designs to store and infiltrate the runoff (17).

Table 2. Constant (K) for Design Equation for Triangular Shape

Z (Side Slope) (1 Vertical / Z Horizontal)	K (U.S. Units)	K (SI Units)
1	10,516	75,552
2	9,600	68,971
3	8,446	60,680
4	7,514	53,984
5	6,784	48,740
6	6,203	44,565
7	5,730	41,167
8	5,337	38,344
9	5,006	35,966
10	4,722	33,925

The swale block volume can be calculated for a fixed length of swale using:

Volume of runoff – volume infiltrated = swale block volume

$$Q(\Delta t) - Q_i(\Delta t) = \text{swale block volume}$$

$$Q(\Delta t) - \left[\frac{L\, n^{3/8}\, i}{K\, S^{3/16}}\right]^{8/5} (\Delta t) = \text{swale block volume} \qquad (1\text{–}2)$$

where

Q_i = average infiltration rate (m^3/sec)
Δt = runoff hydrograph time (sec)

Wanielista and Yousef (18) present the following example problem using Equations 1 and 2 for designing a swale with cross blocks to satisfy a specific water quality goal:

Given

n = 0.05
i = 7.5 cm/hr
S = 0.0279
z = 7
Q_i = 0.0023m^3/sec for Δt = 100 min

what swale length would be necessary to percolate all the runoff?

Using Equation 1,

$$L = \frac{41{,}167\,(0.0023)^{5/8}\,(0.0279)^{3/16}}{(0.05)^{3/8}\,7.5} = 193 \text{ meters.}$$

If only 76 m is available, how much storage volume is necessary?

Using Equation 2,

$$(0.0023)(60)(100) - \left[\frac{(76)(0.05)^{3/8}(7.5)}{41{,}167(0.0279)^{3/16}}\right]^{8/5} 60(100) = \text{volume,}$$

and the volume of storage is equal to 10.7 m^3.

In highway designs for high-speed situations, safety must be considered; thus, a maximum depth of water equal to 0.5 m (about 1.5 ft) and flow line slopes on the berms of 1 vertical/20 horizontal are recommended. Along lower speed highways or in some residential/commercial urban settings, steeper flow line berm slopes (1/6) are acceptable.

The studies of swales in Washington state resulted in the following recommendations to improve water quality benefits (15):

- Maximum design velocity should not exceed 27 cm/sec.
- A hydraulic residence time of at least 9 min is recommended for removal of about 80 percent of the total suspended solids. Longer residence times will provide higher removal effectiveness.
- Swale width should be limited to 2 to 2.5 m unless special measures are provided to ensure a level swale bottom, uniform flow spreading, and management of flows to prevent formation of low-flow channels.
- Swale slopes should be between 2 and 4 percent.
- Water depth should be limited to no greater than one half the height of the grass, up to a maximum of 7.5 cm.
- Swale length will be a function of the hydraulic residence time, swale width, and stormwater volume and velocity.

Porous Pavement

Local land development codes typically specify the type of material for a parking lot (i.e., paved, grass, gravel) and determine the number and size of parking spaces within a parking lot. These requirements should be reviewed carefully to ensure that they are necessary (Is paving really required in every case?) and that the number of spaces is related to actual traffic demands. After these requirements have been reviewed and verified, the use of porous pavement within a parking lot should be examined. Porous pavement materials include porous asphalt, porous concrete, turf blocks, and even Geoweb covered with sod.

Overall, experiences with porous pavements have not been very good. Porous pavements have been prone to clogging. Causes include poor erosion and sediment control during construction, unstabilized drainage areas after construction, improper mixing and finishing of the pavement, and poor maintenance. Field investigations of porous concrete that has been in use for up to 15 years in Florida, however, indicate that these parking lots can continue to infiltrate rainfall and runoff if they were installed and maintained properly (19). Recommendations to improve the utility of porous pavements include the following:

- Be sure that the installer is properly trained in the design, mixing, installation, and finishing of the porous pavement material. Both porous asphalt and concrete must be mixed and installed much differently than regular asphalt or concrete.
- Exemplary erosion and sediment control during construction and complete site stabilization after construction are essential to prevent clogging of the void spaces within the porous pavement.
- The porous pavement must receive regular, routine vacuuming to remove accumulating solids. At times, nonroutine maintenance may involve cleaning with high-pressure water.
- The entrance to any porous pavement area should have a large sign warning those about to enter that porous pavement is in use. Precautions should include prohibiting vehicles with large amounts of soil on their tires.

Problems Associated With Infiltration Practices

There have been several concerns regarding the use of infiltration practices, including their propensity to fail, their potential effects on ground-water quality, and their need for maintenance.

Infiltration systems seem to have a very high rate of failure. The author believes, however, that this high failure rate is a reflection of improperly estimated infiltration rates and improper erosion and sediment control during the construction process. A 1990 field survey of stormwater infiltration facilities constructed in Maryland replicated a 1986 field survey, thereby providing data on the performance of infiltration practices after they have been in operation for several years (20). Table 3 summarizes the information from this project.

From Table 3 it can be seen that the overall condition and functioning of infiltration systems declined over time. In 1986, about two-thirds of all facilities were functioning as designed, while in 1990 only about half were. Only 42 percent of the facilities were functioning as designed in both 1986 and 1990, while about 27 percent were not functioning as designed in both years. About 24 percent of the systems were functioning in 1986 but not in 1990, while only 7 percent of those not working in 1986 were working in 1990. Maintenance was needed at more facilities in 1990 (66 percent) than in 1986 (45 percent). Additionally, many facilities (38 percent) that needed maintenance in 1986 still needed maintenance in 1990, while 32 percent of the facilities that did not need maintenance in 1986 did need it in 1990. Only 10 percent of the systems that needed maintenance in 1986 did not need maintenance in 1990. These data indicate that little effort is expended on maintaining the operational capabilities of stormwater management systems.

A second concern about infiltration practices is whether they simply are transferring the stormwater pollution problem from surface waters to ground waters. Harper (14) has shown that stormwater pollutants, especially heavy metals, quickly bind to soil particles, while vegetation is effective in filtering pollutants, thereby minimizing the risk of ground-water contamination. Ground water beneath swales and retention areas located in

Table 3. Comparison of the Operation of Maryland Infiltration Practices

Type of BMP	1986 Number of Sites	1986 Number of Sites Working	1990 Number of Sites	1990 Number of Sites Working
Basins	63	30 (48%)	48	18 (38%)
Trenches	94	75 (80%)	88	47 (53%)
Dry wells	30	23 (77%)	25	18 (72%)
Porous pavement	14	7 (50%)	13	2 (15%)
Swales	6	3 (50%)	3	2 (67%)
Totals	207	138 (67%)	177	87 (49%)

highly sandy soils with low organic content and sparse vegetative cover, however, did show elevated levels of heavy metals down to depths of 20 ft (21).

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Stormwater Reuse: An Alternative Method of Infiltration

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Abstract

Runoff water stored in a wet detention pond can be an asset if it is used to recharge surficial aquifer levels. The recharge can occur directly from the pond by infiltrating the detained water, or the detained water can be irrigated over the watershed. Reuse in the watershed or infiltration at the pond lessens the quantity of water discharged, thus reducing the pollutant mass discharged to surface waters. A benefit of irrigation is a reduction in the use of potable water otherwise used for irrigation.

A mass balance on pond storage volume using rainfall data for select areas in the southeastern United States was completed to determine the percentage of stormwater runoff that can potentially be irrigated or infiltrated for each area as a function of contributing area, runoff coefficient, volume of temporary storage, and irrigation rate. Design curves were developed that relate the efficiency (E), or the percentage of runoff that is irrigated on a yearly basis, to the volume of temporary storage (V) in a reuse pond and the rate of irrigation (R). The design curves, called REV curves, permit the selection of a temporary storage volume and irrigation rate for a given efficiency, runoff coefficient, and geographic area. This paper contains example REV curves and presents simplified uses of the results.

Introduction

The pollutants associated with stormwater and the volume of stormwater discharges can result in significant impacts to the natural and manufactured environments of any watershed. As watersheds are made more impervious due to paving and other construction activities, the volume of runoff and pollutant mass discharged to surface waters increases relative to predeveloped conditions.

Potential impacts from uncontrolled runoff are loss of freshwater from an area where the rainfall occurred, additional freshwater discharges to estuaries, increased pollutant mass loadings, decreased river base flows, reduced wetland areas, and an economic loss associated with the need to replace discharged freshwater with potable or other waters.

Water policy in the state of Florida requires a performance standard for all stormwater management methods. A stormwater pollutant annual average load reduction of 80 percent for discharges to most waters and of 95 percent for those discharging into outstanding Florida waters (1) are required. Of the currently used stormwater management methods, off-line retention and chemical treatment can achieve the stated pollutant removal efficiencies. Wet detention ponds that discharge to adjacent surface waters, however, do not. If some of the detained water can be used within the watershed and not discharged to surface waters, the wet detention ponds may also meet the standards.

A Stormwater Reuse Pond

A stormwater reuse pond is proposed to retain runoff water within a watershed and to reduce the mass of pollutants in the discharges to surface water bodies. The difference between a wet detention pond and a reuse pond is the operation of the temporary storage volume. A wet detention pond is designed to discharge the runoff water and possibly some ground water to adjacent surface waters, while a reuse pond is designed to reuse a specific fraction of the runoff volume and not discharge that fraction. In this paper, mathematical relationships are developed between the reuse volume (temporary storage volume), the rate at which stormwater is reused, and the percentage of annual surface runoff that is reused.

The traditional design of pond temporary storage volume for a wet detention pond has been based on the consideration of water quality and uses a design storm. The design storm, however, usually ignores the preceding rainfall record and assumes that there is an antecedent dry period long enough to ensure that the pond is at some control elevation. The usual assumption is a zero temporary storage.

To address the sensitivity of the temporary storage volume to interevent dry periods, long-term rainfall records were used from 25 Florida and seven other southern states' rainfall stations in a model that simulates the behavior of a reuse pond over time. A spreadsheet was used to build a 15-year mass balance for a pond. After each rainfall event, surface runoff and reuse volumes were respectively added to and subtracted from the previous pond storage volume. If the temporary storage volume exceeded the available storage volume, discharge occurred. If the temporary storage volume was less than zero (the permanent pool volume was used for reuse water), supplemental water was used to replenish the pond and maintain the permanent pool. Both the rate of reuse from the pond and the reuse volume were varied. The reuse efficiency, defined as one minus the total volume of surface discharge divided by the total volume of runoff times 100, was calculated for each combination.

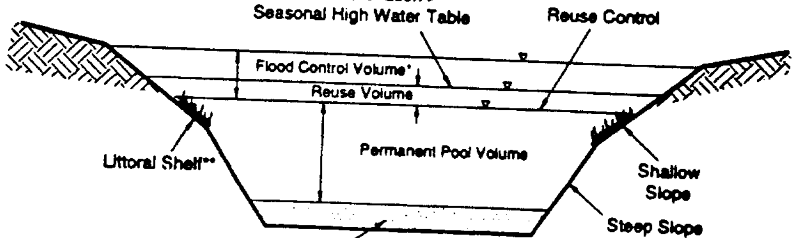
Simulation of a Reuse Pond

To establish a relationship between the efficiency, the reuse rate, and the reuse volume of a pond, a continuous time model was used to simulate the dynamics of a reuse pond. Continuous models are reported to be most representative (2). The efficiency of the pond, or the percentage of runoff that is reused, was calculated for different reuse volumes and reuse rates. Charts for different regions were produced using the local rainfall records of these regions. The term "model" is used to refer to the basic unchanged equation of the mass balance in which different rainfall records were inserted and reuse volumes and reuse rates were varied. "Simulation" is used to refer to the complete calculations of the model in which volume and rate were defined. There is only one model, while many simulations were done.

Figure 1 depicts a cross section of a typical reuse pond. The sediment storage volume lies at the bottom to receive settled matter. Above this is the permanent pool volume, which provides a minimum residence time for stormwater. The reuse volume (temporary storage volume) is the volume above the permanent pool and below the flood control structure. The flood control volume would typically be above the reuse volume.

The reuse pond differs from a typical detention pond in that instead of the temporary storage volume being depleted by a surface water discharge device (such as a bleed-down orifice in an outlet pipe), it is drawn down by a reuse system and is thus called the reuse volume. A reuse pond may deplete the pond volume below the permanent pool boundary requiring a supplemental volume to maintain this volume. A discharge structure is still necessary for flood control. Common practice should be used for the design of sediment storage, permanent pool, and flood control volumes, and their elevations and side slopes. This paper provides methodology and design criteria for the reuse volume only.

The water level of a typical reuse pond fluctuates during a year. During and following a rainfall event, there is runoff into the pond, and the water level rises to some depth above the permanent pool. If this new water level exceeds the level of the surface discharge control, discharge will occur at some rate until the water level drops back to the elevation of the control structure. The reuse pond volume is incremented daily, removing an amount of water for reuse. If the reuse volume is expended, supplemental water, such as ground water, may be used to maintain the permanent pool voluma. This could occur as seepage through the sides of the pond or by mechanical pumping. This scenario was simulated by creating a mass balance for pond operation.



* Can be measured above permanent pool; however, some regulatory agencies measure above the reuse volume.
** The reader should consult local water management districts and other regulatory agencies to determine specific geometric and littoral zone design requirements.

Figure 1. Schematic of a stormwater reuse pond.

The Model

The model is based on the continuity equation

$$\text{INPUTS} - \text{OUTPUTS} = \Delta S. \qquad \text{(Eq. 1)}$$

If all potential water movements are considered, a complete hydrologic balance may be expressed in volume units as

$$R_E + G + P \pm F - R - D - ET = \Delta S, \qquad \text{(Eq. 2)}$$

where

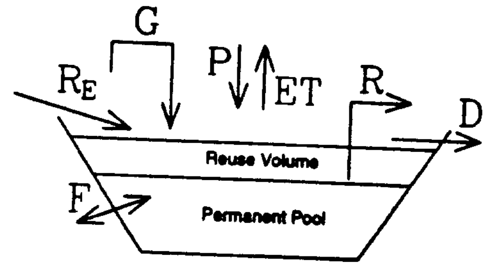
R_E = rainfall excess or runoff volume
G = supplemental water (ground water)
P = precipitation directly on the pond
F = water movement through the sides of the pond
R = reuse (infiltration)
D = discharge
ET = evapotranspiration
S = storage in pond

In Florida, the average evapotranspiration rate for a pond is generally equal to the average precipitation on the pond in a 1-year period (approximately 50 in.). Additionally, evaporation data are only available in mean monthly rates compared with the daily time step of the model, making the estimate of evaporation potentially inaccurate. These parameters were dropped from the mass balance. Also, because of its complexity, the flow of ground water through the sides of the pond was assumed to equal zero, and Equation 2 was further simplified to

$$R_E + G - R - D = \Delta S. \qquad \text{(Eq. 3)}$$

For Florida modeling purposes, there were two inputs, runoff and supplement, and two outputs, reuse and discharge (Figure 2). Runoff was established from known precipitation and watershed data. The reuse rate was a controlled variable. Both supplemental water and discharge were functions of the water level of the pond, or the storage volume. Because ground-water movement was assumed to equal zero, supplemental water is considered as that which is pumped into the pond mechanically. Supplement occurs at a rate necessary to maintain the permanent pool; the maximum required rate would equal that of reuse. Because potential storage capacity is being constantly eliminated by supplement, this may be considered as being conservative. With the previous simplifications, the actual pond may be simulated by the model.

The calculations for each simulation were done using Quattro Pro, an electronic spreadsheet. The top and bottom calculations and input data for one simulation can be seen in Figure 3. The columns of the upper portion of the simulation are the incremental registers of



$$R_E + G + \cancel{P} \pm \cancel{F} - R - D - \cancel{ET} = \Delta S$$
$$R_E + G - R - D = \Delta S$$

Figure 2. Summary of mass balance of reuse pond, simplified for Florida conditions.

the various parameters, which are labeled along the top. Each of these variables is defined as follows:

EVENT	A distinct rainfall occurrence; for computational purposes, each day of a multiday rainstorm is considered a separate event.
DATE	The date on which an event occurs.
DRY	The dry period separating rainfall events (days); if events occur on consecutive days there are no dry days. This value is not used in the basic model but is needed for the sensitivity analysis of the discharge potential.
RAIN	The amount of rainfall recorded during each event (inches). This information was taken directly from National Oceanic and Atmospheric Administration (NOAA) rainfall data.
RUNOFF	The amount of runoff that enters the pond during an event (inches).
REUSE	The amount of water reused during the day of an event and the dry days following the previous event (inches); the rate of reuse remains constant during a single simulation.
DISCHARGE Potential:	The potential amount of discharge for an event (inches): the amount that could, if necessary, physically discharge during the time since the previous event. This was established as 2 in./day over the equivalent impervious area (EIA).

ORLANDO RAINFALL STATION (May 1974 - Dec. 1988) Volume = 3 in, Rate = 0.2 in/day

EVENT	DATE	DRY Days	RAIN In.	RUNOFF In.	REUSE In.	DISCHARGE Poten.	DISCHARGE Actual	SUPLMNT In.	NET In.
0	04-May-74								0
1	05-May-74	0	0.12	0.12	0.2	2	0	0.08	0.00
2	06-May-74	0	0.77	0.77	0.2	2	0	0.00	0.57
3	07-May-74	0	0.04	0.04	0.2	2	0	-0.00	0.41
4	08-May-74	3	0.33	0.33	0.2	2	0	0.00	0.54
5	12-May-74	1	0.15	0.15	0.8	8	0	0.11	0.00
6	14-May-74	0	0.11	0.11	0.4	4	0	0.29	0.00
7	15-May-74	0	0.46	0.46	0.2	2	0	0.00	0.26
8	16-May-74	0	0.07	0.07	0.2	2	0	0.00	0.13
9	17-May-74	5	0.23	0.23	0.2	2	0	0.00	0.16
10	23-May-74	3	0.35	0.35	1.2	12	0	0.69	0.00
11	27-May-74	4	0.06	0.06	0.8	8	0	0.74	0.00
12	01-Jun-74	0	1.19	1.19	1	10	0	0.00	0.19
13	02-Jun-74	0	0.07	0.07	0.2	2	0	0.00	0.06
14	03-Jun-74	6	0.05	0.05	0.2	2	0	0.09	0.00
15	10-Jun-74	0	2.19	2.19	1.4	14	0	0.00	0.79
16	11-Jun-74	2	0.18	0.18	0.2	2	0	0.00	0.77
17	14-Jun-74	0	0.05	0.05	0.6	6	0	-0.00	0.22
18	15-Jun-74	1	0.54	0.54	0.2	2	0	0.00	0.56
19	17-Jun-74	6	0.09	0.09	0.4	4	0	0.00	0.25
20	24-Jun-74	0	0.95	0.95	1.4	14	0	0.20	0.00
21	25-Jun-74	0	1.07	1.07	0.2	2	0	0.00	0.87
22	26-Jun-74	0	3.47	3.47	0.2	2	0	0.00	4.14
23	27-Jun-74	0	1.89	1.89	0.2	2	1.14	-0.00	4.69
24	28-Jun-74	1	3.36	3.36	0.2	2	1.69	0.00	6.16
25	30-Jun-74	0	0.17	0.17	0.4	4	3.16	0.00	2.77
26	01-Jul-74	0	0.12	0.12	0.2	2	0	-0.00	2.69
27	02-Jul-74	0	0.88	0.88	0.2	2	0	0.00	3.37
1386	23-Dec-88	4	0.04	0.04	1.4	14	0	1.36	0.00
1387	28-Dec-88		0.05	0.05	1	10	0	0.95	0.00
Summation:			706.88	706.88	1070.40		75.72	439.24	

% Discharged = Total Discharge/Total Runoff = 10.71%
% Reused = 1 - Total Discharge/Total Runoff = 89.29%

Inputs:
Runoff: 706.88 in.
Supplement: 439.24 in.

1146.12 in.

Outputs:
Reuse: 1070.40 in.
Discharge: 75.72 in.

1146.12 in.

Inputs 1146.12 in.
- Outputs -1146.12 in.

Storage 0.00 in.

Figure 3. Example of computer model using rainfall data from Orlando, Florida.

Actual:	The amount that does discharge during an event (inches); depends on the water level of the pond but is restricted to the potential discharge.
SUPLMNT	The amount of water needed between events to maintain the permanent pool volume (inches).
NET	The amount of water above the permanent pool recorded at the end of each event (inches).

Every day in which a rainfall event takes place represents one line in the simulation. This is the fundamental time step of the model. All inputs and outputs occur during this 24-hour period. At the end of the period, the net storage value of the pond is calculated. From this value, decisions are made concerning discharge and supplement. The process then repeats itself.

The 15-year totals for rain, runoff, reuse, actual discharge, and supplement are calculated as shown in Figure 3. From these values, the efficiency, or the percentage of runoff reused, can be determined for a particular simulation. The efficiency is equal to one minus the volume of water that is discharged divided by the volume of runoff times 100. The percent discharged, the volume of water discharged divided by the volume of runoff, is also calculated. The percent reused plus the percent discharged equals 100.

At the bottom of Figure 3 is a summary of the mass balance for the entire record. Both the inputs and outputs are listed and totaled. The difference between the inputs and outputs, labeled "Storage," is compared with the final value for NET. The values should be identical. This is used primarily to check the calculations.

This single model was used to predict the behavior of a reuse pond subjected to the rainfall record of 32 different locations in the southeastern United States. Previously, one location in Florida was reported (4). To simulate a pond in a particular region, the rainfall record of that region was inserted into the DATE and RAIN columns of the model. The model was then lengthened or shortened to match the span of the rainfall record. Otherwise, no changes were made to the model. By using one model and varying only the rainfall record, the consistency of the simulations was assured.

Length of Rainfall Record

An investigative question that arises when examining the random behavior of rainfall is how large a record must be to accurately represent the meteorological characteristics of a region. In other words, how many years of rainfall data must be used to estimate the ultimate dynamics of the pond? Obviously, the greatest accuracy can be obtained by using the most data. But the incremental benefit of each additional unit of data diminishes so that there is a point beyond which using more is no longer reasonable. This is the limit for investigation.

Twenty-four individual simulations were run for the Moore Haven and Tallahassee stations using, first, 1 year of rainfall data (1988) and then incrementally adding the next previous year to the rainfall record. The yearly efficiencies for several combinations of reuse volumes and reuse rates were recorded. As expected with only a few years of data, the average yearly efficiencies fluctuated widely but then leveled out as more years of data were added. As the size of the database increased, each additional year had less impact. Beyond 15 years, there was very little change in the average annual estimate.

Volume Units

Runoff, discharge, reuse, supplement, and net storage are volumes of water that are expressed in units of inches. Volumes are commonly expressed as inches over a defined area and, likewise, the parameters of this model are based on a variable unit area that the user defines. Rates are merely volumes delivered over a period and thus can be expressed in the same manner. This unit area is the EIA of the watershed or the product of the runoff coefficient and the contributing watershed area. The volumetric unit of inches on the EIA is a way in which the results are generalized for any runoff coefficient and contributing area. Once the EIA is known, the values can be converted to more practical units using simple conversions.

Model Output

The basic function of the model is to determine a relationship between the reuse rate, the reuse volume, and the efficiency. This was done by varying the reuse rate and the reuse volume, then calculating the efficiency. Thus, a simulation was done for each combination of reuse rate and reuse volume. The reuse volumes considered varied between 0.25 and 7.0 in. on the EIA. The reuse rates varied between 0.04 and 0.30 in./day on an area equivalent to the EIA. The respective efficiencies are shown as fractions. The results are presented in chart form as shown in Figure 4. The ultimate functional product of the reuse pond model is the rate-efficiency-volume (REV) chart. Wanielista et al. (5) presents the REV charts for all of the 25 locations in Florida for which accurate and long-term rainfall data were available. Individual REV charts are specific to geographical regions with similar meteorological characteristics.

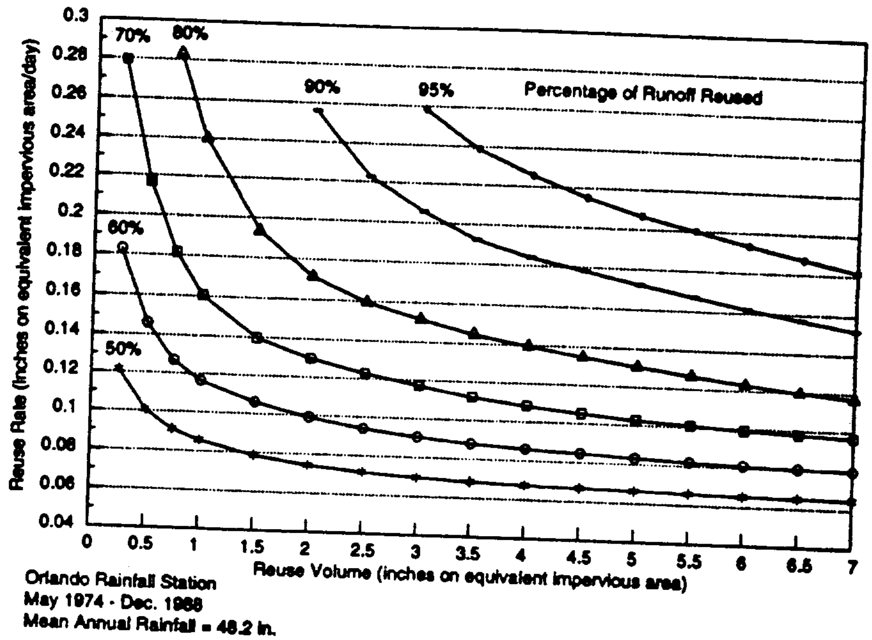


Figure 4. REV chart for Orlando, Florida.

Use of the REV Charts

REV charts relate the reuse rate, the efficiency, and the reuse volume of a pond. Recommended irrigation rates for Florida are between 0.38 in./week in the winter to 2.25 in./week in the summer (6). Information concerning any two of these three variables is necessary for the determination of the third. The use of a REV chart requires an understanding of the concept of the EIA. The units of both the reuse rate and the reuse volume are based on this area. A REV chart is specific for an area, and the accuracy of the predictions are related to the accuracy of the input data. The REV charts of this paper have been placed in a computer program that reduces the possibility of calculation errors (7).

The efficiency is defined as the average percentage of runoff that is reused over a period, specifically 15 years. A pond that discharges to surface waters 10 percent of the runoff that flows into it must reuse the remaining and so is 90 percent efficient. It may sometimes be desirable to determine the efficiency of an existing pond. More often it will be necessary to achieve a required efficiency established by local regulations, thus making the efficiency one of the known values. On every REV chart, there is a curve for each of the following efficiency levels (in percentage): 50, 60, 70, 80, 90, and 95.

Examples of Direct Use

Example 1

A watershed in Orlando must reuse 80 percent of the annual runoff from a 10-acre impervious area. The pond area is included in the impervious area. The maximum reuse storage volume available for the pond is equal to the runoff from a 3-in. rainfall event. At what rate must the runoff be reused?

Because the entire watershed is impervious, the EIA is equal to 10 acres. Because runoff equals rainfall on impervious areas, the storage volume is equal to 3 in. on the EIA. The reuse rate is a function of the efficiency and the reuse volume:

R = f (E,V)
= f (80%, 3 in.)
= 0.152 in./day

By referring to the Orlando REV chart (Figure 4), the necessary reuse rate is estimated at 0.152 in./day on the EIA. The rate and volume can be expressed in other units:

$$V = 3 \text{ in.} \times \text{EIA} \times \frac{10 \text{ ac}}{\text{EIA}}$$

$$= 30 \text{ ac-in.} \times \frac{43{,}560 \text{ ft}^2}{\text{ac}} \times \frac{\text{ft}}{12 \text{ in.}}$$

$$= 109{,}000 \text{ ft}^3$$

and

$$R = 0.152 \frac{\text{in.}}{\text{day}} \times \text{EIA} \times \frac{10 \text{ ac}}{\text{EIA}}$$

$$= 1.52 \frac{\text{ac-in.}}{\text{day}} \times \frac{43{,}560 \text{ ft}^2}{\text{ac}} \times \frac{\text{ft}}{12 \text{ in.}}$$

$$= 5{,}520 \frac{\text{ft}^3}{\text{day.}}$$

Example 2

An apartment complex located in Tallahassee needs to reuse 90 percent of the runoff from its parking lots. The EIA is equal to the directly connected impervious area and is 4 acres. The complex wants to use 0.26 in. of water per day over the EIA. What must the reuse volume be to maintain these conditions?

From the REV chart for Tallahassee (Figure 5), the required reuse volume is determined to be 3.5 in. on the EIA:

$$V = f(E,R)$$
$$= f(90\%, 0.26 \text{ in./day})$$
$$= 3.5 \text{ in.}$$

Again, the volume and rate can be expressed in other units:

$$V = 3.5 \text{ in.} \times \text{EIA} \times \frac{4 \text{ ac}}{\text{EIA}}$$

$$= 14 \text{ ac-in.} \times \frac{43{,}560 \text{ ft}^2}{\text{ac}} \times \frac{\text{ft}}{12 \text{ in.}}$$

$$= 50{,}800 \text{ ft}^3$$

and

$$R = 0.260 \frac{\text{in.}}{\text{day}} \times \text{EIA} \times \frac{4 \text{ ac}}{\text{EIA}}$$

$$= 1.04 \frac{\text{ac-in.}}{\text{day}} \times \frac{43{,}560 \text{ ft}^2}{\text{ac}} \times \frac{\text{ft}}{12 \text{ in.}}$$

$$= 3{,}780 \frac{\text{ft}^3}{\text{day.}}$$

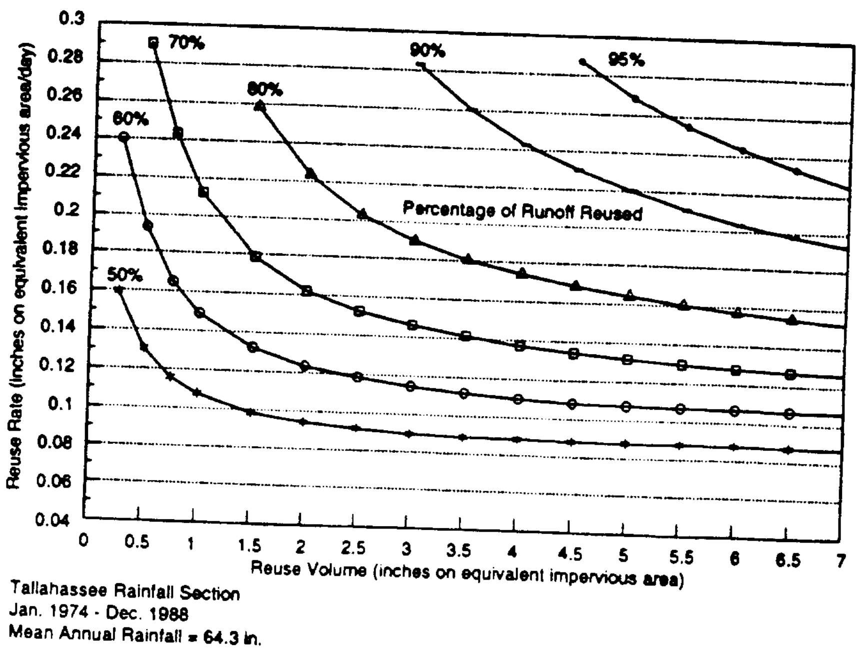


Figure 5. REV chart for Tallahassee, Florida.

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The previous examples illustrate the most simple application: the watershed being impervious and the volume and rate given in terms of the EIA. Much more complex design problems, however, can be solved using the same technique. The following steps can be used in any design situation:

1. Select the appropriate chart.
2. Compute the EIA of the watershed (EIA = contributing area x effective C).
3. Determine known variables in terms of the EIA.
4. Reference the chart to obtain a solution.
5. Convert the answer to desired units.

Evaporation and Rainfall on Pond

One of the initial simplifications of the pond mass balance was the assumption that the mean annual evaporation from the pond is equal to the mean annual rainfall on the pond. The evaporation totals in the Southeast may range from 30 to over 60 in./yr. Precipitation rates range from 37 in./yr in Key West to 64.5 in./yr in Tallahassee.

While evaporation and direct rainfall rates are based on the size of the pond, all other model parameters were based on the EIA. Therefore, a ratio was established between the size of the pond and the EIA. Because detention ponds usually require no more than 5 percent of the total area of the watershed, depending on the impervious area, a conservative estimate of pond area to a completely impervious area was chosen as 1:10. As an example, a 1-in. rainfall event, through direct precipitation, would add 1 in. of rainfall to the pond or 0.10 in. over the EIA.

Evaporation data were obtained from NOAA Climatological Data publications for the years 1985 through 1989. Because the locations of climatological stations match those of precipitation stations in only a few instances, evaporation data from nearby stations were used with selected model locations. Evaporation data from Lisbon and Lake Alfred were introduced into the models of Orlando and Parrish, respectively. The evaporation data were available in monthly pan evaporation totals. Fifteen years of records were used and converted to surface water evaporation rates by multiplying by a pan coefficient. The mean annual total evaporation for the two locations is 56.46 in. for Lake Alfred and 41.07 in. for Lisbon.

The evaporation function was added to the models by distributing evaporation depths in inches for each time interval. The amount of evaporation for each interval is the product of the number of days in that interval and mean daily evaporation rates for the month. To ensure the assumed distribution did not affect the total evaporation volume, the mean annual evaporation volumes for the 15-year simulations were compared with the mean volumes obtained from NOAA. The totals were almost identical.

To use the REV charts, rainfall on the pond must be included in the calculation of the EIA. When the area of the pond (approximated at 15 percent of the EIA) was added to the EIA, the pond reuse volume increased, and for a fixed reuse rate the average annual efficiency increased by at least 2.5 percent. Because rainfall on the pond reflects an impervious condition (all rainfall yields rainfall excess), it must be added to the EIA while maintaining consistent units (depth on an impervious area).

Recommendations

A mathematical mass balance model can be developed to simulate the operation of a stormwater reuse pond. This can be done for areas that have daily rainfall data available for a significant period, about 15 years.

The reuse of stormwater within a watershed from which it came should be encouraged and in some areas required. Reuse ponds can be designed to conserve water within a watershed and to reduce the mass of pollutants entering the surface waters.

The effective impervious area for a watershed should include the area of the pond when using the REV curves. The effective impervious area calculation is necessary for the use of the REV curves. More than one REV curve for a location is expressed in a figure called a REV chart.

For an average annual pollutant mass removal of 80 percent in a wet detention pond, at least 50 percent of the runoff volume should be reused when the REV charts are used for design. For a 95 percent annual pollutant mass removal, at least 90 percent of the runoff volume should be reused. The reuse percentages assume a wet detention pond will remove an average 60 percent of the incoming runoff pollution mass annually before surface discharge, which may overestimate the actual efficiency.

The reuse of stormwater is both an environmentally and economically sound management practice. The current common practice is to release stormwater to adjacent surface waters from detention ponds using weirs and orifices. Frequently, if not all the time, this detained volume of water is greater than the volume of water released from the land in its natural condition. Some fraction of this detained water can be reused within the watershed to 1) irrigate open areas, 2) recharge ground water, 3) supplement water used for certain industrial purposes, 4) enhance and create wetlands, and 5) supply water for agricultural users.

Currently, the most popular reuse method has been the irrigation of relatively open spaces, for example, golf courses, cemeteries, recreation areas, citrus groves, and common areas of apartment complexes. The primary reason for these reuse systems is economics. Many irrigation systems use treated ground water. An alternative to the use of ground water is detained stormwater. Treated ground water cost about $1.00/thousand gallons. A golf course of 100 acres using treated ground water at a cost of $1.00/thousand gallons and irrigating at 2 in./wk would pay almost $300,000/yr for the irrigation. Using detained stormwater, the irrigation system yearly cost could be less than $40,000.

In this paper, continuous modeling for reuse ponds was completed and was based on a mass balance using area-specific rainfall data to develop design criteria for stormwater reuse ponds. The design procedure relates pond temporary storage (reuse volume) to reuse rate and a percent reuse of the runoff water and is expressed as a REV curve. Also, mathematical equations for the curves have been computer coded.

The REV curves can be used for various watershed sizes or runoff coefficients. They may be used to determine the reuse rate, the reuse volume, or the efficiency of a pond. Supplemental water needs in a hydrologic balance also can be estimated. The REV charts presented in this paper could facilitate the rational planning of stormwater reuse systems.

Acknowledgments

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Use of Sand Filters as an Urban Stormwater Management Practice

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Background

As our recognition of the need for stormwater control, from both quantity and quality perspectives, has increased, efforts to develop strategies and practices to address stormwater runoff have emerged all over the country. Many of these efforts have been developed on a state or local level depending on the specific issues that motivated program development.

The concerns over stormwater control and strategies for dealing with stormwater are now international in scope. Society as a whole needs to learn about what individuals have already accomplished to allow for evolution of control strategies and individual practices. Efforts under way at the state level (in Delaware, Florida, Maryland, South Carolina, and Washington) and at the municipal level (in Austin, Texas; Washington, DC; and Alexandria, Virginia) provide some hands-on knowledge regarding the programs and types of stormwater control practices that have been used successfully.

The intent of this paper is to discuss stormwater control practices, in particular, filtration systems. Experience with stormwater control ponds and infiltration systems has led to considerable knowledge about these methods, but interest is increasing in the use of sand filters in several locations around the country for stormwater treatment. Use of these systems will expand as national efforts addressing stormwater control are implemented.

Existing Efforts in the Use of Sand Filter Systems

The first interesting point is the way that sand filter systems have been used historically around the country. These systems are being used for onsite and regional control, as well as for water quality control only and for both water quality and water quantity control.

Austin, Texas

The city of Austin has pioneered the use of sand filters for stormwater treatment. Other areas have experimented over the years with sand filters, but Austin has made a long-term commitment to their use and evolution. The design standards for sand filters have evolved based on performance and maintenance considerations.

Sand filters are used on site and on a regional basis (usually less that 50 acres of drainage), and the filters are sized to accept and treat the first half-inch of stormwater runoff from the contributing drainage area (1). They are frequently used in conjunction with a stormwater detention basin, which provides for control of larger storms from a water quantity perspective. Good water quality data for the performance of these systems have resulted, which indicates that sand filters can be very effective at pollutant removal.

Washington, DC

Sand filter use is based on a design standard developed by the Stormwater Management Branch of the Department of Consumer and Regulatory Affairs. The sand filter system design is based on whether water quantity is a concern in addition to water quality on a specific site. Washington, DC, has a combined sewer system, and sites that discharge into a combined sewer system must design their sand filters to provide for peak control of the 15-year storm. If only water quality is an issue, a design procedure is established based on the degree of site imperviousness. For water quality control alone, storage requirements are between 0.3 and 0.5 in. of runoff per acre (2). The Stormwater Management Branch is initiating a monitoring program to determine the performance of the sand filters.

State of Delaware

Delaware has developed a sand filter design system based on the Austin design but that serves for water quality control only. It is intended for sites where stormwater runoff, only from impervious areas, may drain to the sand filter. The sand filter is designed to accept and treat the first inch of stormwater runoff and is used as either a "stand alone" practice or in conjunction with another practice, such as an infiltration practice (3). Where infiltration practices are used, the sand filter provides pretreatment of the runoff to reduce premature clogging of the infiltration practice. At this time, design performance is not being monitored, but achieving an 80-percent reduction in suspended solids is considered an acceptable practice as required under the statewide stormwater management law.

Alexandria, Virginia

The city of Alexandria has developed a design manual that supplements the northern Virginia BMP handbook (4). The Alexandria supplement details the design requirements of "no net increase" in pollutant loading for new development and a 10-percent reduction in pollutant loading at site redevelopment locations. To achieve these goals, phosphorus was accepted as a "keystone" pollutant for design purposes. The Alexandria supplement provides information on a number of different sand filter design procedures and is probably the single best compilation of information relating to design procedures developed in areas such as Austin, Delaware, and Washington.

Other Areas and Efforts

The only other procedure that is more experimental (although, in reality, they all still are) is the peat-sand filter developed by the Washington Council of Governments. This procedure is a variation of the traditional sand filter design that uses peat as a medium for enhanced nutrient reduction. The State of Washington has recently completed a stormwater design manual that presents a sand filter design based on the Austin system.

Discussion

Sand filters represent an emerging technology with significant potential for evolution in coming years. The procedure developed for the State of Delaware was intended for use on small sites where overall site imperviousness was maximized. Examples of these sites would be fast food restaurants, gas stations, or industrial sites, where space for retrofitting is not readily available. Another emphasized use for sand filters is as a pretreatment system for stormwater infiltration practices. Infiltration practices are very susceptible to clogging by particulates, and sand filters could provide an effective means to reduce particulate loading and to block oil and grease from entry into infiltration systems.

Sand filters are especially appropriate for highway systems where site conditions and right-of-ways limit the types of feasible stormwater treatment practices. Sand filter systems generally have lower maintenance needs than infiltration practices have, so their use appeals to highway officials if the costs can be made reasonable.

If the sand filter is moved to the edge of the parking lot or roadway, where structural strength is not as important, the system can be installed at significantly lower cost. The City of Alexandria has developed a variation of the Delaware approach where the sand filter is behind curb openings. In addition, increasing the head over the filter can increase the time between required maintenance of the filter, thus lowering the system's operation and maintenance costs. Consideration should be given to placing stone over the sand to prevent scour of the sand as water drops on the filter, in addition to increasing the overall depth of the sand to improve performance.

The design procedure developed for use in Delaware is meant as guidance and can be modified or enhanced as needed depending on specific site conditions. The practice as presented may be used in the middle of a parking lot, where concrete and grate strength are established, so that automobiles or trucks could travel over the system. Consultants have taken that design standard literally, which has made construction costs extremely high.

Any one of these systems could be modified or improved with proper engineering. Conversations have started with different manufacturers to see if sand filter units could be prefabricated which would reduce the overall cost of installation. The use of sand filters will dramatically increase if construction costs are reduced.

Conclusion

Sand filters have a strong potential for becoming an effective tool for stormwater treatment, but engineering expertise is necessary to improve performance and cost. With proper maintenance and in conjunction with other practices, sand filters can assist in water quality protection. They also have potential in arid regions, where more conventional practices such as wet ponds are not feasible.

We live in an era where our desires and mandates for clean water exceed our abilities to actually protect our aquatic resources when structural controls are considered as the only method of stormwater control. The term "treatment train" is certainly a concept that must be expanded if resource protection is to be realized. Sand filters are one car of the "treatment train," but the overall train must include many different considerations. Ultimately, land use must be a consideration in overall site stormwater planning, and considerations of roadway widths, curbing, and site compaction and utilization must be flexible depending on individual site needs. Why does a residential street have to be wide enough for a fire engine to turn around in? We need to question basic planning assumptions with respect to resource protection, and to evaluate whether a specific design requirement is necessary in light of that requirement's impact on our natural resources. Otherwise, we need to recognize and accept the fact that a decline in quality and productivity of our resources will occur.

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Application of the Washington, DC, Sand Filter for Urban Runoff Control

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Abstract

Conventional infiltration systems are frequently used for water quality control of urban runoff. These types of urban best management practices (BMPs), however, may adversely affect ground-water quality through the migration of pollutants into ground-water aquifers. Additionally, these BMPs may not be feasible in high-density urban areas because of the large land areas required for their installation.

To address these problems, this paper presents an alternative solution: to replace conventional infiltration BMPs with the confined, underground sand filter water quality (SFWQ) control structure. Over 70 of these structures have been installed in Washington, DC, since 1988.

The Washington, DC, underground sand filter is a gravity flow system consisting of a concrete structure with three chambers. It is designed to provide quality control for the first ½ in. of runoff. The first chamber performs pretreatment of stormwater runoff by removing floating organic material such as oil, grease, and tree leaves. The second chamber is the filter chamber (process chamber) and optimally contains a 3-ft filter layer. The filter layer consists of gravel, clean sand, and geotextile filter fabric. At the bottom of the filter is a subsurface drainage system of polyvinyl chloride perforated pipes in a gravel bed. The third chamber is a discharge chamber that collects flow from the underdrain pipes.

The SFWQ structure may vary in size and shape. The depth can range from 8 to 10 ft depending on the final grading of the site.

Introduction

Urbanization resulting in surface- and ground-water contamination is a serious and constant threat to water quality. In turn, poor water quality is an undesirable economic burden on taxpayers. Because of the extremely high cost involved in restoring contaminated surface and ground water, prevention seems to be the only economical course of action to protect natural water systems.

To regulate and provide protection for surface- and ground-water systems, the federal government passed the Clean Water Act. As part of this effort, the District of Columbia enacted stormwater management regulations (DC Law 5-188, section 509-519) in January 1988. These regulations require new developments and redevelopments to control nonpoint source pollution transported from construction sites by urban runoff, using best management practices (BMPs) or best available technologies (BATs).

Infiltration devices are the most frequently used BMPs for controlling stormwater runoff in urban areas. These conventional BMPs have limitations, however, due to soil and site-specific constraints. These BMPs may also adversely affect ground water through the migration of pollutants into ground-water aquifers. Additionally, conventional infiltration systems may not be feasible in an urban environment because of the large land areas required for their installation. In an effort to mitigate these problems, an alternative design is outlined in this paper to replace the conventional infiltration BMPs, where applicable. This alternative system is called the confined sand filter water quality (SFWQ) structure and is illustrated in Figure 1. The system uses multiple filter layers combined with a moderate detention time to filter the suspended pollutant particles and hydrocarbons from urban runoff. A multiple-layer filter was chosen because it has proven to be more effective than a single-layer filter design.

Background

Infiltration practices have been widely used to improve the quality of urban stormwater runoff. Several limitations, however, are associated with the use of conventional

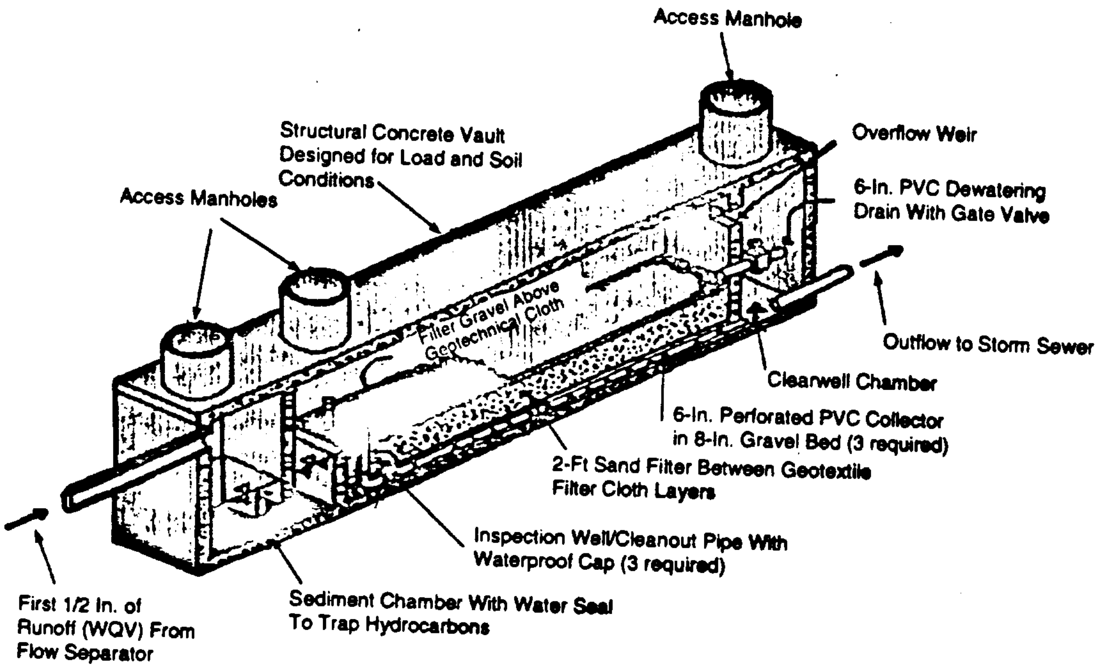

Figure 1. DC three-dimensional sandfilter centerline cutaway (source: District of Columbia).

infiltration systems. According to several studies (1-3), the practice of infiltration may have a negative impact on ground-water quality. In addition, infiltration practices are only recommended for sites with soil infiltration rates higher than 0.27 in./hr and with a clay content of less than 30 percent. Recently, a study by the Metropolitan Washington Council of Government (MWCOG) shows that over 50 percent of the infiltration trenches installed in the Metropolitan Washington region either partially or totally failed within the first 5 years of construction (4). Research has also found that clogging may occur in infiltration trenches and is also very common in other infiltration systems. In surface systems, clogging is most likely to occur near the top of the structure, between the upper layer of stone and the protective layer of filter fabric. For underground infiltration systems, clogging is likely to occur at the bottom of the structure, at the filter fabric, and at the soil interface.

Restoration of both surface and underground infiltration systems is tedious and very costly, requiring the removal of the vegetation layer, top soil, protective plastic layer, stone aggregate, and filter fabrics. If the surface layer is pavement or concrete, the rehabilitation effort becomes even more difficult and expensive. Conventional infiltration systems also require relatively large areas of land for their installation; therefore, this family of BMPs is not feasible due to the high cost of land in an urban environment.

Design Rationale

Whenever a liquid containing solids in suspension is placed in a relatively quiescent state, solids having a higher specific gravity than the liquid settle, while those having a lower specific gravity rise. The design of the SFWQ structure uses the one-dimensional "falling head test" in Darcy's Law for calculating the head loss of fluid flow through a multiple-layer filter medium to treat stormwater runoff. The design uses various media layers with different permeabilities to intercept pollutant particles as fluid flows vertically through the filter layers. This principle can be used to accelerate the removal of pollutants by increasing the residence times of stormwater runoff, and to facilitate the filtering process in the filter chamber. The SFWQ structure also utilizes Stoke's Law for terminal falling velocities of individual particles in allowing time for particles to settle out of stormwater runoff. The average detention time of this system ranges from 6 to 8 hr for an optimal design consideration.

Functional and Physical Description

The SFWQ structure is a gravity flow system consisting of three chambers. The facility may be precast or cast-in-place. The first chamber (same as water quality inlet) is a pretreatment facility removing any floating organic material such as oil, grease, and tree leaves. The chamber has a submerged weir leading to the second chamber (filter chamber) and may be designed with a flow splitter or with a bypass weir if the system is for off-line storage, as illustrated in Figure 2.

The second chamber contains 3 ft of filter material consisting of gravel, geotextile fabric, and sand, and is situated behind a 3-ft weir. At the bottom is a subsurface drainage system consisting of a parallel polyvinyl chloride (PVC) pipe system in a gravel bed. A dewatering valve is at the top of the filter layer for maintenance purposes and for safety release in case of emergency. It also has an overflow weir at the top to protect the system from backing up when the storage volume is exceeded, if the system is designed for on-line storage (Figure 3).

Water enters the first chamber of the system by gravity or by pumping. This chamber removes most of the heavy solid particles, floatable trash, leaves, and hydrocarbon material. A submerged weir (designed to minimize the energy of incoming stormwater) conveys the effluent to the second chamber. The effluent enters the filter layer by overflowing the weir typically 3 ft above the bottom of the structure. The water is filtered through various filtering layers to remove suspended pollutant particles. The filtered stormwater is then picked up by the subsurface drainage system that empties it into the third chamber. The third chamber also receives any overflow from the second chamber for an on-line system and overflow from the first chamber flow splitter for an off-line system.

Applicability

The SFWQ structure is specifically designed for highly urbanized areas where open space is not available. The

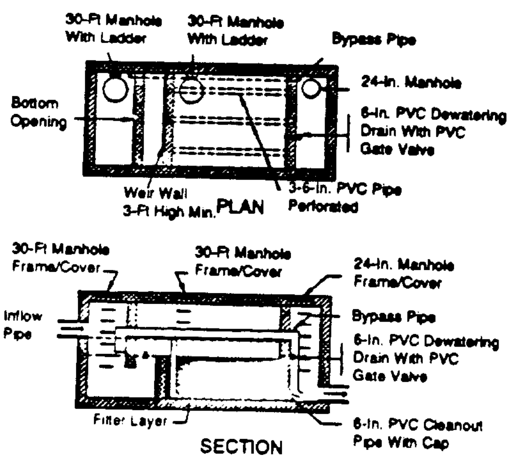

Figure 2. DC off-line underground sand filter (source: District of Columbia).

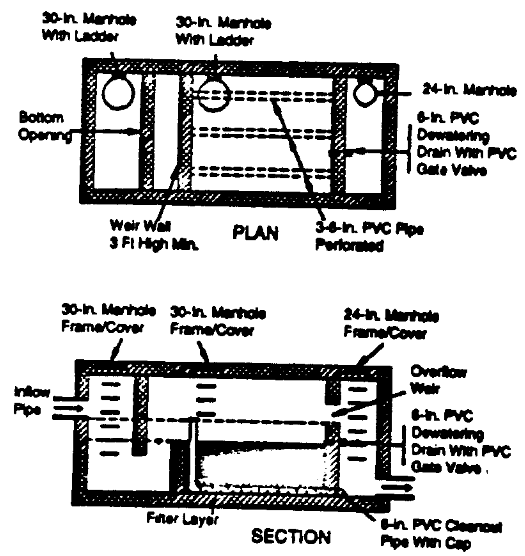

Figure 3. DC on-line underground sand filter (source: District of Columbia).

structure works best for impervious catchment areas of 1 acre or less. Multiple systems are recommended for catchment areas greater than 1 acre.

Over 70 underground and surface sand filter structures have been installed in Washington, DC, since 1988. In fact, the structure has been adopted and incorporated in the stormwater management programs of several states and neighboring jurisdictions.

The structure may also be designed to provide detention, especially for on-line application when discharge rates must be modified in accordance with local and municipal regulations. Recommended areas where this device may be used include:

- Surface parking lots.
- Underground parking lots or multilevel garages.
- Parking apron, taxiway, and runway shoulders at airports.
- Emergency stopping and parking lanes and sidewalks.
- Vehicle maintenance areas.
- On-street parking aprons in residential areas.
- Recreational vehicle camping area parking pads.
- Private roads, easement service roads, and fire lanes.
- Industrial storage yards and loading zones.
- Driveways for residential and light commercial use.
- Office complexes.

Planning Considerations

Location

The SFWQ structure must be located in areas where it is accessible for inspection and maintenance, as well as to the vacuum trucks that are usually required to provide maintenance.

Ground Water and Bedrock

The seasonally high ground-water table and bedrock should be at least 2 to 4 ft below the footing of the structure.

Size

The SFWQ structure may vary in size from a small-site single installation to large or multiple facility installations. Site topography and the presence of underground utilities, however, may limit the size and depth of the system. Use of other practices in combination with the SFWQ structure may solve this problem.

Hydraulic Head

Because the SFWQ structure is a gravity flow system, sufficient vertical clearance between the inverts of the inflow and outflow pipes must be provided. When elevation is insufficient, a well pump may be used to discharge the effluent from the third chamber into the receiving drainage system.

Water Trap

In combined sewer areas, a water trap must be provided in the third chamber to prevent the backflow of odorous gas.

Design Criteria

In designing the SFWQ structure, the nature of the area, such as imperviousness, determines the control volume of the sand filter chamber. Other recommended steps to consider when designing a SFWQ structure are the following:

- Examine the site topographical conditions and select possible outfalls from the existing drainage or sewer map.
- Review the final grading plans and determine the maximum head available between the proposed inflow and outflow pipes.
- Determine the total connected impervious area.
- Select the design (first flush) runoff based on land use characteristics. (Washington, DC, uses 0.5 in. for surface parking lots, 0.3 in. for rooftops, and 0.4 in. for other impervious surfaces.)
- Estimate the storage volume and the release rate. The storage volume and release rate depends on local stormwater management regulations.
- Select design storm(s). This should be based on the storm frequencies selected by the stormwater management authorities.
- Determine the size of the inflow, outflow, and emergency release pipes. These should be sized to pass the lowest selected storm frequency permitted by local stormwater regulations. (Washington, DC, uses 15-yr, 5-min storms for postdevelopment runoff.)
- Determine detention time. All SFWQ structures should be designed to drain the design (first flush) runoff from the filter chamber 5 to 24 hr after each rainfall event.
- Determine structural requirements. A licensed structural engineer should design the structure in accordance with local building codes.
- Provide sufficient headroom for maintenance. A minimum head space of 5 ft above the filter is recommended for maintenance of the structure. If 5 ft of headroom is not available, a removable top should be installed.

Design Procedures

Determine Design Invert Elevations

Determine the final surface elevation, invert in, invert out, and bottom invert elevation of the structure (see Figure 4):

$$D_t = (\text{Inv. in} - \text{Inv. out}) + H_w + 1, \qquad \text{(Eq. 1)}$$

where

D_t = total depth of structure (ft)
Inv. in = final invert elevation of inflow pipe (ft)
Inv. out = final invert elevation of outflow pipe (ft)
H_w = vertical height of overflow weir (ft)
1 = freeboard constant (ft)

Peak Discharge Calculation for Bypass Flow

Using the Rational Method:

$$Q_{pk} = CIA, \qquad \text{(Eq. 2)}$$

where

Q_{pk} = bypass peak flow (ft_3/sec)
C = runoff coefficiency (dimensionless)
I = rainfall intensity (in./hr)
A = drainage area (ac)

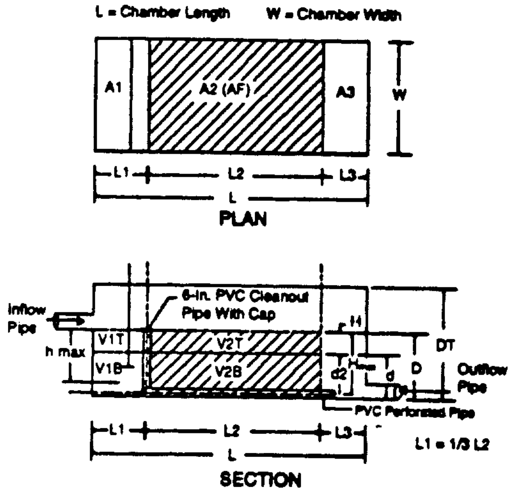

Figure 4. Design guide for DC sandfilter (source: District of Columbia).

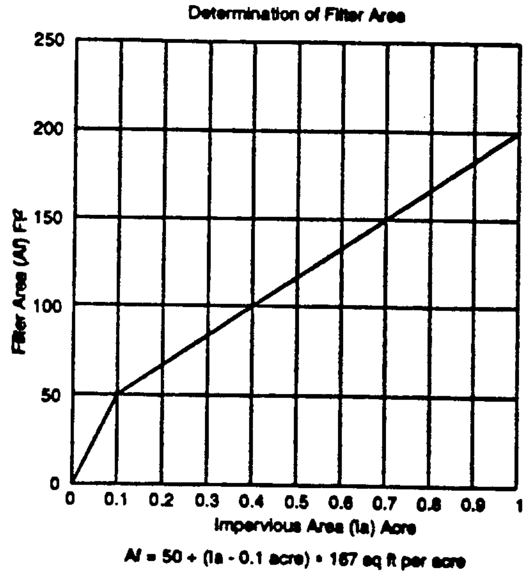

Figure 5. Filter area versus watershed imperviousness (source: District of Columbia).

Determine Area of Sand Filter

Use Figure 5 or the following equation:

$$A_f = 50 + [Ia - 0.1 \text{ acres}] \times 167 \text{ ft}^3/\text{ac}, \qquad \text{(Eq.3)}$$

where

A_f = sand filter area (ft2)
I_a = impervious area (ac)

Determine Storage Volume

Use the equation

$$V_w = (Q_i \times I_a) - (F \times T \times A_f), \qquad \text{(Eq. 4)}$$

where

V_w = volume storage needed (ft3)
Q_i = first flush runoff (in)
I_a = impervious area (ft^2)
F = final infiltration rate for filter (ft/hr)
T = filling time (1 hr, based on empirical data)
A_f = sand filter area (ft^2)

Calculate Bottom Storage Volume in Second Chamber

Use the equation

$$V_{2b} = Af \times d \times V_v, \qquad \text{(Eq. 5)}$$

where

V_{2b} = bottom volume of filter chamber (ft3)
A_f = surface area of filter layer (ft2)
d = depth of filter layer (ft)
V_v = sum of void ratio for filter media

Calculate Bottom Storage Volume in First Chamber

Use the equation

$$V_{1b} = A_1 \times d, \qquad \text{(Eq. 6)}$$

where

V_{1b} = bottom volume of first chamber (ft^3)
A_1 = surface area of first chamber (ft^2)
d = depth of filter layer (ft)

Note: $A_f/3 < A1 < A_f/2$ for optimum design condition.

Calculate Storage Volume in First and Second Chambers

Use the equation

$$(V_{1t} + V_{2t}) = V_w - (V_{2b} + V_{1b}), \qquad \text{(Eq. 7)}$$

where

$V_{1t} + V_{2t}$ = sum of top volume of first and second chambers

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V_w = volume of water from Equation 4
$V_{2b} + V_{1b}$ = sum of bottom volume of first and second chambers

Determine Maximum Storage Depth for On-Line System

Use the equation

$$D = [(V_{1t} + V_{2t})/(A_1 + A_2)] + d, \quad \text{(Eq. 8)}$$

where

D = maximum storage depth (ft)
$V_{1t} + V_{2t}$ = sum of top volume of first and second chambers
$A_1 + A_2$ = sum of surface area of first and second chambers
d = depth of filter layer (ft)

Note: D must be equal to or smaller than the difference between the invert in and invert out from Equation 1.

Determine Size of Submerged and Overflow Weirs

Submerged weir opening in first chamber:

$$A(h \times l) = Q_{pk}/C \times (2 \times g \times h_{max})^{0.5}, \quad \text{(Eq. 9)}$$

where

$A(h \times l)$ = area of weir opening (ft^2)
Q_{pk} = bypass flow from Equation 2 (ft3/sec)
C = 0.6, weir coefficient
g = 32.2 ft^2/sec
h_{max} = hydraulic head above the center line of weir (ft)
h = weir height, minimum 1 ft

Overflow weir opening in second chamber:

$$H^{1.5} = Q_{pk}/CL, \quad \text{(Eq. 9a)}$$

where

H = height of weir opening (ft)
Q_{pk} = bypass flow (ft^3/sec)
C = 3.33, weir coefficient
L = length of weir opening (ft)

Determine Flow Through Filter and Detention Time After Storage Volume Fills Up

Average flow through the filter:

$$q_f = k \times A_f \times i, \quad \text{(Eq. 10)}$$

where

q_f = flow through the filter (ft^3/hr)
k = sand permeability (ft/hr)
A_f = filter area
i = hydraulic gradient ($H_{max}/2$ x filter depth)

Estimate the detention time:

$$T_s = V_w/q, \quad \text{(Eq. 11)}$$

where

T_s = average dewatering time for SFWQ structures (hr)
V_w = volume of first flush storage from Equation 3 (ft^3)
q = average flow from Equation 10 (ft^3/hr)

Develop Inflow and Outflow Hydrographs

Figure 6 is a typical illustration of inflow/outflow hydrographs for the SFWQ structure.

For inflow hydrograph, use Modified Rational Method Hydrograph with:

$T = T_c$
$T_R = 1.67\ T_c$,

where

T = time to peak
T_c = time of concentration
T_R = recession period

For outflow hydrographs, use the following equations to determine when flow occurs:

when

$$T_c \times Q_{pk} < 2V_w, + \quad \text{(Eq. 12)}$$
$$T = [2 \bullet T_c 2 - (2T_c 2 - 2V_w \bullet T_c/Q_{pk})^{0.5}].$$

when

$$T_c \times Q_{pk} = 2V_w, + \quad \text{(Eq. 13)}$$
$$T = (0.5T_c) + (V_w/Q_{pk})$$

when

$$T_c \times Q_{pk} > 2V_w, + \quad \text{(Eq. 14)}$$
$$T = [(2V_w \bullet T_c)/Q_{pk}]^{0.5}.$$

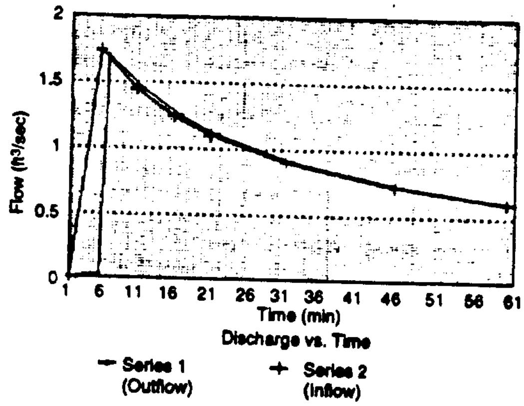

Figure 6. Typical inflow-outflow hydrograph (source: District of Columbia).

Filter Layer Details

Figure 7 is a typical cross section of the filter chamber.

Upper Gravel Layer

The washed gravel or aggregate layer at the top of the filter may be 1 to 3 in. thick and meet American Society for Testing Materials (ASTM) standard specifications for 1-in. maximum diameter or DC #57 gravel.

Geotextile Fabrics

The filter fabric (geotextile fabric) beneath the top gravel layer should be Enkadrain 9120 or equivalent with the specifications shown in Table 1.

The filter cloth beneath the sand should meet the specifications shown in Table 2.

The fabric roll should be cut with sufficient dimensions to cover the entire wetted perimeter of the filter area with a 6-in. minimum overlap.Sand Filter Layer

Sand Filter Layer

The sand filter layer should be 18 to 24 in. deep. ASTM C33 Concrete Sand is recommended, but sand with similar specifications may be used.

Table 1. Geotextile Fabric Specifications

Property	Test Method	Unit	Specification
Material	Nonwoven geotextile fabric		
Unit weight	ASTM D-1777	oz/yd²	4.3 (min)
Flow rate	"Falling head test" ASTMD-751	gpm/ft² lb	120 (min) 60 (min)
Puncture thickness		in.	0.8 (min)

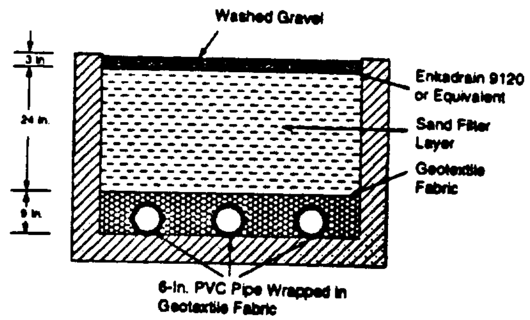

Figure 7. Cross section of filter compartment (source: District of Columbia).

Bottom Gravel Layer

The bottom gravel layer surrounding the collector (perforated) pipes should be 1/2- to 2-in. diameter gravel and provide at least 3 in. of cover over the tops of the drainage pipes. No gravel is required under the pipes. The gravel and the sand layer above must be separated by a layer of geotextile fabric that meets the specifications listed above.

Underdrain Piping

The underdrain piping consists of three 6-in. pipes with 3/8-in. perforations and should be reinforced to withstand the load of the overburden. All piping should be to schedule 40 polyvinyl chloride (PVC) or greater strength.

The minimum grade of piping shall be 1/8 in./ft or 1 percent slope. Access for cleaning all underdrain piping is needed. Cleanouts for each pipe should extend to the invert of overflow weir or maximum surface elevation of the storage water.

Each pipe should be carefully wrapped with geotextile fabric that meets the above specifications before placement in the filter.

Table 2. Filter Cloth Specifications

Property	Test Method	Unit	Specification
Material	Nonwoven geotextile fabric		
Unit weight		oz/yd²	8.00 (min)
Filtration rate		in./sec	0.08 (min)
Puncture strength	ASTM D-751 (Modified)	lb	125 (min)
Mullen burst strength	ASTM D-751	psi	400 (min)
Tensile strength	ASTM D-1682	lb	300 (min)
Equivalent opening size	U.S. Standard Sieve	no.	80 (min)

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Construction Specifications

The SFWQ structure may be either cast-in-place or precast. In Washington, DC, precast structures require advanced approval. The approved erosion and sediment control plans should include the specific measures to provide the protection of the filter system before the final stabilization of the site.

Excavation and Installation

Excavation for SFWQ structure and connecting pipes should include removal of all materials and objects encountered in excavation; disposal of excavated material as specified in the approved erosion and sediment control plans; maintenance and subsequent removal of any sheeting, shoring and bracing; dewatering and precautions; and work necessary to prevent damage to adjacent properties resulting from this excavation. Access manholes and steps to the filtration system should conform to local standards.

Leak Test

After completion of the SFWQ structure shell, a leak test may be performed to verify watertightness before the filter layers are installed.

Filter Materials

All filter materials in the second chamber should be placed according to construction and materials standards and specifications, as specified on an approved construction plan.

Completion and Site Stabilization

No runoff should be allowed to enter the sand filter system before completion of all construction activities, including revegetation and final site stabilization. Construction runoff should be treated in separate sedimentation basins and routed to bypass the filter system. Should construction runoff enter the filter system prior to final site stabilization, all contaminated materials must be removed and replaced with new, clean filter materials before a regulatory inspector approves its completion.

System Calibration and Verification

The water level in the filter chamber should be monitored by the design engineer after the first storm event before the project is certified as completed. If the dewatering time of the filter chamber takes longer than 24 hr, the top gravel layer and filter fabric underneath must be replaced with a more rapid draining fabric and clean gravel. The structure should then be checked again to ensure a detention time that is less than 24 hr.

Maintenance Requirements

The SFWQ structure is designed to minimize maintenance. It is subject to clogging, however, by sediment, oil, grease, grit, and other debris. Actual performance and service life of the structure is not available at this time. Nevertheless, it is still very important to provide general standard maintenance guidelines to maintain adequate structure operation. The maintenance of the system includes the following steps:

- The water level in the filter chamber should be monitored by the owner on a quarterly basis and after every large storm for the first year after completion of construction. A log of the results should be maintained, indicating the rate of dewatering after each storm and the water depth for each observation. Once the regulatory stormwater inspector indicates that satisfactory performance of the structure has been demonstrated, the monitoring schedule may be reduced to an annual basis.
- As with other pretreatment structures, the first chamber must be pumped out semiannually. If the chamber contains an oil skim, it should be removed by a firm specializing in oil recovery and recycling. The remaining material may then be removed by a vacuum pump truck and disposed of in an approved landfill. After each cleaning, refill the first chamber to a depth of 3 ft with clean water to reestablish the water seal.
- After approximately 3 to 5 yr, the upper layer of the filter can be expected to become clogged with fine silt. When the drawdown time for the filter exceeds 72 hr, the upper layer of gravel and geotextile fabric must be removed and replaced with new, clean materials conforming to the original specifications.

Conclusion and Discussion

At the present time, the environmental and economic impacts of the SFWQ structure have not been fully evaluated. A long-term monitoring program is being implemented in Washington, DC, to determine water quality benefits and address long-term maintenance concerns. The results from this monitoring effort will provide important information on the removal efficiency of common urban pollutants. In addition, the monitoring data will provide information on actual headloss in the system, which will indicate the need for filter replacement.

Based on the results of the Austin, Texas, monitoring program on its sand filter systems and on several years of success in the application of the SFWQ structure in Washington, DC, the feasibility of the SFWQ structure has been demonstrated for use in an urban environment. The authors believe that the SFWQ structure may be used as an alternative urban BMP for highly developed areas where other options are not available.

In conclusion, the design presented here is an attempt to provide an alternative solution to control nonpoint source pollution from urban stormwater runoff. The application of this system should be viewed with some caution, as the structure has not been monitored for optimal effectiveness.

When the SFWQ structure is used strictly as a gravity flow system, one of its limitations is that it requires a hydraulic head of at least 4 ft relative to the outflow pipe. To minimize this problem, further study is needed to evaluate the different thicknesses of the sand layers (with thicknesses such as 18, 12, and 6 in.) to determine the relationship between the depth of sand layer and pollutant removal efficiency.

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Stormwater Measures for Bridges: Coastal Nonpoint Source Management in South Carolina

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Abstract

Although stormwater runoff from bridges has a direct pathway to estuaries, rivers, and lakes, little research has been undertaken to directly measure the concentration of pollutants flushed from the bridge surface or the impact of those pollutants on the receiving water body. A general correlation can be made, however, from the body of research available concerning runoff from roads and streets in general and from the wider body of information regarding urban runoff characteristics. The general assumption is that runoff from highways (and bridges) can negatively affect the water quality of receiving waters through the shock of acute loadings during rainfall events and through long-term exposure and/or accumulations of pollutants in sediments or marine organisms. Research does indicate a relationship between the average daily traffic volume and potential water quality impacts. Concern is heightened where the runoff has a direct, unobstructed pathway to the receiving waters and, even more so, where the receiving waters are extremely sensitive, such as shellfish habitat.

This paper provides a brief overview of potential water quality pollutants from highway and bridge runoff, then focuses on management and control measures for runoff from bridges. These include requirements of Section 6217 of the Coastal Zone Act Reauthorization Amendments and stormwater management requirements for bridges in the coastal zone of South Carolina. Included is a case study of retrofitting a major bridge already designed and under construction, which transverses significant shellfish resources in coastal South Carolina.

Introduction

South Carolina's 187-mile coastline is only the facade for some 3,000 shoreline miles of estuaries, bays, rivers, and creeks that intertwine among some 500,000 acres of coastal marshes and wetlands. This immense coastal system supports approximately 279,000 acres of estuarine shellfish-growing waters and thousands of acres of other sensitive habitats. For people to live and work in this environment, all of these coastal resources, rivers, bays, marshes, and sensitive habitats must be transversed in one form or another, most often by roadways and bridges. These roadways and bridges and their associated uses can provide a direct source of contaminants to our coastal waters and, as such, must be managed to reduce or alleviate the potential impacts.

For coastal states, addressing pollution from bridges may no longer be a choice. Section 6217 of the Coastal Zone Act Reauthorization Amendments of 1990 requires states with coastal zone programs to develop coastal nonpoint source pollution programs. Such programs must address pollution in the following areas: agriculture, silviculture, hydrologic modifications, marinas, and urban settings, the latter of which include roads and, even more specifically, bridges.

A basic assumption contained herein is that the results of studies on highways and their associated pollution potential from runoff are also applicable to highway bridges.

Contaminants

A series of studies sponsored by the U.S. Department of Transportation in the 1980s (1-3) confirms the presence and possible sources of a wide variety of contaminants that may be associated with roadways and bridges. A basic listing is presented in Table 1. These contaminants accumulate on roadway surfaces between major removal events, such as rainfalls and street sweeping (which may be rare or nonexistent in nonurban areas). The severity and order of magnitude of these contaminants are site specific and variable, and can depend on such factors as traffic characteristics, highway or bridge design, maintenance activities, accidental spills, surrounding land use, and climate.

Table 1. Common Highway Runoff Constituents and Their Primary Sources (1)

Constituent	Primary Sources
Particulates	Pavement wear, vehicles, atmosphere, highway maintenance
Nitrogen, phosphorus	Atmosphere, roadside fertilizer application
Lead	Leaded gasoline (auto exhaust), tire wear (lead oxide filler material), lubricating oil and grease, bearing wear
Zinc	Tire wear (filler material), motor oil (stabilizing additive), grease
Iron	Auto body rust, steel highway structures (guardrails, bridges, etc.), moving engine parts
Copper	Metal plating, bearing and bushing wear; moving engine parts; brake lining wear; fungicides and insecticides (roadside maintenance operations)
Cadmium	Tire wear (filler material), insecticides
Chromium	Metal plating, moving engine parts, brake lining wear
Nickel	Diesel fuel gasoline (exhaust) and lubricating oil, metal plating, bushing wear, brake lining wear, asphalt paving
Manganese	Moving engine parts
Bromide	Auto exhaust
Cyanide	Anticake compound (ferric ferrocyanide, etc.) used to keep deicing salt granular
Chloride	Deicing salts
Sulphate	Roadway beds, fuel, deicing salts
Petroleum	Spills, leaks, or blow-by of motor lubricants; antifreeze, and hydraulic fluids, asphalt surface leachate
Polychlorinated biphenyls (PCBs), synthetic pesticides	Spraying of highway right-of-ways, background atmospheric deposition, PCB catalyst in tires
Pathogenic bacteria (indicators)	Soil, litter, bird droppings, trucks hauling livestock and stockyard waste
Rubber	Tire wear
Asbestos	Clutch and brake lining wear

The studies have revealed some interesting results that may influence management decisions. To elaborate on one pollutant, tests (1) indicated that the pathogenic bacteria indicators fecal coliform and fecal *Streptococcus* were not consistently present on roadway systems at any given time or place; their presence is most often associated with nonspecific events, i.e., animal and bird droppings, soil spills, and road kills. When present, however, the bacteria can remain viable for relatively long periods in highway sweepings (up to 7 weeks) and up to 13 days in stagnant storm sewer systems. As one would expect, the tests showed that the coliform bacteria were consistently lower when runoff was conveyed through a grassy area, although none of the standard nonpoint source management measures effectively kills coliforms and their associated microbes (2).

According to the U.S. Department of Transportation (1), the major portion of priority pollution load in highway runoff was attributed to metals (e.g., lead, zinc, and copper), although a significant number of organic pollutants were present in the highway environment.

Studies (4, 5) indicate that the magnitude of pollutants associated with highway runoff is related to traffic volume. Research (2) tends to indicate that 30,000 average daily traffic (ADT) is a general threshold for the potential of impacts from highway runoff; however, several variables must be factored into this conclusion, including sensitivity of receiving waters, distance to receiving waters, type of traffic, road or bridge design, and others.

The U.S. Department of Transportation (2) has drawn the following conclusions from these studies and other literature concerning highway runoff pollution potential:

- Highway runoff does have the potential to adversely affect the water quality and aquatic biota of receiving waters.
- The significance of these adverse effects is variable by highway type and design, receiving water, and runoff event.
- Runoff from urban highways with high ADT volumes may have a relatively high potential to cause adverse effects.
- Runoff from rural highways with low ADT volumes has a relatively low potential to cause adverse effects.

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Basic Management Practices and Processes

Of the variety of best management practices available for nonpoint source pollution control, four basic management measures are generally considered cost effective for treatment of highway runoff based on effectiveness for specific pollutants, relative capital costs, land requirements, and operation and maintenance costs (2):

- Vegetative controls
- Wet detention basins
- Infiltration basins
- Wetlands

Pollution measures that were not considered effective when used as a sole management tool were street cleaning, catch basins, filtration devices for sediment control, dry detention ponds, and porous pavements (2). The first three methods were not effective in capturing the fine sediments to which many pollutants attach themselves, while the dry detention pond tended to reflush the settled particles after each rainfall event. Porous pavement is limited to low-volume traffic areas, such as parking lots, because of current highway construction standards.

All of the measures have in common several physical or biochemical processes that occur to provide the necessary control of pollutants: settling, filtering, adsorption, bioassimilation, biodegradation, and volatilization or evaporation. Table 2 lists the process associated with each management measure as related to the general type of pollutant control.

Management Measures for Bridges

Although bridges can be assumed to cause the same types of water quality impacts as highways, and although the techniques to manage those impacts are fairly straightforward and generally well accepted, the unique location of bridges presents some problems. First, the runoff from the bridge must be intercepted from seeking its natural pathway and routed back to high land or another area suitable for treatment; secondly, land areas for treatment are usually limited.

Collection and transportation are most easily solved in the design of the bridge, although in coastal areas runoff may have to be transported long distances with little grade. The physical land requirements for the appropriate treatment method, however, tend to be the most limiting factors. Solutions are very site specific and must be included in the earliest planning stages of the bridge. Topography at the bridge/land junction is often the single most important factor in considering the design of an appropriate treatment method, although other factors, such as high water tables, soil types, and adjacent land use, also can be important in the design consideration process. The design of the stormwater system should not drive the design of the bridge, but neither should the design of the bridge preclude the design of an effective stormwater treatment system.

All of the traditional stormwater management methods can be considered for treatment of runoff from bridges: wet detention ponds, infiltration systems, grassed waterways, and wetlands. These can be used even in combination with less favorable methods, such as frequent sweeping or catch basins, if the lack of good alternatives so dictates. Other opportunities that may be present in the area should also be considered, such as nearby spoil disposal containment areas, preexisting treatment systems for nearby development, or discharge routing to less sensitive areas.

The U.S. Environmental Protection Agency (EPA) (6) lists several general guidelines and management practices for illustrative purposes, specifically for bridges, in the Section 6217 management measure guidance document.

Table 2. Principal Pollutant Fate Processes by Major Management Measures

	Management Measures			
Pollutant	Vegetative Control	Detention Basins	Infiltration Systems	Wetlands
Heavy metals	Filtering	Adsorption, settling	Adsorption, filtration	Adsorption, settling
Toxic organics	Adsorption	Adsorption, settling, volatilization	Adsorption, biodegradation	Adsorption, settling, biodegradation, volatilization
Nutrients	Bioassimilation	Bioassimilation	Absorption	Bioassimilation
Solids	Filtering	Settling	Adsorption, settling	Adsorption
Oil and grease	Adsorption	Adsorption, settling	Adsorption	Adsorption, settling
Biochemical oxygen demand	Biodegradation	Biodegradation	Biodegradation	Biodegradation
Pathogens	NA	Settling	Filtration	NA

NA = information not available

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- Coordinate design with the Federal Highway Administration (FHWA), U.S. Coast Guard, U.S. Army Corps of Engineers, and other state and federal agencies as appropriate.
- Review National Environmental Policy Act requirements to ensure that environmental concerns are met.
- Avoid highway locations requiring numerous river crossings.
- Direct pollutant loadings away from bridge decks by diverting runoff waters to land for treatment.
- Restrict the use of scupper drains on bridges less than 400 ft in length and on bridges crossing very sensitive ecosystems.
- Site and design new bridges to avoid sensitive ecosystems.
- On bridges with scupper drains, provide equivalent urban runoff treatment in terms of pollutant load reduction elsewhere on the project to compensate for the loading discharged off the bridge.

Regardless of the "illustrative" nature of the above practices, EPA and the National Oceanic and Atmospheric Administration (NOAA) expect the states to address nonpoint pollution from bridges and to adopt enforceable policies by 1995 to manage the runoff or to document why such runoff is not a problem.

South Carolina's Approach

In 1988, the South Carolina Coastal Council was faced with the permitting of a new 2-mile bridge connecting the mainland with a major developed barrier island (see below) and crossing a major shellfish-producing area. As an outcome of the permitting of this project, the Coastal Council developed a set of guidelines to use in conjunction with the South Carolina Department of Highways and Public Transportation to allow all parties to anticipate the design of stormwater controls in new bridges. It is not unusual for bridges to be designed well in advance of the permitting process, and the inclusion of new design criteria can cause both new expenses and a politically unpleasant situation. The guidelines have been in use since 1989 and have been introduced as regulations to the 1993 South Carolina General Assembly. The regulations appear to meet the basic intent of the EPA/NOAA Section 6217 guidance, although this has yet to be determined. The basic regulations are as follows.

Stormwater Management Requirements for Bridge Runoff

The following are the criteria used to address stormwater management for bridges traversing saltwater and critical areas.

- No treatment is necessary for runoff from bridge surfaces spanning Class SA and Class SB tidal saltwaters. (SA and SB waters are suitable for primary and secondary contact recreation, crabbing, and fishing. The two classes differ in their dissolved oxygen [DO] limitations: SA waters must maintain daily averages of not less than 5.0 mg/L, and SB waters must maintain DO levels not less than 4.0 mg/L.) This runoff can be discharged through scupper drains directly into surface waters. The use of scupper drains, however, should be limited as much as possible.
- If the receiving water is classified as either outstanding resource waters (ORW) or shellfish harvesting waters (SFH), then the stormwater management requirements shall be based on projected traffic volumes and the presence of any nearby shellfish beds. Table 3 lists the necessary treatment practices over the different classes of receiving waters.
- The ADT volume is based on the design carrying capacity of the bridge.

Table 3. Requirements for Stormwater Management on Bridges in the Coastal Zone, South Carolina

	ADT Volume	
Water Quality Classification	0-30,000	30,000
ORW (within 1,000 ft of shellfish beds)	A	A
ORW (not within 1,000 ft of shellfish beds)	B	B
SFH (within 1,000 ft of shellfish beds)	B	A
SFH (not within 1,000 ft of shellfish beds)	B	B
SFH (not within 1,000 ft of shellfish beds)	B	B
SA (exceptional)	C	C
SB (high quality)	C	C

A = The first 1-in. of runoff from the bridge surface must be collected and routed to an appropriate stormwater management system or routed so that maximum overland flow occurs, encouraging exfiltration before reaching the receiving water body. Periodic vacuuming of the bridge surface should be considered.

B = A stormwater management plan must be implemented that may require the overtreatment of runoff from associated roadways to compensate for the lack of direct treatment of runoff from the bridge surface itself. Periodic vacuuming should be considered. The use of scupper drains should be limited as much as possible.

The Isle of Palms Connector: A Case Study in Retrofitting

The incorporation of a stormwater management system into a bridge design usually can be done without any great difficulty. Trying to incorporate a system into a bridge already designed and ready for permitting, however, can be much more difficult. Such was the case with the Isle of Palms Connector, an 11,500-ft, $30 million bridge that was to provide alternate access to the Isle of Palms, a barrier island town just outside of Charleston, South Carolina. The bridge route called for the crossing of some 9,000 ft of marsh, two major marsh creeks, and the Intracoastal Waterway. Location and environmental studies and basic bridge design were completed in 1979, the same year the state's coastal zone management program was authorized. Funding limitations slowed the process until 1987, when federal funds became available.

The proposed route for the Isle of Palms Connector crossed over some of the state's most productive commercial and recreational shellfish grounds. The live oyster volume in Hamlin Creek and Swinton Creek alone was surveyed by the South Carolina Wildlife and Marine Resources Department at 32,000 bushels. Annual clam production potential in the immediate area of the bridge is estimated to be between 140,000 and 250,000 clams.

The bridge was originally designed with traditional methods of handling stormwater; water was drained directly from the bridge through scuppers except at one previously identified sensitive area, where discharge was eliminated. Because there were no objections to the stormwater design in the original environmental impact assessment, approved by the FHWA in 1986, the South Carolina Department of Highways and Public Transportation was reluctant to make any changes. Relocation of the bridge was not an option, nor, as it turned out, was redesign of the bridge. The bridge was designed with approximately 9,000 ft at 0.0 percent grade, with elevated spans over the Intracoastal Waterway and one of the creeks (Figure 1). The State Highway Department estimated redesign to accommodate positive flows to both ends of the bridge at $10 million, a one-third increase in bridge cost (7).

The South Carolina Coastal Council, however, as primary permitting agency for the bridge, was sensitive to public demand that the bridge must incorporate a stormwater management system that met basic coastal stormwater guidelines (8). After several meetings, which included public input, the South Carolina Department of Highways and Transportation agreed to work with the Coastal Council in addressing stormwater within the limits of two constraints: the bridge location could not be changed, and the stormwater system must be adaptable to the existing bridge design. Once this decision was reached, both agencies began a serious and cooperative effort in resolving the problem. It was immediately apparent that the traditional methods of stormwater treatment usually employed on high land must be ruled out; other than pumping, which was explored and rejected due to cost, there was no way to get the runoff back to high ground for treatment. Therefore, the study team threw

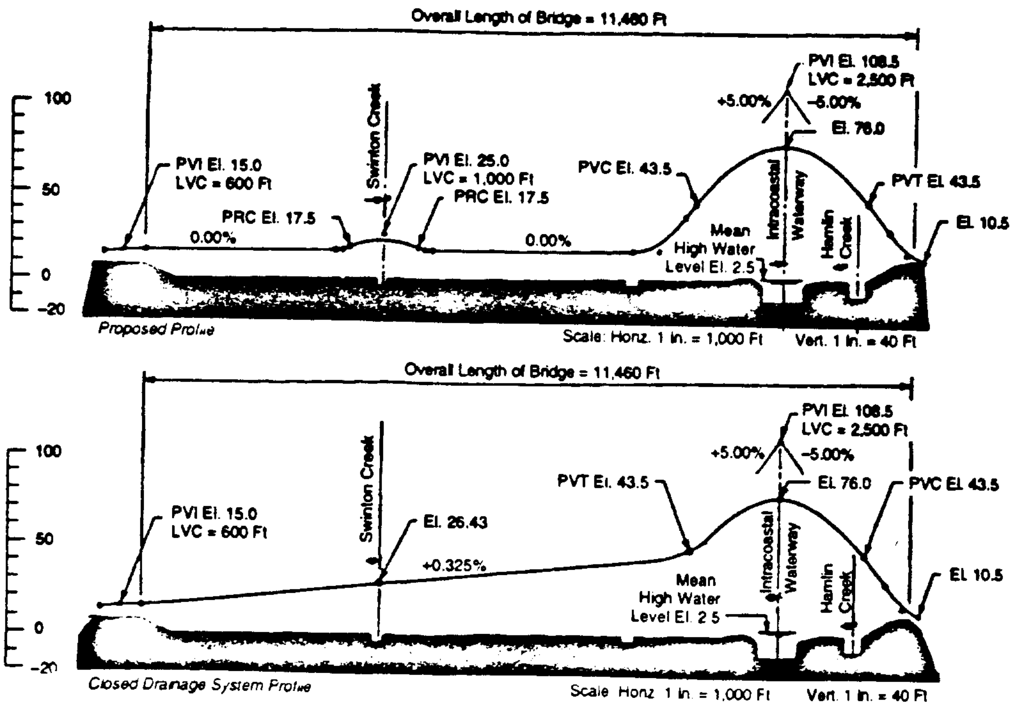

Figure 1. Proposed and closed drainage system profiles for Isle of Palms Connector.

out the preconceived traditional approaches and focused on the basic tenents of stormwater management: retention, settling, and pollutant removal. A variety of alternatives were identified, evaluated, and rejected for various reasons. Among these alternatives were storage and retention in gutters of several configurations along the shoulder of the bridge roadway and the design of an "in the marsh" sand filtering system constructed in large cylinders.

What emerged from this process was the design of an open-faced "runoff pan," 15 ft long by 32 in. wide, to be bolted in place to catch the discharge from each scupper drain (Figure 2). The pan, constructed of fiberglass, was 1 ft deep with a baffle overflow to prevent the discharge of oil and grease. In addition to containing the first 3/4 in. of runoff, the pans were to be managed with a vigorous maintenance program that would include dry/wet vacuuming on a to-be-determined basis and disposal of the residue in accordance with state hazardous waste regulations. The estimated cost for the stormwater management system, to include piping of runoff from the vertical expansions of the bridge to high ground and an adjacent spoil disposal area, was about 3.5 percent of the total bridge cost.

Accompanying this alternative was the commitment of the State Highway Department and the Coastal Council to develop a monitoring program to test the effectiveness of this technique. The monitoring program was to be implemented on completion of the bridge, estimated for the fall of 1993. Background data was collected in the summer and fall of 1993.

Both agencies, along with the concerned public, eagerly await the results of the monitoring. If successful, the runoff pan may provide one alternative for addressing stormwater management on existing bridges crossing sensitive waters.

Conclusion

Roadways and bridges are certainly not unique in their potential contribution to lessened water quality. Virtually all human activities on the land, on the water, and in the air contribute to the problem. No one solution to correct the problem exists; rather, the solution lies with the incremental "micromanagement" of each specific activity that contributes to the problem.

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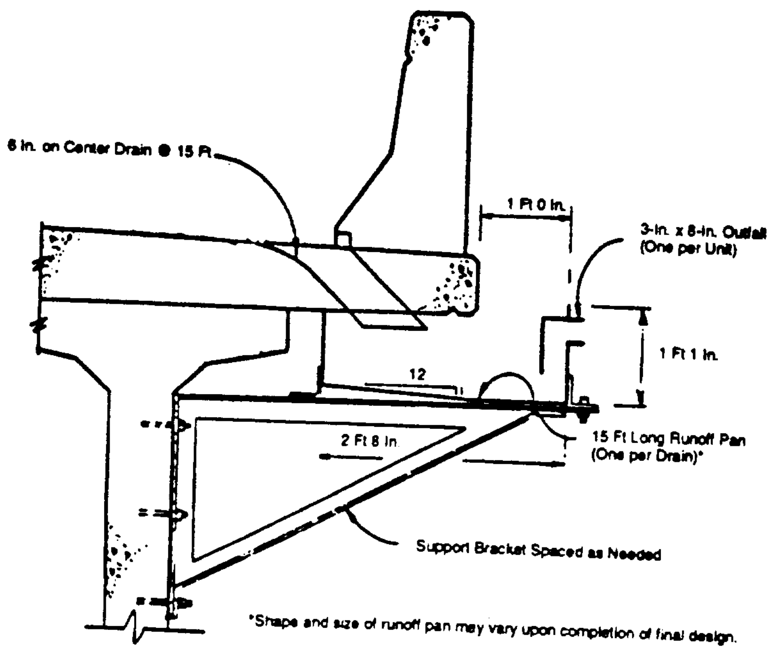

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Controlling Pollutants in Runoff From Industrial Facilities

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Abstract

Industrial facilities can be significant contributors of pollutants to urban runoff. On November 16, 1990, the U.S. Environmental Protection Agency (EPA) published National Pollutant Discharge Elimination System (NPDES) permit application requirements for "stormwater discharges associated with industrial activities." These regulations provide a framework for reducing pollutants in runoff from the industrial facilities addressed. EPA subsequently developed a long-term strategy for issuing NPDES permits for these discharges. As the initial step in this strategy, the Agency issued general permits on September 9, 1992, and September 25, 1992, for the majority of stormwater discharges in states where EPA issues NPDES permits. This paper provides an overview of major categories of sources that contribute pollutants to runoff at industrial sites and describes pollution prevention measures in EPA's NPDES general permits.

Introduction

Pollutants in urban runoff depend in part on the nature of land use. Several studies indicate that runoff from industrial land uses is of relatively poorer water quality than runoff from other general land uses (1-5). In addition, industrial sites can be significant sources of polluted, uncontrolled nonstormwater to separate storm sewers (6, 7).

Source of Pollutants to Industrial Runoff

The volume and quality of stormwater discharges associated with industrial facilities depend on several factors, including the industrial activities occurring at the facility, the nature of precipitation, and surface imperviousness. The sources of pollutants that can affect the quality of stormwater from industrial facilities differ with the type of operations and specific facility features. For example, air emissions may be a significant source of pollutants at some facilities, material storage operations at others, and still other facilities may discharge stormwater associated with industrial activity with relatively low levels of pollutants.

Six classes of activities can be identified as major potential sources of pollutants in stormwater discharges associated with industrial activity (7-11):

- Loading or unloading of dry bulk materials or liquids.
- Outdoor storage of raw materials or products.
- Outdoor process activities.
- Dust or particulate generating processes.
- Illicit connections or inappropriate management practices.
- Waste disposal practices.

The potential for pollution from many of these activities may be influenced by the presence and use of toxic chemicals.

Loading and unloading operations typically are performed along facility access roads and railways and at loading/unloading docks and terminals. These operations include pumping of liquids or gases from trucks or rail cars to a storage facility or vice versa; pneumatic transfer of dry chemicals to or from the loading or unloading vehicle; transfer by mechanical conveyor systems; and transfer of bags, boxes, drums, or other containers from vehicles by forklift trucks or other materials handling equipment. Material spills or losses may discharge directly to the storm drainage systems or may accumulate in soils or on surfaces, to be washed away during a storm or facility washdown.

Outdoor storage includes the storage of fuels, raw materials, byproducts, deicing chemicals, intermediates, final products, and process residuals and wastes. Methods of material storage include use of storage containers (e.g., drums or tanks), platforms or pads, bins, silos, boxes, and piles. Materials, containers, and material storage areas exposed to rainfall or runoff may contribute pollutants to stormwater when solid materials wash off or materials dissolve into solution.

Other outdoor activities include certain types of manufacturing and commercial operations and land-disturbing operations. Although many manufacturing activities are performed indoors, some activities (e.g., equipment and vehicle maintenance and cleaning, timber processing, rock crushing, vehicle maintenance and cleaning, and concrete mixing) typically occur outdoors. Processing operations may result in liquid spillage and losses of material solids to the drainage system or surrounding surfaces, or creation of dusts or mists that can be deposited locally. Some outdoor industrial activities cause substantial physical disturbance of land surfaces that result in soil erosion by stormwater. For example, disturbed land occurs in construction and mining. Disturbed land may result in soil losses and other pollutant loadings associated with increased runoff rates. Facilities whose major process activities are conducted indoors may still apply chemicals such as herbicides, pesticides, and fertilizer outdoors for a variety of purposes.

Dust or particulate generating processes include industrial activities with stack emissions or process dusts that settle on plant surfaces. Localized atmospheric deposition can be a particular concern with heavy manufacturing industries. For example, monitoring of areas surrounding smelting industries has shown much higher levels of metals at sites nearest the smelter. Other industrial sites, such as mines, cement manufacturing plants, and refractories, generate significant levels of dusts.

Illicit connections or inappropriate management practices result in improper nonstormwater discharges to storm sewer systems. Pollutants from nonstormwater discharges to the storm sewer systems are caused typically by a combination of improper connections, spills, improper dumping, and improperly disposed of rinse waters, cooling waters, or other process and sanitary wastewater. Often dischargers believe that the absence of visible solids in a discharge is equivalent to the absence of pollution. Illicit connections are often associated with floor drains that are connected to separate storm sewers. Rinse waters used to clean or cool objects discharge to floor drains connected to separate storm sewers. Large amounts of rinse waters that discharge to floor drains may originate from industries using regular washdown procedures; for example, bottling plants use rinse waters for removing waste products, debris, and labels. Rinse waters can be used to cool materials by dipping, washing, or spraying objects with cool water; for example, rinse water is sometimes sprayed over the final products of a metal plating facility for cooling purposes. Condensate return lines of heat exchangers often discharge to floor drains. Heat exchangers, particularly those used under stressed conditions (e.g., exposure to corrosive fluids), such as in the metal finishing and electroplating industry, may develop pinhole leaks that result in contamination of condensate by process wastes. These and other nonstormwater discharges to storm sewers may be intentional, based on the belief that the discharge does not contain pollutants, or they may be inadvertent, if the operator is unaware that a floor drain is connected to the storm sewer.

Waste management practices include temporary storage of waste materials and operations at landfills, waste piles, and land application sites that involve land disposal. Outdoor waste treatment operations also include wastewater and solid waste treatment and disposal processes, such as waste pumping, additions of treatment chemicals, mixing, aeration, clarification, and solids dewatering.

Options for Control

Options for controlling pollutants in stormwater discharges associated with industrial activity are discussed below in terms of two major pollutant sources: 1) materials discharged to separate storm sewers via illicit connections, improper dumping, and spills; and 2) pollutants associated with runoff.

Nonstormwater Sources

As discussed above, nonstormwater discharges to separate storm sewers come from a wide variety of sources, including illicit connections, improper dumping, spills, or leakage from storage tanks and transfer areas. Measures to control spills and visible leakage can be incorporated into the best management practices discussed below.

In many cases, operators of industrial facilities may be unaware of illicit discharges or other nonvisible sources of nonstormwater to a storm sewer. In such cases, the key to controlling these discharges is to identify them. Several methods for identifying the presence of nonstormwater discharges are discussed below. (A more complete discussion of methods to identify illicit connections can be found in U.S. EPA [6, 12]). A comprehensive evaluation of the storm sewers at a facility often should incorporate several of the following methods:

- *Evaluation of drainage map and inspections:* Drainage maps should identify the key features of the drainage system (i.e., each of the inlet and discharge structures, the drainage area of each inlet structure, storage and disposal units, and materials loading areas) that may be the source of an illicit discharge or improper dumping. In addition, floor drains and other water disposal inlets thought to be connected to the sanitary sewer should be identified. A site inspection

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can be used to augment and verify map development. These inspections, along with the use of the drainage map, can be coordinated with other identification methods discussed below.

- *End-of-pipe screening:* Discharge points or other access points such as manhole covers can be inspected for the presence of dry weather discharges and other signs of nonstormwater discharges. Dry weather flows, material deposits, and stains are often indicators of illicit connections. Dry weather flows can be screened by a variety of methods. Inexpensive onsite tests include measuring pH; observing for oil sheens, scums, and discoloration of pipes and other structures; and colorimetric detection for chlorine, detergents, metals, and other parameters. In some cases, it may be appropriate to collect samples for more expensive analysis in a laboratory for fecal coliform, fecal *Streptococcus*, volatile organic carbon, or other appropriate parameters.

- *Manhole and internal TV inspection:* Inspection of manholes and storm sewers, either physically or by television, can be used to identify a potential entry point for illicit connections. TV inspections are relatively expensive and generally should be used only after a storm sewer has been identified as having illicit connections.

- *Dry weather testing:* Where storm sewers do not normally discharge during dry weather conditions, water can be introduced into floor drains, toilets, and other points where nonstormwater discharges are collected. Storm drain outlets are then observed for possible discharges.

- *Dye testing:* Dry weather discharges from storm sewers can occur for several legitimate reasons, including ground-water infiltration or the presence of a continuous discharge subject to a National Pollutant Discharge Elimination System (NPDES) permit. Where storm sewers do have a discharge during dry weather conditions, dye testing for illicit connections can be used. Dye testing involves introducing fluorometric or other types of dyes into floor drains, toilets, and other points where nonstormwater discharges are collected. Storm drain outlets and manholes are then observed for possible discharges. Dye testing can also be used to identify unknown submerged outfalls to nearby receiving waters.

- *Water balance:* Many sewage treatment plants require that industrial discharges measure the volume of effluent discharged to the sanitary sewer system. Similarly, the volume of water supplied to a facility is generally measured. A significantly higher volume of water supplied to the facility relative to that discharged to the sanitary sewer and other consumptive uses may be an indication of illicit connections. This method is limited by the accuracy of the flow meters used.

- *Schematics:* Where they exist, accurate piping schematics can be inspected as a first step in evaluating the integrity of the separate storm sewer system. The use of schematics is limited because schematics usually reflect the design of the piping system and may not reflect the actual configuration constructed. Schematics should be updated or corrected based on additional information found during inspections.

Smoke tests are sometimes listed in the literature as a method for detecting illicit connections to separate storm sewers. While smoke tests can be used to identify inflow of stormwater to sanitary sewers, they can be much less effective for identifying discharges of nonstormwater to storm drains. This is because many nonstormwater drainage locations have a sewer gas trap that blocks smoke used in a test. Smoke tests can identify nonstormwater discharges to storm drains if the piping for the nonstormwater discharge has a vent or does not have a sewer gas trap.

Options for Preventing Pollutants in Stormwater

The following five categories describe options for reducing pollutants in stormwater discharges from industrial plants:

- Providing end-of-pipe treatment.
- Implementing best management practices (BMPs) to prevent pollution.
- Diverting stormwater discharge to treatment plants.
- Using traditional stormwater management practices.
- Eliminating pollution sources/water reuse.

A comprehensive stormwater management program for a given plant often includes controls from each of these categories. Development of comprehensive control strategies should be based on a consideration of plant characteristics.

End-of-Pipe Treatment

At many types of industrial facilities, it may be appropriate to collect and treat the runoff from targeted areas of the facility. This approach was taken with the 10 industrial categories with national effluent guideline limitations for stormwater discharges: cement manufacturing (40 CFR 411), feedlots (40 CFR 412), fertilizer manufacturing (40 CFR 418), petroleum refining (40 CFR 419), phosphate manufacturing (40 CFR 422), steam electric (40 CFR 423), coal mining (40 CFR 434), mineral mining and processing (40 CFR 436), ore mining and dressing (40 CFR 440), and asphalt emulsion (40 CFR 443).

Best Management Practices

BMPs encompass a wide range of management procedures, schedules of activities, prohibitions on practices, and other management practices to prevent or reduce the pollution of waters of the United States. BMPs also include operating procedures, treatment requirements and practices to control plant site runoff, and drainage from raw materials storage, spills, or leaks. Requirements for BMP-based pollution prevention plans generally applicable to all industries are discussed in more detail in the paper in the context of the U.S. Environmental Protection Agency's (EPA's) general permits for stormwater discharges associated with industrial activity.

In addition to generic BMPs or pollution prevention plans, industry- or activity-specific BMPs can be used. Table 1 provides a listing of industry-specific BMPs that the Washington State Department of Ecology has developed.[1]

Diversion of Discharge to Treatment Plant

Where stormwater discharges contain significant amounts of pollutants that can be removed by a wastewater or sewage treatment plant, the stormwater discharge can be diverted to a wastewater treatment plant or sanitary sewage system. Such diversions must be coordinated with the operators of the sewage treatment plant and the collection system to avoid problems with either combined sewer overflows (CSOs), basement flooding, or wet weather operation of the treatment plant. Where CSO discharges, flooding or plant operation problems can result, and onsite storage followed by a controlled release during dry weather conditions may be considered.

Traditional Stormwater Management Practices

In some situations, traditional stormwater management practices such as grass swales, catch basin design and maintenance, infiltration devices, unlined onsite retention and detention basins, regional controls (offsite retention or detention basins), and oil and grit separators can be applied to an industrial setting. Care must be taken, however, to evaluate the potential of many of these traditional devices for ground-water contamination. Other types of controls, such as secondary containment systems, can be used to prevent catastrophic events that can lead to surface or ground-water contamination via traditional stormwater measures. In some cases, it is appropriate to limit traditional stormwater management practices to those areas of the drainage system that generate stormwater with relatively low levels of pollutants (e.g., many rooftops, parking lots, etc.). At facilities located in northern areas of the country, snow removal activities may play an important role in a stormwater management program.

Elimination of Pollution Sources/Water Reuse

In some cases, the elimination of a pollution source or water reuse may be the most cost-effective way to control pollutants in stormwater discharges associated with industrial activity. Options for eliminating pollution sources include reducing onsite air emissions affecting runoff quality, changing chemicals used at the facility, and modifying materials management practices such as moving storage areas into buildings. Water reuse involves collecting runoff and using it in a process or in some manner that does not release the pollutants in the stormwater to the environment. For example, many inorganic wood preserving facilities use drip pad runoff to dilute wood preserving fluids used in their processes. In some cases, it may be less expensive to store and treat stormwater for subpotable, industrial water supply purposes than purchasing municipal potable water.

Clean Water Act Requirements

In 1972, the Clean Water Act (CWA) was amended to provide that the discharge of any pollutants to waters of the United States from a point source is unlawful, except where the discharge is authorized by an NPDES permit. The term "point source" is broadly defined to include "any discernible, confined and discrete conveyance, including but not limited to any pipe, ditch, [or] channel, . . . from which pollutants are or may be discharged." Congress has specifically exempted agricultural stormwater discharges and return flows from irrigated agriculture from the definition of point source.

Most court cases have supported a broad interpretation of the term "point source" under the CWA. For example, the holding in *Sierra Club v. Abston Construction Co., Inc.*, 620 F 2d. 41 (5th Cir., 1980) indicates that changing the surface of land or establishing grading patterns on land where the runoff from the site ultimately is discharged to waters of the United States will result in a point source:

> A point source of pollution may be present where [dischargers] design spoil piles from discarded overburden such that, during periods of precipitation, erosion of spoil pile walls results in discharges into a navigable body of water by means of ditches, gullies and similar conveyances, even if the [dischargers] have done nothing beyond the mere collection of rock and other materials. . . . Nothing in the Act relieves [dischargers] from liability simply because the operators did not actually construct

[1] The document *Best Management Practices for the Use and Storage of Hazardous Materials* (14) also provides examples of industry-specific BMPs. The guidance addresses small mechanical repair facilities, large mechanical repair facilities, dry cleaning facilities, junkyards, photo processing facilities, print shops and silk screen shops, machine shops and airport maintenance facilities, boat manufacturing and repair facilities, concrete plants and mining facilities, agricultural facilities, paint manufacturers and distributors, and plastics manufacturers.

Table 1. Categories of Targeted Stormwater Controls Addressed in Puget Sound Guidance (13)

Category	Targeted Stormwater Controls
Manufacturing facilities	Cement
	Chemical
	Concrete products
	Electrical products
	Food products
	Glass products
	Industrial machinery and equipment, trucks and trailers, aircraft, parts and aerospace, railroad equipment
	Log storage and sorting yards, debarking
	Metal products
	Petroleum products
	Printing and publishing
	Rubber and plastic products
	Ship and boat building and repair yards
	Wood products
	Wood treatment
	Other manufacturing businesses
Transportation and communication	Airfields and aircraft maintenance
	Fleet vehicle yards
	Railroads
	Private utility corridors
	Warehouses and miniwarehouses
	Other transportation and communication businesses
Wholesale and retail businesses	Gas stations
	Recyclers and scrap yards
	Restaurants/fast food
	Retail general merchandise
	Retail/Wholesale vehicle and equipment dealers
	Retail/Wholesale nurseries and building materials
	Retail/Wholesale chemicals and petroleum
	Retail/Wholesale foods and beverages
	Other retail/wholesale businesses
Service businesses	Animal care services
	Commercial car and truck washes
	Equipment repair
	Laundries and other cleaning
	Marinas and boat clubs
	Golf and country clubs, golf courses, and parks
	Miscellaneous services
	Professional services
	Vehicle maintenance and repair
	Multifamily residences
	Construction businesses
Pubic agencies	Public buildings and streets
	Vehicle and equipment maintenance shops
	Maintenance of open space areas
	Maintenance of public stormwater facilities
	Maintenance of roadside vegetation and ditches
	Maintenance of public utility corridors
	Water and sewer districts and departments
	Port districts
Source controls	Fueling stations
	Vehicle/Equipment washing and steam cleaning
	Loading and unloading liquid materials
	Liquid storage in aboveground tanks
	Container storage of liquids, food wastes, and dangerous wastes
	Outside storage of raw materials, byproducts, and finished products
	Outside manufacturing activities
	Emergency spill cleanup plans
	Vegetation management/integrated pest management
	Maintenance of storm drainage facilities
	Locating illicit connections to storm drains

those conveyances. . . . Conveyances of pollution formed either as a result of natural erosion or by material means, and which constitute a component of a drainage system may fit the statutory definition and thereby subject the operators to liability under the Act.

Although the definition of point source is very broad, before 1987 efforts under the NPDES program to control water pollution focused on controlling pollutants in discharges from publicly owned treatment works (POTWs) and industrial process wastewaters. The major exceptions to this are the 10 effluent limitation guidelines that EPA has issued for stormwater discharges: cement manufacturing (40 CFR 411), feedlots (40 CFR 412), fertilizer manufacturing (40 CFR 418), petroleum refining (40 CFR 419), phosphate manufacturing (40 CFR 422), steam electric (40 CFR 423), coal mining (40 CFR 434), mineral mining and processing (40 CFR 436), ore mining and dressing (40 CFR 440), and asphalt emulsion (40 CFR 443).

As part of the Water Quality Act of 1987, Congress added Section 402(p) to the CWA to require EPA to develop a comprehensive, phased program for regulated stormwater discharges under the NPDES program. One of the first priorities under the stormwater program was to develop NPDES requirements for stormwater discharges associated with industrial activity.

On November 16, 1990, EPA published the initial NPDES regulations under Section 402(p) of the CWA (see 55 FR 47990). The November 16, 1990, regulations:

- Defined the initial scope of the program by defining the terms "stormwater discharge associated with industrial activity" and large and medium "municipal separate storm sewer systems."
- Established permit application requirements.

The regulatory definition of the term "stormwater discharge associated with industrial activity" is provided at 40 CFR 122.26(b)(14) and addresses point source discharges of stormwater from eleven major categories of facilities. Table 2 summarizes these 11 major categories.

The NPDES regulations provided three options for submitting permit applications for stormwater discharges associated with industrial activity: 1) individual applications, 2) group applications for groups of similar industrial discharges, and 3) where an appropriate general permit has been issued, submittal of a notice of intent (NOI) to be covered by a general permit. The group application option is no longer available; EPA received over 1,100 group applications covering over 45,000 facilities. The Agency has organized these applications into the 32 industrial sectors shown in Table 3 and intends to develop guidance on issuing permits for the 32 industrial sectors.

Table 2. Summary of Classes of Industrial Facilities Addressed by Regulatory Definition of "Stormwater Discharge Associated With Industrial Activity"

Class	Description
(i)	Facilities subject to stormwater effluent limitations guideline, new source performance standards, or toxic pollutant effluent standards (see 40 CFR Subpart N)
(ii)	Manufacturing facilities classified as Standard Industrial Classification (SIC) 24 (except 2434), 26 (except 265 and 267), 28 (except 283), 29, 311, 32 (except 323), 33, 3441, and 373
(iii)	Active and inactive mining operations classified as SIC 10-14
(iv)	Hazardous waste treatment, storage, or disposal facilities that are operating under interim status or a permit under Subtitle C of RCRA
(v)	Landfills, land application sites, and open dumps that receive industrial wastes
(vi)	Recycling facilities, including metal scrapyards, battery reclaimers, salvage yards, and automobile junkyards
(vii)	Steam electric power generating facilities
(viii)	Transportation facilities classified as SIC 40, 41, 42 (except 4221-25), 43, 44, 45, and 5171, which have vehicle maintenance shops, equipment cleaning operations, or airport deicing operations
(ix)	Sewage treatment plants with a design flow of 1.0 million gal/day or more or required to have an approved pretreatment program
(x)	Construction activities except operations that result in the disturbance of less than 5 acres of total land area and that are not part of a larger common plan of development or sale
(xi)	Facilities under SIC 20, 21, 22, 23, 2434, 25, 265, 267, 27, 283, 285, 30, 31 (except 311), 323, 34 (except 3441), 35, 36, 37 (except 373), 38, 39, and 4221-25 (and which are not otherwise included within categories (i)-(x))

Table 3. Industrial Sectors Identified in NPDES Group Application Process

Sector	SIC Codes/Activities Represented	Number of Facilities
1	SIC 24—Lumber and Wood Products	2,640
2	SIC 26—Paper and Allied Products	1,023
3	SIC 28—Chemicals and Allied Products	1,498
4	SIC 29—Petroleum Refining and Related Industries	2,245
5	SIC 32—Stone, Clay, Glass, and Concrete Products	4,786
6	SIC 33—Primary Metal Industries	730
7	SIC 10—Metal Mining	188
8	SIC 12—Coal Mining	495
9	SIC 13—Oil and Gas Extraction	457
10	SIC 14—Mining and Quarrying of Nonmetallic Minerals	2,437
11	Hazardous Waste Treatment Storage or Disposal Facilities	77

Table 3. Industrial Sectors Identified in NPDES Group Application Process (continued)

Sector	SIC Codes/Activities Represented	Number of Facilities
12	Industrial Landfills, Land Application Sites, and Open Dumps	1,430
13	SIC 5015—Used Motor Vehicle Parts	2,009
14	SIC 5093—Scrap and Waste Materials	1,688
15	Steam Electric Power Generating Facilities	162
16	SIC 40—Railroad Transportation	1,024
17	SIC 41—Local and Suburban Transit and Interurban Highway Passenger Transportation SIC 42—Motor Freight Transportation SIC 43—United States Postal Service	13,089
18	SIC 44—Water Transportation	368
19	SIC 3731—Ship Building and Repairing SIC 3732—Boat Building and Repairing	498
20	SIC 45—Air Transportation	1,581
21	SIC 5171—Petroleum Bulk Stations and Terminals	131
22	Domestic Wastewater Treatment Plants	1,249
23	SIC 20—Food and Kindred Products SIC 21—Tobacco Products	2,608
24	SIC 22—Textile Mill Products SIC 23—Apparel and Other Finished Products Made From Fabrics and Similar Materials	872
25	SIC 25—Furniture and Fixtures	339
26	SIC 27—Printing, Publishing, and Allied Industries	65
27	SIC 30—Rubber and Miscellaneous Plastic Products	190
28	SIC 31—Leather and Leather Products	61
29	SIC 34—Fabricated Metal Products SIC 391—Jewelry, Silverware, and Plated Ware	965
30	SIC 35—Industrial and Commercial Machinery SIC 37—Transportation Equipment	935
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Long-Term Strategy

Many of the initial concerns regarding the NPDES stormwater program focused on adapting the NPDES permit program to effectively address the large number of stormwater discharges associated with industrial activity. In response to these concerns, EPA developed a strategy for permitting stormwater discharges associated with industrial activity that will serve as a foundation for future program development and technology transfer. The strategy consists of two major components: a tiered framework for developing permitting priorities and a framework for the development of state stormwater management plans.

Permitting Priorities

Under the strategy, most stormwater permitting activities are described in terms of the following four classes of activities:

- *Tier I—Baseline permitting:* One or more general permits will be developed initially to cover the majority of stormwater discharges associated with industrial activity.
- *Tier II—Watershed permitting:* Facilities within watersheds shown to be adversely affected by stormwater discharges associated with industrial activity will be targeted for individual or watershed-specific general permits.
- *Tier III—Industry-specific permitting:* Specific industry categories will be targeted for individual or industry-specific general permits.
- *Tier IV—Facility-specific permitting:* A variety of factors will be used to target specific facilities for individual permits.

These four classes of activities will be implemented over time and will reflect priorities within given states. In most states, Tier I activities will be the starting point. Initially, the coverage of the baseline permits will be broad. As priorities and risks within the state are evaluated, however, classes of stormwater discharges or individual stormwater discharges will be identified for Tier II, III, or IV permitting activities.

State Stormwater Management Programs

State stormwater management programs are to provide, among other things, a description of NPDES permit issuing activities for stormwater discharges associated with industrial activity, including categories of industrial activity that are being considered for industry-specific general permits. These plans will assist EPA in developing technology transfer activities with other states, evaluating states' progress in implementing stormwater permitting activities, and identifying both successes and difficulties with ongoing program implementation.

EPA's Baseline General Permits

Consistent with the long-term permit issuance strategy, EPA published Tier I general permits, which potentially could apply to the majority of stormwater discharges associated with industrial activity located in 12 states on

September 9, 1992, and September 25, 1992 (see 57 FR 41236 and 57 FR 44438). The 12 states where the EPA general permits apply are Alaska, Arizona, Florida, Idaho, Louisiana, Maine, Massachusetts, New Hampshire, New Mexico, Oklahoma, South Dakota, and Texas. Other states have authorized NPDES state programs, and the state issues NPDES permits instead of EPA.

Consolidating many sources under a general permit greatly reduces the administrative burden of issuing permits for stormwater discharges associated with industrial activity. Several advantages to this approach are:

- Pollution prevention measures and/or BMPs are established for discharges covered by the permit.
- Facilities whose discharges are covered by the permit are certain of their legal responsibilities and have an opportunity to comply with the CWA.
- EPA and authorized NPDES states will begin to collect and review data on stormwater discharges from priority industries, thereby supporting subsequent permitting activities.
- The public, including municipal operators of municipal separate storm sewers, will have the opportunity to review data and reports developed by industrial permittees pursuant to NPDES requirements.
- The baseline permits will provide a basis for coordinating 1) requirements for stormwater discharges associated with industrial activity with 2) requirements of municipal stormwater management programs in permits for discharges from municipal separate storm sewer systems.
- The baseline permits will provide a basis for bringing selected enforcement actions.
- The baseline permit, along with state stormwater permitting plans, will provide a focus for public comment on draft permits and subsequent phases of the permitting strategy for stormwater discharges.

The Agency believes that Tier I permits can establish the appropriate balance between monitoring requirements and implementable controls that will initiate facility-specific controls and provide sufficient data for compliance monitoring and future program development.

Permit Requirements

The major requirements of EPA's Tier I stormwater general permits are notification requirements, requirements for stormwater pollution prevention plans, and special requirements for selected facilities.

Notification Requirements

The general permits require the submittal of an NOI by the discharger before the authorization of discharges. In addition, operators of stormwater discharges that discharge through a large or medium municipal separate storm sewer system must, in addition to submitting an NOI to the Director, submit a copy of the NOI to the municipal operator of the system receiving the discharge.

Tailored Pollution Prevention Plan Requirements

All facilities covered by EPA's general permits must prepare and implement a stormwater pollution prevention plan. These tailored requirements allow the implementation of site-specific measures that address features, activities, or priorities for control associated with the identified stormwater discharges. The approach taken allows the flexibility to establish controls that can appropriately address different sources of pollutants at different facilities.

The pollution prevention approach adopted in the general permits focuses on two major objectives: 1) to identify sources of pollution potentially affecting the quality of stormwater discharges from the facility, and 2) to describe and ensure implementation of practices to minimize and control pollutants in stormwater discharges.

The stormwater pollution prevention plan requirements in the general permits are intended to facilitate a process whereby the operator of the industrial facility thoroughly evaluates potential pollution sources at the site and selects and implements appropriate measures to prevent or control the discharge of pollutants in stormwater runoff. The process involves the following four steps:

- Formation of a team of qualified plant personnel responsible for preparing the plan and assisting the plant manager in its implementation.
- Assessment of potential stormwater pollution sources.
- Selection and implementation of appropriate management practices and controls.
- Periodic evaluation of the ability of the plan to prevent stormwater pollution and comply with the terms and conditions of this permit.

This process is shown in Figure 1. A complete description of this process can be found in U.S. EPA (15).

Pollution Prevention Team

As a first step in the process of developing and implementing a stormwater pollution prevention plan, permittees must identify a qualified individual or team of individuals to be responsible for developing the plan and assisting the facility or plant manager in its implementation. When

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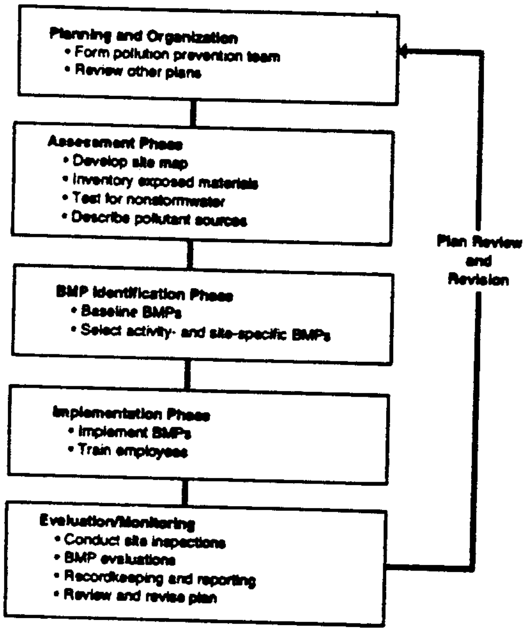

Figure 1. Pollution prevention plan process.

selecting members of the team, the plant manager should draw on the expertise of all relevant departments within the plant to ensure that all aspects of plant operation are considered. The plan must clearly describe the responsibilities of each team member as they relate to specific components of the plan. In addition to enhancing the quality of communication between team members and other personnel, clear delineation of responsibilities will ensure that a specified individual or group of individuals addresses every aspect of the plan.

Description of Potential Pollution Sources

Each stormwater pollution prevention plan must describe activities, materials, and physical features of the facility that may contribute significant amounts of pollutants to stormwater runoff or, during periods of dry weather, result in pollutant discharges through the separate storm sewers or stormwater drainage systems. This assessment of stormwater pollution risk will support subsequent efforts to identify and set priorities for necessary changes in materials, materials management practices, or site features, as well as aid in the selection of appropriate structural and nonstructural control techniques. Plans must describe the site drainage, provide an inventory of exposed materials, describe significant spills and leaks that have occurred at the facility, and include existing sampling data.

Each pollution prevention plan must include a certification that discharges from the site have been tested or evaluated for the presence of nonstormwater discharges. The certification must describe possible significant sources of nonstormwater, the results of any test and/or evaluation conducted to detect such discharges, the test method or evaluation criteria used, the dates on which tests or evaluations were performed, and the onsite drainage points directly observed during the test or evaluation. Acceptable test or evaluation techniques are discussed earlier in this paper.

The description of potential pollution sources culminates in a narrative assessment of the risk potential that sources of pollution pose to stormwater quality. This assessment should clearly point to activities, materials, and physical features of the facility that have a reasonable potential to contribute significant amounts of pollutants to stormwater. Any such activities, materials, or features must be addressed by the measures and controls subsequently described in the plan. In conducting the assessment, the facility operator must consider loading and unloading operations, outdoor storage activities, outdoor manufacturing or processing activities, significant dust or particulate generating processes, and onsite waste disposal practices. The assessment must list any significant pollution sources at the site and identify the pollutant parameter or parameters (i.e., biochemical oxygen demand, suspended solids, etc.) associated with each source.

Measures and Controls

Following completion of the source identification and assessment phase, the permittee must evaluate, select, and describe the pollution prevention measures, BMPs, and other controls that the facility will implement. BMPs include processes, procedures, schedules of activities, prohibitions on practices, and other management practices that prevent or reduce the discharge of pollutants in stormwater runoff.

The plan requirements emphasize the implementation of pollution prevention measures that reduce possible pollutant discharges at the source. Source reduction measures include, among others, preventive maintenance, chemical substitution, spill prevention, good housekeeping, training, proper materials management, material segregation or covering, water diversion, and dust control. The remaining classes of BMPs, which involve recycling or treatment of stormwater, allow the reuse of stormwater or attempt to lower pollutant concentrations before discharge.

The pollution prevention plan must include a schedule specifying the time or times during which each control or practice will be implemented. In addition, the plan should discuss ways in which the controls and practices relate to one another and, when taken as a whole, produce an integrated and consistent approach for preventing or controlling potential stormwater contamination problems. The portion of tne plan that describes the measures and controls must address the following minimum components:

- *Good housekeeping:* Good housekeeping involves using common sense to identify ways to maintain a clean and orderly facility and keep contaminants out of separate storm sewers. It includes establishing protocols to reduce the possibility of mishandling chemicals or equipment, and training employees in good housekeeping techniques.
- *Preventive maintenance:* Permittees must develop a preventive maintenance program that involves regular inspection and maintenance of stormwater management devices and other equipment and systems. The program description should identify the devices, equipment, and systems that will be inspected; provide a schedule for inspections and tests; and address appropriate adjustment, cleaning, repair, or replacement of devices, equipment, and systems. For stormwater management devices such as catch basins and oil/water separators, the preventive maintenance program should provide for periodic removal of debris to ensure that the devices are operating efficiently.
- *Spill prevention and response procedures:* Based on an assessment of possible spill scenarios, permittees must specify appropriate material handling procedures, storage requirements, containment or diversion equipment, and spill cleanup procedures that will minimize the potential for spills and in the event of a spill enable proper and timely response. Areas and activities that typically pose a high risk for spills include loading and unloading areas, storage areas, process activities, and waste disposal activities. These activities and areas, and their accompanying drainage points, must be described in the plan. For a spill prevention and response program to be effective, employees should clearly understand the proper procedures and requirements and have the equipment necessary to respond to spills.
- *Inspections:* Qualified facility personnel must be identified to inspect designated equipment and areas of the facility at appropriate intervals specified in the plan. A set of tracking or followup procedures must be used to ensure that appropriate actions are taken in response to the inspections.
- *Employee training:* The pollution prevention plan must describe a program for informing personnel at all levels of responsibility of the components and goals of the stormwater pollution prevention plan. Where appropriate, contractor personnel also must be trained in relevant aspects of stormwater pollution prevention.
- *Recordkeeping and internal reporting procedures:* The pollution prevention plan must describe procedures for developing and retaining records on the status and effectiveness of plan implementation. At a minimum, records must address spills, monitoring, and inspection and maintenance activities. The plan also must describe a system that enables timely reporting of stormwater management-related information to appropriate plant personnel.
- *Sediment and erosion control:* The pollution prevention plan must identify areas that, due to topography, activities, soils, cover materials, or other factors, have a high potential for significant soil erosion. The plan must identify measures that will be implemented to limit erosion in these areas.
- *Management of runoff:* The plan must contain a narrative evaluation of the appropriateness of traditional stormwater management practices (i.e., practices other than those that control pollutant sources) that divert, infiltrate, reuse, or otherwise manage stormwater runoff to reduce the discharge of pollutants. Appropriate measures may include, among others, vegetative swales, collection and reuse of stormwater, inlet controls, snow management, infiltration devices, and wet detention/retention basins.

Based on the results of the evaluation, the plan must identify practices that the permittee determines to be reasonable and appropriate for the facility. The plan also should describe the particular pollutant source area or activity to be controlled by each stormwater management practice. Reasonable and appropriate practices must be implemented and maintained according to the provisions prescribed in the plan.

In selecting stormwater management measures, it is important to consider the potential effects of each method on other water resources, such as ground water. Although stormwater pollution prevention plans primarily focus on stormwater management, facilities must also consider potential ground-water pollution problems and take appropriate steps to avoid adversely affecting ground-water quality. For example, if the water table is unusually high in an area, an infiltration pond may contaminate a ground-water source unless special preventive measures are taken. Under EPA's July 1991 Ground Water Protection Strategy, states are encouraged to develop comprehensive state ground-water protection programs (CSGWPP). Efforts to control stormwater should be compatible with state ground-water objectives as reflected in CSGWPPs.

Comprehensive Site Compliance Evaluation

The stormwater pollution prevention plan must describe the scope and content of comprehensive site inspections that qualified personnel will conduct to 1) confirm the accuracy of the description of potential pollution sources contained in the plan, 2) determine the effectiveness of the plan, and 3) assess compliance with the terms and conditions of the permit. The plan must indicate the frequency of such evaluations, which in certain cases must be at least once a year.

Material handling and storage areas and other potential sources of pollution must be visually inspected for evidence of actual or potential pollutant discharges to the drainage system. Inspectors also must observe erosion controls and structural stormwater management devices to ensure that each is operating correctly. Equipment needed to implement the pollution prevention plan, such as that used during spill response activities, must be inspected to confirm that it is in proper working order. The results of each site inspection must be documented in a report signed by an authorized company official.

Based on the results of each inspection, the description of potential pollution sources and the measures and controls in the plan must be revised as appropriate within 2 weeks after each inspection.

Special Requirements for Selected Facilities

EPA's general permits also establish special requirements for selected classes of facilities. These include:

- *Sampling requirements:* Targeted classes of facilities are required to monitor their stormwater discharges for specified parameters. Facilities that are a member of a targeted class but that can certify that they do not have materials or equipment exposed to precipitation are not required to monitor. This is intended to provide facilities with an incentive to eliminate exposure to precipitation.
- *EPCRA facilities:* Certain facilities that are subject to reporting requirements under Section 313 of the Emergency Planning and Community Right-to-Know Act (EPCRA) because they manufacture or use large amounts of toxic chemicals are subject to special requirements under the NPDES general permits. These special requirements include provisions that are similar to spill prevention, countermeasure, and control (SPCC) plan requirements, and include provisions for secondary containment or equivalent controls for liquid storage areas. In addition, a professional engineer (PE) must inspect the site, review the plan, and certify that the stormwater pollution prevention plan has been prepared in accordance with good engineering practices.
- *Salt piles:* Salt piles must be enclosed or covered to prevent exposure to precipitation.
- *Coal pile runoff:* The permit establishes numeric effluent limitations for coal pile runoff.

Municipal Role in Implementation

The NPDES stormwater program establishes a permit approach that envisions complementary, cooperative efforts by the permit-issuing agency and municipal operators of large and medium municipal separate storm sewer systems to develop programs that result in controls on pollutants in stormwater discharges associated with industrial activity that discharge through municipal systems.

Under the complementary permit approach, stormwater discharges associated with industrial activity that discharge through large and medium municipal separate storm sewer systems are required to obtain permit coverage. Permits for these discharges will establish requirements (such as pollution prevention requirements or monitoring) for industrial operators. Any records, reports, or information obtained by the NPDES permit-issuing authority as part of the permit implementation process, including site-specific stormwater pollution prevention programs that are developed pursuant to the draft general permit, are available to municipalities. This will assist municipalities in reviewing the adequacy of such requirements and developing priorities among industrial stormwater sources. In addition, these permits provide a basis for enforcement actions directly against the owner or operator of stormwater discharges associated with industrial activity.

A second permit, issued to the operator of the large or medium municipal separate storm sewer, establishes the responsibilities of the municipal operators in controlling pollutants from stormwater associated with industrial activity that discharges through their systems. Municipal programs to reduce pollutants in industrial site runoff specifically will address municipal responsibilities in controlling pollutants from industrial facilities. In addition, programs to identify and control nonstormwater discharges to municipal separate storm sewer systems will in many cases focus on industrial areas because these areas often have a significant potential for illicit connections, spills, and improper dumping.

Municipal operators of these systems can assist NPDES permit issuing authorities:

- By identifying priority stormwater discharges associated with industrial activity to their systems.
- In inspecting facilities and reviewing and evaluating stormwater pollution prevention plans that industrial facilities are required to develop under the draft general permit.
- In compliance efforts regarding stormwater discharges associated with industrial activity to their municipal systems.

A pilot program conducted by municipalities in the Santa Clara Valley illustrates how a municipality can work with an NPDES authority to control pollutants in stormwater discharges associated with industrial activities. (A more complete description of the pilot program and its findings is provided in the Santa Clara Valley Nonpoint Source Pollution Control Program [3]). One of the major goals of the program was to reduce discharges to storm drains of dry- and wet-weather heavy metals that result from activities such as processing, storage, and maintenance activities conducted at industrial sites. Components of the program included the following:

- Municipalities developed industrial inspection and illegal dumping/illicit connection programs to ensure that activities focus on priority industries.
- Monitoring requirements were established in the California NPDES general permit for industries. Municipalities evaluated monitoring data collected by priority industries.
- The California NPDES general permit allowed for exemption for industries from monitoring where the municipality provides certification that the industry pollution prevention plan is adequate.
- Municipalities developed industry specific guidance.[2]
- Municipalities implemented a "Clean Bay Business" award program.
- Market-based incentives were considered, such as trading reductions from car pooling and telecommunication programs for pretreatment requirements.

Key findings of the pilot programs identified the following components needed for a successful program:

- Hands-on field training conducted by an experienced industrial inspector.
- Classroom training on industrial stormwater requirements and on methods of communicating with facility managers.
- Classroom training on other related industrial regulatory programs (e.g., HAZMAT, pretreatment).
- A reference manual on the regulations and local legal authority.
- Adequate legal authority to allow site access and take progressive enforcement actions.
- Prioritizing facilities based on existing information before conducting inspections.
- Advance communications, in the form of a letter, to industries before conducting the inspections.
- A plan for followup actions, including enforcement, where necessary.

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[2]See *California Storm Water Best Management Practice Handbook: Industrial/Commercial* (16), which addresses how to prepare a stormwater pollution prevention plan and how to select BMPs. The guidance also addresses source controls for nonstormwater discharges; vehicle and equipment fueling; vehicle and equipment washing and steam cleaning; vehicle and equipment maintenance and repair; outdoor loading/unloading of materials; outdoor container storage of liquids; outdoor process equipment operations and maintenance; outdoor storage of raw materials, products, and byproducts; waste handling and disposal; contaminated or erodible surface areas; building and grounds maintenance; building repair; remodeling and construction; and overwater activities. In addition, the guidance covers treatment control BMPs and measuring BMP performance.

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The Role of Education and Training in the Development of the Delaware Sediment and Stormwater Management Program

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On May 31, 1990, the General Assembly of the State of Delaware enacted new legislation on stormwater management and placed it within the revised framework of the state's sediment control law to emphasize the integral relationship between the two programs. Governor Castle signed the legislation into law at a public ceremony on June 15, 1990. The effective date of the regulations was January 23, 1991. Program implementation was initiated on July 1, 1991.

The role of education and training in the development and implementation of Delaware's sediment and stormwater program was recognized at the legislative onset. The educational effort continued through the evolution, development, and promulgation of the regulations and remains an essential component of program strategy. The sediment and stormwater regulations are specific as to the training requirements and opportunities for education that are to be provided for contractors, construction review/inspection personnel, and plan design professionals.

This paper discusses the education and training accomplishments to date, their value to successful program inauguration, and specific training objectives being developed to meet the requirements of the new law and regulations in Delaware.

Background

The State of Delaware has had an erosion and sediment control program since 1978. That program was only marginally successful due to budget and personnel limitations. Environmentally oriented initiatives in other states and within the federal government have since provided an impetus for the Department of Natural Resources and Environmental Control (DNREC) to attempt program improvements with respect to sediment control and stormwater management.

In 1989, DNREC representatives conducted onsite reviews of the existing sediment control program to document program effectiveness. It was readily apparent that too few resources were devoted to a program that lacked legislative and regulatory authority. The site problems were recorded through slide documentation so that a public education program could be developed that clearly showed the need for program improvements.

At the same time, DNREC, in association with local conservation districts, was considering the need for a statewide stormwater management program that considered water quantity and water quality requirements. Fortunately (or unfortunately, depending on the perspective), during the summer of 1989, Delaware had several severe flooding events that reinforced the concept that the state needed a stormwater management program that would prevent existing problems from getting worse.

Delaware does not have a strong environmental lobby group to advocate the passage of new environmental programs, so DNREC has developed a consensus-style approach to get legislation and subsequent regulations accepted by the legislative bodies and the regulated community.

Legislative Process

As the legislation was developed, DNREC sponsored two workshops at which the concept behind the proposed legislation was discussed in a public forum accompanied by slide presentations. The slide presentation focused on problem identification, the proposed state program to address the problems, and the degree to which, in the opinion of DNREC, the sediment and stormwater program was going to evolve. Individual meetings were held with contractors' associations, engineering consultants, land developers, and the general public.

In addition to those workshops and meetings, presentations were made to legislative committees in an informal setting so that individual committee members would have a basic understanding of the need for legislation.

The proposed legislation passed through a state senate committee and the full senate in only 2 days, with not one negative vote. The passage of the legislation through two committees in the state house of representatives and the full house took approximately 1½ months and again received no negative votes. The educational process prior to submission of the legislation and during the legislative process was so successful that not one affected group submitted comments that were in opposition to the legislation. The legislation passed through three committees and two houses unanimously. The legislation was signed into law by Governor Castle in a public ceremony on June 15, 1990.

Regulatory Process

The legislation has several components that specifically address education and training, but one component critical to the process of regulation adoption was the requirement in the law that the regulations were to be developed with the assistance of a regulatory advisory committee. Recognizing the need for program consensus, DNREC placed the regulatory advisory committee requirement within the legislation so that the affected entities would participate in the regulatory process.

The regulatory advisory committee was composed of representatives of 20 organizations representing such groups as contractors, developers, consulting engineers, utility companies, local governments, and conservation districts. DNREC prepared drafts of the regulations prior to meetings. Each section, subsection, paragraph, sentence, and word that was proposed for the regulations was subject to the scrutiny of the regulatory review committee. Each member of the committee did not have to approve all aspects of the regulations, but rather the committee needed to substantially concur. Eight full committee meetings were held, and through the meeting process committee members could understand the rationale behind the various regulatory requirements. As a result, the committee members substantially concurred on all aspects of the regulations. In fact, committee members tended to become advocates of the regulations when they were published for public input.

In addition to the regulatory review committee process, meetings were also held with any interested individual or entity. Once the regulations were in a rough state of completion, three public workshops were held around the state to solicit input from a broader range of interests than just those represented by the regulatory review committee. The input received during this public review process was limited, but the informal public process prepared people for what was intended in the regulations so that any significant opposition to any of the requirements could be addressed before the formal regulation adoption process.

On the basis of the input received from the workshops, DNREC initiated formal regulation adoption procedures with no major changes to the body of the regulations. Announcements were placed in newspapers regarding DNREC's intentions, and a formal public hearing was held on January 16, 1991. Due to the consensus-building process, in which the regulated community participated in developing the regulations, not one adverse comment was received during the public hearing process. The entire public hearing took less than 15 minutes, as there were no questions or comments due to public awareness of the regulations' contents.

The entire process of legislative and regulatory development and approval clearly demonstrates that a consensus-building approach to environmental requirements may be an effective means of obtaining the programmatic infrastructure needed to implement an effective program. In large part due to the strong involvement of the regulated community, there is a significant effort in the law and regulations regarding education and training of contractors, inspectors, consultants, and the general public. It is the position of the authors that environmental programs can only be effective if the regulated community is involved in program development and evolution, recognizes the program need, and understands and accepts their obligations under the regulatory requirements. The individual educational and training obligations under the law and regulations are discussed as they affect the overall sediment and stormwater program.

Delaware Sediment and Stormwater Contractor Certification Program

During the development of the Delaware Sediment and Stormwater Regulations, a provision was made to provide for mandatory training and certification of individuals performing sediment and stormwater related construction. Section 13 of the regulations states that "After July 1, 1991, any applicant seeking sediment and stormwater plan approval shall certify to the appropriate plan approval agency that all responsible personnel involved in the construction project will have a certificate of attendance at a Departmental sponsored or approved training course for the control of sediment and stormwater, before initiation of land-disturbing activity."

"Responsible personnel" means any foreman or superintendent who is in charge of onsite clearing and land-disturbing activities for sediment and stormwater control associated with a construction project.

"Land-disturbing activity" means a land change or construction activity for residential, commercial, silvicultural, industrial, and institutional land uses that may result in soil erosion from water or wind or movement of sediments or pollutants into state waters or onto lands in the state, or which may result in accelerated stormwater runoff including, but not limited to, clearing, grading, excavating, transporting, and filling of land.

Contractor Certification Program Development

The development of the Contractor Certification Program was part of a general sediment and stormwater educational package funded by a Section 205 (G) grant under the Clean Water Act from the U.S. Environmental Protection Agency. Other tasks included a review of similar programs throughout the mid-Atlantic region, contracting for aerial photography of sites under construction, preparation of a portable soils exhibit, and identifying future training and educational needs. The grant tasks were carried out jointly through a memorandum of understanding between DNREC's Division of Water Resources and the New Castle Conservation District. A steering committee was formed in April 1990 and met seven times over the course of the following 9 months. The purpose of the committee was to provide input for the development and implementation of the grant tasks.

It was determined that the certification program was to use a slide presentation format since excellent documentation was already available and additional field slides were easily obtained. In addition to the field slides of sediment and stormwater construction practices, text and technical slides needed preparation. A local company was contracted to produce this material.

The certification program was developed with a 3½- to 4-hour time frame in mind. This would allow for morning or afternoon sessions, even occasional evenings, as necessary. Maryland has enjoyed success for many years in their sediment control training program using a similar format and time frame.

A 55-page narrative describing the slide presentation was developed and made available to the audience upon request. This was done to encourage attention to the slide presentation rather than preoccupation with taking notes. Finally, it was decided that participants should receive a durable plastic laminate card with the state logo and the individual's name and certification number imprinted on it. This would give the participants a tangible item to associate with the completion of the program.

Contractor Certification Program Implementation

By the end of January 1991, the program was ready to be presented. Certain restrictions were placed upon class size in order to communicate most effectively. Optimal class size was 30 to 40 members. Limiting the class size meant that the program would have to be presented many times; therefore, by July 1, 1991, not all of the contractors needing to complete the certification program would have the opportunity to do so. The Sediment and Stormwater Regulations provide for interim certification if individuals notify DNREC of their intent to register for the next available course.

The certification program was designed for presentation in two ways. First, the conservation districts, counties, and other agencies given the responsibility of certain program elements would set up the programs in their own jurisdictions, giving them a chance to meet with the regulated community and explain local program requirements. Second, DNREC would present the program to any regulated company, business or organization if they could provide a suitable location and a minimum of 15 individuals to be trained. DNREC also provided training for DNREC staff and several hundred Delaware Department of Transportation inspectors, technical staff, and engineers.

Throughout the first 6 months of presentations, we were surprised and pleased not only with the response from the contractors but also from the engineers, consultants, and developers who wanted to attend the certification program. All told, from February 1991 until July 1991, DNREC presented the program on 37 occasions, certifying over 1,100 individuals from 300 companies and organizations.

As stated earlier, this was possible only with the assistance from the three state conservation districts, county governments, the Department of Transportation, and organizations such as the Associated Builders and Contractors and the Delaware Contractors Association. As of January 1, 1993, almost 2,000 individuals have completed this training.

Initially, a program quiz was developed not so much to grade the participants but to obtain feedback on the retention of the material being provided. A program evaluation was later substituted for the quiz so that we could determine if any changes or improvements should be made to the training program. A representative sample of 100 evaluations was compiled, the results of which appear in Figure 1. Most notable is that 96 percent of respondents would recommend this training (Question 7), and 86 percent wished to continue in this training (Question 8).

By continuing the Contractor Certification Program, not only are the requirements of the Delaware Sediment and Stormwater Regulations being met, but the knowledge gained by the participants in this program is being transferred to the field through proper construction practices.

Delaware Certified Construction Reviewer Course

The Delaware Sediment and Stormwater Regulations also provide for special site inspection or review requirements under certain site conditions. Section 12 of the

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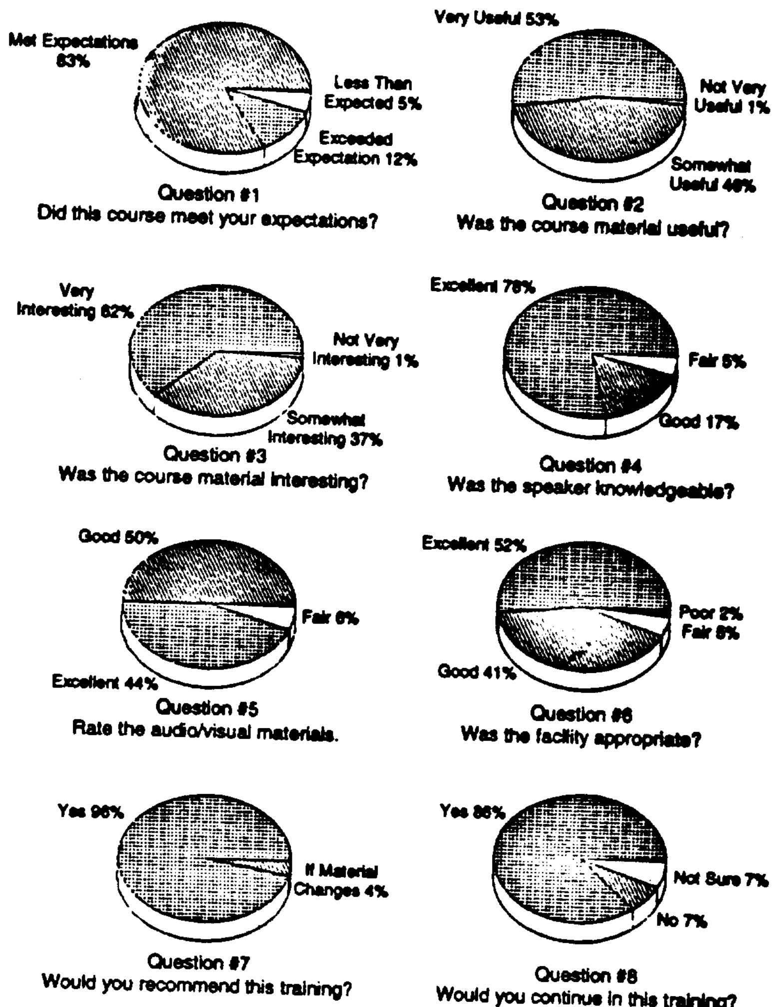

Figure 1. Sediment and stormwater contractor certification program course evaluation.

regulations identifies these site conditions that allow DNREC or the appropriate plan approval agency to require that a certified construction reviewer be present on site. Examples of site conditions that would warrant this requirement would be a site in excess of 50 acres of disturbed area or any site experiencing significant sediment and stormwater problems. The owner or developer of the site in these cases would be responsible for providing a certified construction reviewer for any or all parts of the construction phase as deemed necessary by the plan approval agency. The main responsibility of these individuals is to ensure the adequacy of construction pursuant to the approved sediment and stormwater management plan.

As with the Contractor Certification Program, DNREC has the responsibility to provide training to certify these construction reviewers. A formal Sediment and Stormwater Management Certified Construction Reviewer Course was developed in cooperation with Delaware Technical and Community College. Course material was developed to instruct participants in basic hydrology and hydraulics, soils, vegetative establishment, construction practices, plan preparation and implementation, inspection, enforcement, and maintenance. To instruct this course, over 20 professionals in the area of sediment and stormwater management were recruited, representing government agencies, private industry, and the consulting and engineering community.

The course format was developed to be presented in eight 3½-hour weekly sessions. An examination was developed and arrangements made with Delaware Technical and Community College for Continuing Education Credits to be issued.

We anticipated a lot of interest in this course offering, so registration was limited to one individual per company or organization. In addition to the private community, an attempt was made to include at least one individual that works for each agency responsible for delegation of sediment and stormwater program elements. In all, 85 seats were quickly filled for this course. The second time this course was offered, the class sessions were reduced to four all-day sessions. This seemed to suit the class participants' schedule better.

One important measure of success is the evaluation question that asked class participants to indicate whether the course did not meet, met, or exceeded expectations. The breakdown is as follows:

- 41 responses, or 74 percent of the class, stated that the course met their expectations.
- 12 responses, or 22 percent of the class, stated that the course exceeded their expectations.
- 2 responses, or 3.5 percent of the class, stated that the course did not meet their expectations.

The success of this program is directly attributable to the preparation of the speakers, the attentiveness of the class, and the hard work of the Delaware Sediment and Stormwater Program staff.

Stormwater Management Technical Sessions

The engineering and design community in Delaware has also indicated the need for DNREC to present more design-oriented training in sediment and stormwater management. To date, there have been several workshops in U.S. Department of Agriculture Soil Conservation Service TR-55 and TR-20 hydrologic analyses sponsored by local conservation districts and enlisting the assistance of the Soil Conservation Service. DNREC recognizes the need to expand this basic training and make available more design-oriented training for the consultant community.

Coinciding with the development and release of the *Delaware Stormwater Management Design Manual* in the summer of 1993, training classes were scheduled to present this material in modules, as the manual was developed. This training will help ensure that stormwater management practices are designed to meet established minimum criteria.

Summary

The education and training component of the Delaware Sediment and Stormwater Management Program is one of several areas of program development that will continue to respond to the needs of the regulated community. One obvious benefit in a small state like Delaware is that the efforts of a regulatory agency in providing education and training to the regulated community are recognized and appreciated. As previously discussed, the Sediment and Stormwater Management Program depends highly on interagency cooperation and communication with the businesses and industry involved. By maintaining education and training objectives as a high priority, DNREC will increase chances for program success.

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Development and Implementation of an Urban Nonpoint Pollution Educational and Informational Program

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Abstract

Sampling, Abatement, Follow-up, Education, and Response (SAFER) was formed by the Washtenaw County's Environmental Interest Group on January 1, 1992. SAFER includes the county departments of Environmental Coordination, Environmental Services, Drain Commissioner, Planning, and Cooperative Extension, as well as the Soil Conservation District, Huron River Watershed Council, Ecology Center of Ann Arbor, and the Southeast Regional Groundwater Education Center. The purpose of SAFER is to "provide for coordination of water protection programs through inter- and intra-county agencies and group cooperation."

Education is a key element of SAFER. Four groups are targeted for education by SAFER: government, business and industry, community groups, and schools. SAFER members develop their own specific educational programs and materials. Through SAFER, these are coordinated to provide uniform and accurate information to targeted segments of the community. This avoids costly duplication of services.

To effectively deliver an educational program, the target audience must first be determined, then an analysis of existing educational programs must be made to build on past successes. Through this process, an approach is determined that is most likely to be successful. Prior to beginning the educational program, the establishment of an evaluation process is critical.

Overview of Washtenaw County's SAFER Group

Sampling, Abatement, Follow-up, Education, and Response (SAFER) was formed by Washtenaw County's Environmental Issues Group on January 1, 1992. The Environmental Issues Group consists of departments within Washtenaw County government that indirectly or directly manage the environment of Washtenaw County. This provides the county with a coordinated approach to addressing environmental issues. The Environmental Issues Group is chaired by the Environmental Coordination Office. Other member groups within the Environmental Interest Group are the Sheriff's Department, Environmental Services, Emergency Management, Planning, Public Works, Drain Commissioner, and Cooperative Extension, as well as the county's Health Officer. This group meets monthly to discuss the status of county programming, pending state and federal legislation, "hot" environmental topics or issues, and strategic planning.

SAFER was formed as a work group of the Environmental Issues Group "to provide for coordinative water protection programs through inter- and intracounty agencies and group cooperation." SAFER consists of groups internal and external to Washtenaw County government that are involved in dealing with the county's ground and surface water. SAFER includes the county departments of Environmental Coordination, Environmental Services, Drain Commissioner, Planning, Cooperative Extension, Soil Conservation District, Huron River Watershed Council, and Ecology Center of Ann Arbor, as well as the Southeast Regional Groundwater Education Center (SER-GEM). During its first year of operation in 1992, the group focused on categorizing and compiling all current water quality programs and their products. The 1992 SAFER Directory compiled over 100 products addressing water quality issues within the county.

Education is a key element of SAFER. Four target groups for educational programs in SAFER are government, business and industry, community groups, and schools. The SAFER Educational Subcommittee in 1993 is compiling all educational programs and materials on water quality related issues, similar to the 1992 SAFER Directory. Through SAFER, educational materials are coordinated to provide current and accurate

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information to the community while avoiding costly duplication of services.

Urban Nonpoint Pollution Education

The development and implementation of a nonpoint pollution educational and informational program is critical to a successful urban project. Public awareness of urban nonpoint pollution is relatively low, and the media tends to focus on health or environmental risks that are easy to define, such as AIDS or hazardous waste issues. Due to its nature, nonpoint pollution is harder to pinpoint. Urban nonpoint pollution prevention requires a long-term commitment to changing attitudes.

Urban nonpoint pollution can be directly attributed to people. We all contribute to it. People are accustomed to focusing on easier issues, where the blame can be attributed to activities outside their control. An example is auto safety. People are very concerned about vehicle safety when a manufacturing error is the cause, such as exploding gas tanks. These same people, however, are not as focused on actions that they control, such as wearing seat belts.

An environmental example is oil spills. A study by the Michigan Department of Natural Resources (MDNR) in 1989 found that more oil is illegally released into the environment in Michigan annually than was released in the Valdez tanker incident. Getting people to buy into the idea that they are a major part of the problem is a critical step in gathering their support and cooperation.

Target Audience

Before an education information program can be developed, the target audience must be identified. A general educational approach will not change the habits of a wide range of target groups. Each targeted group must be analyzed independently to understand its particular needs and to develop specific actions it can take. Next, the various media options must be explored.

A multimedia approach enhances the opportunities of reaching larger segments within the target audience. For example, handing out flyers at a garden show will not reach several socioeconomic classes; a spot on a local radio station may be more appropriate. Some common public outreach materials are fact sheets, pamphlets, radio, television, newspapers, magazines, displays, models, posters, group presentations, and one-on-one or community events.

Using existing resources in your educational program is important. An educational program workshop for composting in the community could also be a forum for supplying information to the public on preventing urban nonpoint pollution through the proper application of fertilizers and use of environmentally friendly alternatives to pesticides. By networking with existing programs in the community, nonprofit programs will not compete for and confuse the audience.

Educational Gaps

After analyzing current educational resources within the community, identify audiences and approaches not currently used. All targeted groups need to receive your message. Target groups in the community must "buy into" their contribution to nonpoint pollution and their ability to prevent or minimize it. Urban educational programs must be innovative, well conceived, multimedia, and coordinated with other educational programs in the community.

A large number of ongoing urban nonpoint education programs exist in communities throughout the country. These programs have been developed for various types of audiences. Prior to implementing a program "from scratch," review all ongoing programs. These can be found in EPA "News Notes," as well as through professional groups, conferences, and environmental publications. Regional EPA offices are also a valuable resource for finding suitable ongoing programs. Using existing programs saves time and money.

Program Evaluation

An integral part of all educational programs is evaluation. Valuable time and resources can be wasted if information supplied to an audience is not effective. When developing the evaluation mechanism for the educational process, make sure the educational program focus enhances the overall water quality objectives. One way to evaluate the educational process is to apply Bennett's Hierarchy of Evidence for Program Evaluation. Bennett uses seven steps of evaluation. In an inverted scale, these steps are:

1. Inputs of program resources that are used to make the program work.
2. Activities which can include internal events, such as planning, or external events involving an audience.
3. Involvement of the target audience in activities, focusing on hands-on type activities.
4. The target audience's view of the program.
5. KASA change, or the change in knowledge, attitudes, skills, or aspirations of the audience.
6. Changes in behavior that result from the educational program.
7. End results that reflect the program's goals and objectives.

Many techniques can be used to measure the seven Bennett attributes. The basic who, what, where, and when questions are useful when establishing the specific evaluation technique.

Many books and guides can help in developing program evaluation. Studying these before finalizing an evaluation process is highly recommended. If there are time constraints or expertise is not available for evaluation, this component can be done by an outside party. The key is to establish the evaluation mechanism before implementing the educational program.

Huron River Pollution Abatement Program

Overview

The Huron River Pollution Abatement Project (HRPAP), which encompassed the urbanized area of Washtenaw County, was formed and implemented in 1986 by the county's Drain Commissioner's Office in conjunction with the Environmental Services Department. Public education was a major objective of the project. The educational program used by the HRPAP was designed after reviewing earlier area pilot water quality programs and their targeted community groups. The HRPAP focused on business, industry, community, and school groups.

Business/Industry

The HRPAP conducted surveys and dye tests of facilities located in the urbanized areas of Washtenaw County. Staff interviewed facility owners and managers on their particular businesses and gained critical information about their operations. When a common need was found—for example, an owner unable to dispose of a certain type of waste—the project staff worked with the owner to resolve the problem. For example, many facility operators with oil separators were not familiar with separators and were unable to find a licensed waste hauler to service them. The HRPAP developed a maintenance guideline for the operators, contacted all local waste haulers, and developed a list of haulers that would service oil separators. This information was then distributed to all facilities with oil separators.

Community and Civic Group Education

Over 200 educational presentations were made to the community during the HRPAP's 6 years. The HRPAP used various media to educate the community. One of the most effective was the local press. Articles concerning the HRPAP were published on an ongoing basis. Press releases noted significant events and common problems found within the community.

A second approach to outreach was through community events. Examples are the Ann Arbor City Art Fair and the Ypsilanti City Heritage Festival. These events attract hundreds of thousands of people. Display booths and pamphlets were developed for participating in these events. This became a forum for discussing water quality related issues one-on-one with the public.

School Education

The HRPAP made its first school educational presentation to a third-grade class in 1988. Word of mouth led to over 25 presentations per year in six local school districts. HRPAP student interns with an educational background formulated lesson plans for different grade levels on nonpoint pollution and related topics, such as the water cycle and household hazardous waste.

In classrooms, educational programs concentrated on hands-on activities. Two water quality models were built. One electronic model, entitled "Pathways to Pollution," lights up various pollution pathways when the appropriate button is pushed. A second model is a transparent representation of a town showing the sanitary and storm sewer systems. The students place a dye into catch basins, floor drains, and toilets to observe the route the water takes directly to the stream or the wastewater treatment plant. This model has examples of both proper and improper connections.

Conclusions

The majority of urban nonpoint pollution can be directly attributed to the activities of people. Most people are not aware of the impacts their routine activities at home and at work have on water quality. Education is a key component to improving urban water quality problems. Key target audiences in the community need to be identified, existing educational resources studied, educational program gaps identified, and an evaluation process included to measure a program's effectiveness.

The key to an educational program is to focus on practical activities that the target group can do to eliminate water pollution. A long-term, sustained educational effort leads to an increased awareness and respect for the interdependence of all elements in the ecosystem and for how individual activities affect them. This ultimately leads to a sense of mutual responsibility and a long-term commitment to continued environmentally sound actions.

Acknowledgments

The author would like to acknowledge the support and help of Dr. Rebecca Head, Group Director, Environment and Infrastructure; Janis Bobrin, Drain Commissioner; Robert Blake, Director, Environmental Services; David Dean; H. Leon Moore; Jeffry Krcmarik; and David Wilson, as well as other members of SAFER.

Training for Use of New York's Guidelines for Urban Erosion and Sediment Control

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Introduction

New York State still does not have a statewide erosion and sediment control law. Unlike many of its neighboring states, New York continues to leave the initiation of such control to local units of government. Historically, counties, towns, and villages have enacted ordinances once a significant environmental accident has occurred. Jurisdiction occurs at the local level, with planning boards having approval authority to issue permits to develop. Because each board is dealing with its local area, the regulations and processes for gaining approval vary from locale to locale.

Technical standards for controlling erosion and sediment were developed by the Soil Conservation Service in March 1988 and issued as *New York Guidelines for Urban Erosion and Sediment Control*. This document provides design details and specifications for both temporary and permanent management practices, as well as resource-planning concepts. Known as the "Blue Book," the document provides consistency in the technical approach to erosion and sediment control plans for construction sites. It has been adopted by the New York State Department of Environmental Conservation and the U.S. Army Corps of Engineers, Buffalo District, as criteria for erosion and sediment control plans. The New York State Department of Transportation has incorporated many of its details into its highway design manual.

In April 1992, the New York State Department of Environmental Conservation (NYS-DEC), Division of Water, published *Reducing the Impacts of Stormwater Runoff From New Development*. This document establishes performance standards for stormwater management control in New York for projects requiring NYS-DEC review. Standards were set for both water quantity and water quality. Water quantity is addressed by requiring no greater discharges from the site after development than present before development for the 2-, 10-, and 100-year frequency storm events. Water quality is addressed by retaining the "first flush," which is defined as the greater of one-half inch of runoff or runoff resulting from a 1-year, 24-hour storm, from the land area for which the infiltration rate has been changed.

These two documents finally provide guidance for erosion and sediment control and stormwater management for local units of governments as well as regulatory agency staffs. Their use and application depends on what the site's size and resource constraints are and whether a local ordinance is in place. The local approval process, in communities with such a regulation, generally requires a formal review of the plan with its erosion and sediment control and stormwater management component by either the town or village engineer and a local soil and water conservation district staff person or health department official. Unfortunately, many of these individuals are unable to identify problems or lack the knowledge of design details to control sediment from the site.

Once a developer begins operations in the field, the building inspector, code enforcement officer, or health department official is responsible for inspecting the site for compliance to the approved plan as well as to ensure that the contractor maintains the installed practices. These field inspectors require training in the concepts of erosion and sediment control installation and maintenance.

Clean Water Act Mandates

On October 1, 1992, stormwater regulations went into effect under the Clean Water Act that require individuals, agencies, and municipalities to apply for a National Pollutant Discharge Elimination System (NPDES) permit for stormwater discharges from a variety of activities. New York State is a NPDES-delegated state, and the

Department of Environmental Conservation is administering this program through their State Pollutant Discharge Elimination System (SPDES) permit. One of the 11 categories covered in the regulations is construction activity. Under this activity, any site where 5 or more acres are disturbed must have an erosion and sediment control plan and a stormwater management plan. The 5-acre size limit has been challenged as arbitrary, and the size limit could be changed to 1 acre of disturbed area. A developer needs to file a Notice of Intent at least 48 hours before beginning operations to have "coverage." This notice is filed with the U.S. Environmental Protection Agency in Newington, Virginia. Under the regulations, copies of the erosion and sediment control plan and stormwater management plan are to be kept on site. Copies of each are also sent to the municipality that has jurisdiction. NYS-DEC does not want the notices or plans sent to its offices; they will nòt be reviewing or approving these plans. Who will? What will be the local impacts?

As a result of this mandate, many New York counties, towns, and villages will be receiving many erosion and sediment control and stormwater management plans. The majority of these units of government are still unaware of the requirements of the national program and of what their role is or should be. There is a great need for administrators, planners, and legislators to become aware of the program and the process. Technical staff need to learn the principles of planning, design, construction, and inspection for erosion and sediment control and stormwater management systems.

Positive aspects of the NYS-DEC approach to the program include the opportunity for local policy development, provisions for local ordinances, and the formation of interagency partnerships. Because NYS-DEC recognizes that authority should rest at the local level, communities have control over the quality of the natural resources in their backyards. Of course this may require additional staff or cooperation with other agencies to assist with implementation.

Training Programs

Early efforts in erosion and sediment control began with awareness seminars at the local level. The seminars usually lasted 2 hours an evening for local officials involved in the site review and approval process. Recognizing problems, learning the planning steps, and becoming familiar with practices and guidelines were the limit of these seminars.

The complexity of requirements and the technical needs have increased dramatically due to recent mandates. The Soil Conservation Service, in cooperation with NYS-DEC and Syracuse University, has developed a tiered educational program in erosion and sediment control and stormwater management.

A 1-day seminar has been developed for planning board members, environmental management council members, legislators, and town boards, and has included legal advisors, consulting engineers, and other agency personnel responsible for environmental analysis. This agenda is included as Figure 1. This seminar stresses site planning through a slide presentation that demonstrates problems without control and shows practices necessary to maintain resources on the site. Stormwater management performance standards are reviewed in accordance with NYS-DEC criteria. This seminar is reinforced with two specific site examples. Attendees are asked to work in small design teams to design an erosion and sediment control plan for the first site. These same design teams are asked to critique the second site, which already has an erosion and sediment control plan. Thus, attendees go from designers to reviewers in applying their knowledge of these principles.

A 2-day workshop has been developed for the technical staffs of resource agencies, consulting engineers, local governments, and others with technical review or design responsibility (see Figure 2). This session begins with a quick overview of the principles of erosion and sediment control, then continues with a class exercise to design an erosion and sediment control plan for a development site while working in design teams of approximately four individuals. The afternoon of the first day is spent at a field site gathering specific resource information and data to design a detailed erosion and sediment control plan for the site. The design teams also compute and compare peak discharges for the site for predevelopment and postdevelopment conditions using Soil Conservation Service Technical Release 55, Urban Hydrology for Small Watersheds (TR-55). The session concludes with group presentations.

A 3-day short course with Syracuse University has been developed to address the specific technical needs of consulting engineers working with stormwater and erosion control systems. This tuition-based course provides for more indepth design of erosion and sediment control practices using a field site. Sizing stormwater detention basins is also required. In addition to the increased technical emphasis, additional speakers from state and local agencies provide a component on rules and regulations. Syracuse University awards two continuing education units for this course, which 57 people have completed to date. The agenda is included as Figure 3.

Urban Erosion Control and Stormwater Design (CIE 600) stands as a fully accredited 3-hour graduate level course in the Civil and Environmental Engineering Department at Syracuse University. It was taught for the first time in the 1992 fall semester and will be taught again this September. It was developed as a hands-on course that requires detailed designs for two projects, using field trips and six additional site review projects.

EROSION AND SEDIMENT CONTROL SEMINAR
AGENDA

8:30 AM	Registration
9:00 AM	Introduction and Course Overview
9:15 AM	Developing an Erosion and Sediment Control Plan — Planning Considerations — Factors That Influence Erosion — Elements for a Sound Plan — Vegetative and Structural Components — Standards and Specifications
11:00 AM	Site Example — Develop Conceptual Erosion and Sediment Control Plans
12:00 PM	LUNCH (ON YOUR OWN)
1:00 PM	Site Review — Critique an Erosion and Sediment Plan for a Specific Site
3:30 PM	Wrap Up/Summary
4:30 PM	Adjournment

Figure 1. Erosion and Sediment Control Seminar agenda.

EROSION AND SEDIMENT CONTROL WORKSHOP

AGENDA

First Day

8:30 AM	Registration
9:00 AM	Introduction and Course Overview
9:15 AM	Developing an Erosion and Sediment Control Plan —Planning Considerations —Factors That Influence Erosion —Elements for a Sound Plan —Vegetative and Structural Components —Standards and Specifications
11:00 AM	Site Example —Develop Conceptual Erosion and Sediment Control Plans
12:00 PM	**LUNCH (ON YOUR OWN)**
1:00 PM	Design Session—Site-Specific Practices —Temporary Swale —Sediment Trap —Urban Runoff
2:30 PM	Field Problem—Design Teams —Gather Data —Develop Concepts in Field
4:30 PM	Adjournment

Second Day

8:30 AM	Complete Group Designs
10:00 AM	Design Critiques
12:00 PM	**LUNCH (ON YOUR OWN)**
1:00 PM	Design Session —TR-55 Analysis for Structures —Rock Outlet Protection —Class Discussion
3:00 PM	Wrap Up and Summary
3:45 PM	Adjournment

Figure 2. Erosion and Sediment Control Workshop agenda.

SYRACUSE UNIVERSITY
UNIVERSITY COLLEGE
EROSION AND SEDIMENT CONTROL

SHORT COURSE AGENDA
April 28-30, 1992

First Day

9:00 AM	Registration and Coffee	Dr. Stephan Nix
	Introduction and Course Overview	
10:00 AM	Legislation, Ordinances, and Regulatory Review Process	Mr. Robin Warrender Mr. William Morton Mr. Russell Nemecek
11:00 AM	Developing Your Stormwater Management Plan and Practices	Mr. William Morton
12:00 PM	Lunch	
1:00 PM	Urban Hydrology and Flow Routing	Mr. Donald W. Lake, Jr.
2:15 PM	Break	
2:30 PM	Urban Hydrology and Flow Routing (continued)	
4:30 PM	Adjourn	

Second Day

8:00 AM	Developing Your Erosion Control Plan	Mr. Donald W. Lake, Jr.
9:30 AM	Break	
9:45 AM	Erosion and Sediment Control Practice Standards	Mr. Donald W. Lake, Jr.
11:30 AM	Lunch (En Route to Field Site)	
12:00 PM	Field Tour/Site Problems	Mr. Donald W. Lake, Jr.
3:00 PM	Group Design Session	
5:00 PM	Adjourn	

Third Day

8:00 AM	Group Presentations and Critiques	
10:00 AM	Break	
10:15 AM	Group Presentations (continued)	
11:45 AM	Wrap Up—Adjourn Short Course	Dr. Stephan Nix
1:00 PM	Certified Professional Erosion Specialist Exam Part II (Optional)	Mr. Donald W. Lake, Jr.

Figure 3. Erosion and Sediment Control short course agenda.

In addition, the class participates in a town planning board meeting. Syllabus topics (see Figure 4) include manual and computer analyses of stormwater discharges and lectures by a plant materials specialist, a code enforcement officer, and governmental representatives dealing with rules and regulations. Twelve students enrolled in the first class, which was extremely well received by both students and the people who provided the example sites.

Summary

Over 2,600 people have received training through 76 different seminars, workshops, short courses, and the graduate course since the training effort began in the fall of 1988. These tiered training sessions have evolved one after another based on needs at the local level. Leaders in the NYS-DEC recognized that benefits are local so training efforts should be local. This has led to interagency cooperative agreements between the U.S. Department of Agriculture, Soil Conservation Service, and NYS-DEC to bring training directly to the communities.

There is no sign of these training requests letting up. An average of 10 requests for the seminar sessions are made at the local level during the year. In addition, the proposed cooperative agreement for Fiscal Year 1994 between the Soil Conservation Service and NYS-DEC calls for five 1-day seminars, four 2-day workshops, four 2-day TR-55 hydrology workshops, and two short courses. The Syracuse University graduate course will be taught again this fall. Future projects also include workshops for New York State code enforcement officers, development of a field notebook for job superintendents, and field application courses for equipment operators. After all, equipment operators have the last word in installation.

We have come a long way, but we can see that challenges are still ahead of us to educate public planners, legislators, consultants, technical staff, and contractors in the use of sound erosion and sediment control and stormwater management practices to protect and enhance water quality and the environment.

DEPARTMENT OF CIVIL AND ENVIRONMENTAL ENGINEERING
SYRACUSE UNIVERSITY

CIE 600

URBAN STORMWATER AND EROSION CONTROL DESIGN
FALL 1992

SCHEDULE: Monday/Wednesday
6:15-7:45 PM
Peck Hall, University College

INSTRUCTOR: Donald W. Lake, Jr., PE
State Conservation Engineer, USDA-SCS

TEXT: SWCS, Empire Chapter, **New York Guidelines for Urban Erosion and Sediment Control**, October 1991; Soil Conservation Service, Technical Release 55, **Urban Hydrology for Small Watersheds**, June 1986; New York State Department of Environmental Conservation, **Reducing the Impacts of Stormwater Runoff From New Development**, April 1992.

GRADING:

Assignments:	40%
Mid-Term Exam:	30%
Final Exam:	30%

Course Content:

Week:	Topics:	Reading	Instructor
8/31	Introduction to Urban Stormwater and Erosion Control Design (1)*		Lake
9/7	Resource Planning and Stormwater Impacts (2)	Ch. 1, NY Guide and DEC Manual	Lake
9/14	Computing and Controlling Sediment and Runoff (2)	Ch. 8, Appendix B, NY Guide	Lake
9/21	Stabilizing Soil, Vegetative and Biotech (2)	Chs. 4 and 5, NY Guide	Dickerson Lake
9/28	No lecture—E&S Field Exercise (10/3, 8:30-11:30 AM) (turn in 10/7)	NY Guide	Lake
10/5	Urban Hydrology (2)	SCS-TR-55	Lake
10/12	Urban Hydrology (1) and Site Exercise Critique (1)		Lake
10/19	NO CLASS—HYDROLOGY PROJECT		Lake
10/26	Urban Hydrology Computer Program (1) and MIDTERM	Tr-55	Chapman Lake

Figure 4. Urban Stormwater and Erosion Control Design course agenda.

Week:	Topics:	Reading	Instructor
*Number of lectures that week			
11/2	Construction/Maintenance/Code Enforcement	NY Guide	Proietta
11/9	Town Planning Board Assignment and Stormwater Field Exercise (11/14—9:00 AM)		Lake
11/16	Performance Standards for Stormwater Management	Chs. 5 and 6, DEC Manual	Warrender Morton
11/23	Flow Routing (1)		Nix
11/30	Flow Routing (2)		Nix
12/7	Stormwater Basin Design (2)	DEC Manual	Lake
12/14	Course Review		Nix
12/21	FINAL EXAM		Lake

Instructors

Donald W. Lake, Jr., PE, State Conservation Engineer, USDA-SCS
John Dickerson, Northeast Plant Materials Specialist, USDA-SCS
Dana Chapman, Asst. State Conservation Engineer, USDA-SCS
Robin Warrender, Chief, Nonpoint Source, Division of Water, NYS-DEC
William Morton, Resource Specialist, NYS Department of Environmental Conservation
Dr. Stephan Nix, Professor, Syracuse University, Civil and Environmental Departments

Figure 4. Urban Stormwater and Erosion Control Design course agenda (continued).

Field Office Technical Guide: *Urban Standards and Specifications*

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Abstract

The *Field Office Technical Guide* is the primary technical reference for the Soil Conservation Service (SCS). It presently contains general resource references and soil and site information, and describes conservation management systems, practice standards and specifications, and conservation effects. Although SCS maintains offices and provides assistance in all Illinois counties, the technical guide does not contain any information specific to natural resource use and management in urban areas. Therefore, in June 1992 the SCS in Illinois entered into an agreement with the Illinois Environmental Protection Agency to develop technical information describing best management practices (BMPs) for controlling urban nonpoint source water pollution.

Currently in development, this information will include 40 BMP standards and accompanying construction specifications, material specifications, and standard drawings. It will also include estimates of pollutant removal effectiveness and stormwater pollutant export, as well as planning and design criteria. When complete, this material will become part of the *Field Office Technical Guide*. The Illinois Environmental Protection Agency will also use the information in a separate, stand-alone technical manual. This material will be useful to planners, engineers, architects, and construction contractors, as well as to local government staff.

Background

The Soil Conservation Service (SCS), an agency of the U.S. Department of Agriculture, is the major federal agency providing natural resource management assistance on nonfederal land. Its primary responsibility is to provide leadership and expertise in managing natural resources in nonurban areas. Currently, SCS maintains a network of field offices in nearly every county in the country, providing local citizens with direct access to a wide range of technical specialists. These specialists include engineers, soil scientists, biologists, agronomists, and natural resource planners.

The technical material and expertise that has been developed to support SCS activities largely pertains to agricultural or rural settings. For example, the seed mixtures that most SCS specifications call for are those appropriate for agricultural areas and not necessarily for parks, recreation sites, or lawns. In addition, design criteria for waterways and diversions assume an agricultural land use context.

Despite this rural, nonurban emphasis within the agency, SCS maintains a field staff in urban and urbanizing areas. In Illinois, this urban staff serves over one-half the state's population. This urban presence has enabled SCS to develop some urban expertise. For instance, SCS TR-55 hydrology modeling techniques are widely used to estimate runoff from urban areas. Moreover, the PL-566 watershed projects constructed in the Chicago suburbs have given the agency some expertise in urban construction site issues. The SCS, however, has not provided any systematic technical support to its field staff on natural resource management issues in an urban setting. It has instead relied on the ability of its staff to adapt the provided information from a rural to an urban environment.

To become more effective in addressing key natural resource issues in urbanizing areas, the SCS in Illinois has initiated several activities:

- It is actively participating in a coalition of state and federal agencies to prepare a strategy for coordinating agency activities in northeastern Illinois.
- It is reviewing and clarifying its policy relative to providing assistance in nonagricultural areas.

- It is expanding the technical information its staff uses when providing assistance to decision-makers in urban areas.

The third initiative listed is the subject of this paper. In June 1992, SCS entered into an agreement with the Illinois Environmental Protection Agency to prepare a set of standards and specifications describing BMPs for controlling urban nonpoint source water pollution. In addition, the SCS will provide estimates on the range of pollutant removal effectiveness and criteria for planning runoff management. The agency will incorporate all this material into its *Field Office Technical Guide*.

Field Office Technical Guide

The *Field Office Technical Guide* is the primary technical reference for the SCS. It contains technical information about conservation of soil, water, air, plant, and animal resources. The guide is designed for use by technically trained people who are assisting landowners and users, land managers, government officials, and other decision-makers to plan, apply, and maintain appropriate conservation practices. The technical guide also is a major reference for those addressing top-priority resource goals identified by the National Program for Soil and Water Conservation. These goals are to reduce the damage caused by excessive erosion and to protect water from nonpoint source pollutants. The technical guide identifies sediment, nutrients, animal waste, pesticides, and salinity as nonpoint source pollutants.

The *Field Office Technical Guide* contains five sections:

- The "General Resource References" section lists references, cost data, maps, climate data, cultural resources information, threatened and endangered species, and pertinent state/local laws, ordinances, and regulations.
- The "Soil and Site Information" section describes the soil survey of the local area. It contains soil descriptions and interpretations that can be used to make decisions about land use and management. This section identifies soil characteristics that limit or affect land use and management, and rates soils according to limitations, capability, or potential.
- The section on "Conservation Management Systems" provides information for developing resource management systems to prevent or treat problems associated with soil, water, air, and related plant and animal resources. This section includes quality criteria that describe the level of resource protection that decision-makers should try to achieve to meet resource quality goals.
- The "Practice Standards and Specifications" section alphabetically lists conservation practices used by the field office, followed by practice standards and specifications. It may also include references and documentation requirements for the individual practices. Practice standards establish the minimum level of acceptable quality for planning, designing, installing, operating, and maintaining conservation practices. Practice specifications describe the technical details and workmanship required to install the practice, as well as the quality and extent of materials used in the practice.
- The last section, "Conservation Effects," contains information describing the economic and environmental effects of implementing particular practices and systems. The purpose of this section is to provide decision-makers with a way to evaluate the extent to which various alternatives can meet their goals.

As stated previously, this guide is the primary technical reference for SCS staff, particularly those at the field level. The guide is also useful to Soil and Water Conservation District staff, and to consultants and staff of state, county, and municipal governments. To expand its usefulness, however, the SCS urban field staff in Illinois have recommended that the guide include information that is directly relevant to natural resource management in an urban environment and is user friendly to urban clients. The material now being developed will attempt to meet that need.

New Material for the *Field Office Technical Guide*

The new material will supplement and expand the existing material in the guide's fourth section, *Practice Standards and Specifications*. The SCS will modify or develop 40 BMPs that deal specifically with urban natural resource management.

Each BMP standard will follow a uniform format:

- "Definition": describes what the practice is.
- "Purpose": explains what the intended effect of the practice is, that is, why this practice is used.
- "Conditions Where the Practice Applies": describes the types of sites where the practice would be appropriate; this section also describes limiting factors such as slope percent, maximum drainage areas, and maximum flow velocities.
- "Criteria": describes, in general terms, material and construction requirements and usually provides references to specific material and/or construction specifications.
- "Considerations": offers general information regarding factors to consider when deciding on the appropriateness of a particular practice; in some cases, this section is a brief, narrative, nontechnical summary of the "Conditions" section.

- "Plan and Specification Requirements": describes the nature and extent of the information the contractor needs to build the practice; it lists the requirements of the plans and specifications needed to install a practice.
- "Operation and Maintenance Requirements": describes the needed operation and maintenance actions and suggests the frequency with which they should be performed.

The revised fourth section of the technical guide will also include all the material specifications and constructions referenced in the practice standards, as well as a series of standard drawings for the practices. The standards and specifications will be available on computer disk. The standard drawings, which will be developed using a CAD system, also will be available on disk. This will allow engineers and consultants to access the material in preparing construction plans and specifications.

In addition to the SCS incorporating the new material into the Illinois *Field Office Technical Guide*, the Illinois Environmental Protection Agency plans to issue a stand-alone technical manual of those standards for use by consultants, state agencies, and local governments. The project is scheduled for completion in December 1994.

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Stormwater Outreach at the Federal Level: Challenges and Successes

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Background

Stormwater regulations brought a distinctly different community into the realm of U.S. Environmental Protection Agency (EPA) regulation. Many members of this community have never before been regulated by an environmental program. The regulated community now includes all major cities and unincorporated areas with populations of 100,000 or more, as well as a very large, diverse group of industries. The most important factor influencing success with the stormwater regulations is education. By educating all parties concerned with the program, the community can begin to practice all that EPA is learning about how to provide a cleaner, safer environment.

The principal elements of an outreach program are communication and education, with a focus on influencing how people and organizations act. Given this, the National Pollutant Discharge Elimination System (NPDES) stormwater outreach program at the national level should, among other things:

- Disseminate information and educate people about the effects of receiving water pollution from diffuse sources, such as the loss of recreational activities.
- Promote positive environmental results, including the reduction of pollutant loadings into receiving waters.

Theoretically, accomplishing these goals should elicit a successful outreach program at any level. In fact, success is much more elusive. Of course, many outreach programs implement this theory very effectively. At the federal level, however, EPA has 16 different customers reflecting 10 EPA regions, 50 states, thousands of municipalities, and hundreds of thousands of facilities, trade associations, and professional groups. Moreover, when factoring in to this multitude Congress, EPA's own management, and scarce resources, a successful outreach program becomes a tremendously complex and costly endeavor.

At the federal level, it is crucial to provide as much information as possible to as many people as possible. Therein lies the biggest challenge in outreach at the federal level. This paper presents some of the challenges in developing an outreach strategy for the stormwater program at the federal level. It also describes some of the projects EPA's Office of Water has under way, some of which have worked very well and some of which have not. In addition, the paper discusses what the future holds for the stormwater outreach program.

Challenges of Developing a Stormwater Outreach Strategy

For its first year or so, the strategy of the stormwater outreach program consisted of a hotline, which addressed most needs, and speaking engagements, which filled in the gaps.

Almost immediately after the NPDES stormwater program was born, several years ago, the stormwater hotline was established. Since its inception, the hotline has received over 90,000 calls. The hotline staff answers questions, distributes documents, and handles registration for EPA workshops and seminars.

The other important element of the early stages of the stormwater program was speaking engagements and workshops. These continue to be one of the best ways to get "the word out" correctly. Regulated communities need to know exactly how the stormwater program affects them. For example, the program held 12 workshops between 1990 and 1991 to explain the November 10, 1990, regulations.

As the stormwater program matured, it became apparent that the community needed a more substantial outreach strategy. The hotline staff quickly found it difficult to refer all policy interpretation calls to EPA stormwater staff. At that time, the staff at Headquarters was very small and the regions were overburdened.

Consequently, the Headquarters stormwater staff expanded, and one of its first tasks was to develop an outreach plan. The first step was to identify the plan's customers, which turned out to be just about everyone. Primary customers are the regions and states. Of course, there are 11 categories of regulated industries and over 200 municipalities in Phase I alone. The list of customers continues to grow when the general public, elected officials, professional associations, trade groups, and consultants all are factored in. These groups require a different level of understanding of stormwater regulations. This presented a major challenge because the staff needed to examine each document and ensure that it satisfied the needs of more than one group of customers.

This early outreach strategy assumed knowledge of what the customers wanted. The assumption, however, was wrong. There was one crucial step in strategy development that the stormwater staff neglected to complete: ask the customers. Because of their enormous number, however, asking them all was impossible. Some customers, of course, in addition to the regulated community, are the states and regions, who are trying desperately to run their own stormwater programs. These customers were finally asked about the outreach plan at the 1992 Stormwater Coordinator's Conference in Atlanta, Georgia. The stormwater staff reviewed what they had been doing to date, and customers offered helpful suggestions on what to do next. Customers also participated in a session specifically targeted at designing the stormwater workshops held in April 1993 in Annapolis, Maryland, so as to ensure customer input.

During this meeting, it became apparent that many states and regions were duplicating work unnecessarily, that is, developing something that another state had already developed. This was very frustrating for all those involved. Some kind of clearinghouse or electronic communications system was desperately needed. Research, however, had already shown that it could cost from $750,000 to $1 million to set up such a system. This cost prevented Headquarters from accomplishing this effort on its own. Therefore, it asked the states to help by directing their 104(b)(3) grant funds to this effort. This seemed the only way to accomplish the goal quickly and effectively. Although this sounded like it would work, it has not. There is quite a bit of reluctance to use that money for this task. Therefore, stormwater personnel have begun to look for other avenues.

The challenges multiply when budget constraints are considered. One of the biggest problems involves printing a developed document. The printing budget at Headquarters has taken some very serious cuts. Despite attempts to solve this problem, difficulties continue. For instance, Headquarters has tried to distribute items electronically, but this can cause more problems than it solves. Budget cutbacks have seriously hampered plans to develop more public education materials than are currently available.

Of course, nearly everyone has been hit very hard by budget problems. Some states and counties have offered very creative ideas about getting the "most bang for your buck!" This issue has shed new light on the problem of getting out as much information as possible.

These are just some of the challenges stormwater staff have faced in putting together an outreach strategy. The next section describes some current outreach projects.

Current and Developing Outreach Activities

Research

A primary task has been to research existing outreach activities. Much information on these activities exists, and both researchers and audiences find this an ongoing educational process. Research efforts include:

- Research on outreach activities
  Audience: Headquarters management, regions
- Research on videos
  Audience: Headquarters management
- Research on clearinghouses
  Audience: Headquarters management, regions

Current research on existing outreach activities examines their successes and failures. Hopefully, this effort will help target materials and practices that can be expanded to a national level. While outreach videos have had difficulty with funding, the staff is researching what is out there, again, in case it finds something that works well and can be expanded to a national level. Finally, research on clearinghouses began before stormwater staff heard from the regions and states. The staff tried to learn of available clearinghouses to examine the possibility of their use or adaptation.

Outreach Strategy

The strategy is expected to be presented in a dynamic document. Its audience is Headquarters management and the regions. Hopefully, the document will provide an adaptable framework for designing and completing outreach projects within an assigned time frame.

Fact Sheet Development

Because the stormwater program involves so many issues and firestorms staff often produce fact sheets to clear up confusion. Past fact sheets have focused on:

- The Transportation Act's effect on the stormwater program.
- The Ninth Circuit Court decision that affected municipalities.
- The Municipal Part II guidance document.
- Phase II progress and results of public meetings.

Question and Answer Document

The audience for this document is the regions and industries via trade associations. The first volume was developed based on questions from the hotline. The staff compiled over 50 commonly asked questions and answers into one document, which has been distributed through the hotline.

The second volume covers more complex interpretations of the regulations, including questions on sampling, group applications, and the Ninth Circuit Court decisions. Again, distribution will probably proceed through the hotline.

Stormwater Workshops

In fiscal year (FY) 1991, the stormwater staff at Headquarters conducted 12 workshops on the basics of the stormwater program. The workshop audience consisted of regions, states, and the regulated community. The objective was to inform as many people as possible about the requirements of the November 16, 1990, rule. Attendance was in the thousands. The effort was successful.

In FY 1992, the stormwater staff presented workshops and spoke to over 4,000 people. These workshops focused on the requirements of the general permit and the development of pollution prevention plans. In addition, workshops for municipalities covered the requirements of the Part 2 municipal application. All these workshops were well received and also considered successful.

The FY 1993 workshops presented by Headquarters focused on developing pollution prevention plans. The staff developed a workshop series with the first day targeted to reach state and EPA regional representatives. This day is a train-the-trainer session to teach the audience how to lead a workshop on pollution prevention for industry. The second day is designed for the industrial regulated community and focuses on industrial and construction pollution prevention plan development. This day should include case studies and interactive exercises.

These workshops mark the first effort by the stormwater program to conduct workshops of this kind. The hope was to meet the objectives identified by the regions and states at the 1992 Stormwater Coordinator's Conference in Atlanta. Due to budget problems, Headquarters was limited to the number of workshops it could conduct in each region. The goal was, however, for state and regional staff to be able to present the workshops on their own. Each state was to receive a set of slides and speaking materials for its own use.

Municipal Support Division/Permits Division Pamphlet on Stormwater

The audience for this publication is Headquarters, the regions, and the general public. This project has experienced difficulties getting started due to contractual problems. It is, however, now moving ahead toward completion. The pamphlet is predominantly aimed at members of the general public who have little or no knowledge of the stormwater program.

Updated Stormwater Overview

This document addresses general information needs. Its audience consists of Headquarters, the regions, and the general public. The Overview reviews who the stormwater program covers, what their application options are, and what the deadlines are associated with those applications. As the program grows and changes, the Overview is updated. Distribution is currently through the stormwater hotline.

Raindrop Report (Status of the Stormwater Program)

This document is targeted to Headquarters, the regions, and the general public. It supplies a brief update on current activities in the stormwater program and features relevant information from recent *Federal Registers*. In addition, it describes outreach activities and provides specifics on applications submitted and general permits.

Articles for Newsletters

Stormwater staff are developing articles by request for publication in various journals and newsletters. They are trying to establish a regular submittal effort to some publications, such as the *Nonpoint Source News Notes*, which is published by the Headquarters nonpoint source program to supplement the bulletin board.

General Permit Effectiveness Study

The purpose of this effort is to determine the effectiveness of the general permit approach in implementing Phase I. The evaluation assesses, among other things, the rate of compliance, the level of awareness, and the quality of pollution prevention plans being developed. This effort also is identifying obstacles that prohibit the general permit from being as effective as possible.

Monthly Conference Calls

As of March 1993, Headquarters had completed 15 regularly scheduled conference calls with stormwater regional coordinators. These meetings have proven very successful, and they should continue.

Stormwater Awards

These awards recognize municipalities and industries that demonstrate a commitment to protecting and improving the quality of the nation's waters through outstanding implementation of innovative and cost-effective stormwater control programs and projects. In 1991, the winner for a stormwater control program or project by a municipality was Murray City, Utah. In 1992, the city of Orlando, Florida, won, and Prince George's County, Maryland, took second place. Nominations are sought from the 10 EPA regions.

National Stormwater Coordinator's Conference

This annual event is indispensable for planning and feedback from the states and regions. The meeting is designed for regional and state stormwater coordinators, as well as for Headquarters staff.

Continuous Speaking Engagements

Stormwater staff receive requests to speak to groups twice a week on average. While they are not always able to fill some requests because of a limited travel budget, the staff respond to as many as possible. In FY 1992, staff participated in about two dozen talks or seminars, not including the workshops.

Phase II Outreach Meetings

The Phase II Outreach Meetings are a series of meetings designed to include individuals that may be affected by the Phase II regulations in the development of those regulations. As of this writing, four meetings have been held (two in Washington, one in Dallas, and one in Chicago) to involve as many people as possible.

Information and Education Catalog

Another important project is the management and periodic update of the Information and Education Catalog, which was distributed at the National Urban Runoff Management Conference. The author and Tom Davenport manage this project. Everyone concerned should have a copy of this excellent document. Management plans to expand the manual to include stormwater information. In addition to putting out several calls for information, the conference registration packet included a form to fill out if individuals wanted this catalog to include a particular document. Management believes this document will help in the tremendous demand for technology transfer in the stormwater and nonpoint source programs. This, of course, is a top priority that customers have requested.

Electronic Sources

Linking to other clearinghouses and bulletin boards should improve communications. The nonpoint source program at Headquarters has been extremely helpful by placing information and announcements on its electronic bulletin board and in the *Nonpoint Source News Notes* publication. This has proven to be a good way to meet customer needs.

Further Considerations

Education is becoming one of the most important aspects of the stormwater program as people learn about the regulation and how it affects their day-to-day lives. Industries as part of their pollution prevention plans are developing training and education programs for their own employees. Cities are training their employees in sampling techniques and safety procedures as well as developing excellent public education programs. Tremendous efforts involving stormwater education are being undertaken. Stormwater Headquarters needs to know about the successful programs to help the lesser programs learn.

As this program moves forward, each success in educating those affected by the stormwater program, including the general public, leads to greater accomplishments. As these successes continue to build, more people will understand the intent and effects of protecting and cleaning up the waters of our nation. It is a cycle in which we all play a major role.

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Training for Construction Site Erosion Control and Stormwater Facility Inspection

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Abstract

Probably the leading reason that stormwater management programs fail in effectively protecting water resources is the lack of followup to ensure that permit conditions are met, approved designs are properly installed, and temporary and permanent management practices and facilities are maintained. Avoiding this downfall requires obtaining the legal authority for and then instituting a coordinated program extending from the first submission of permit applications through construction and all phases of site operation. This program should have components covering the construction phase as well as permanent practices and facilities. While somewhat different elements are appropriate for the two components, they share the common precepts of sound underlying planning; competent plan review; and effective inspection, maintenance, and enforcement. The University of Washington's Center for Urban Water Resources Management and Office of Engineering Continuing Education have developed and are offering courses to train personnel responsible for various aspects of the suggested program. This paper emphasizes the training for site inspectors. For construction-site inspectors, it covers the role of the erosion and sediment control (ESC) plan, the applicability of many ESC practices, key points to check when inspecting them, and how to deal with various circumstances that can arise during inspections. For permanent drainage system inspectors, the paper covers both the initial construction and continuing operation of facilities and offers guidance on key inspection points and such issues as safety, tracking maintenance, and waste handling.

Introduction

Effective stormwater management requires successful execution of steps at all phases of a project. These phases and the accompanying management steps include analysis of potential problems in the planning stage, quality design of programs and practices to protect aquatic resources as the project takes shape, competent review of plans at the permit application point, proper implementation of approved plans during construction, and correct operation and practices at facilities after their installation. All phases of the process need improvement through a better basis in knowledge and greater skills in application. Probably the weakest areas and the leading causes of program failures and environmental damage are implementation during construction and long-term operations.

Redressing this weakness will require widespread development of comprehensive and aggressive programs of inspection during the construction of developments and their stormwater management systems, followed by ongoing inspection of operating systems to ensure sufficient maintenance for continuing adequate performance. The diffusion of development and tradition of local land-use control prevalent in most of the United States will necessitate local acquisition of the legal authority, where it does not now exist, to institute these programs. As is already occurring in some places, it is likely that larger units of government will become involved in setting standards for these programs. The U.S. Environmental Protection Agency's National Pollutant Discharge Elimination System (NPDES) program is presently extending authority over programs in the largest cities and counties and at sites of construction larger than 5 acres and involving industrial activity. Still, the details and the responsibility for conducting the programs will very likely rest with local governments.

The concern of this discussion is the development and execution of local programs to upgrade significantly the quality of followup to increase the probability that approved stormwater management plans are effective. The scope of the programs envisioned would extend from the point of permit issuance through construction and all the years of site operation to follow project completion. The programs might be considered to have distinct components, covering, for example, erosion and sediment control (ESC) inspection at construction sites, inspection of the construction of storm runoff quantity and quality control facilities, and the periodic inspection and maintenance of operating facilities. However they are structured, these programs should embrace some common principles. They should be the logical extension of and ultimate implementation vehicle for the foregoing phases of planning, design, and plan review. Further, they should be conceived and conducted as essential elements of a successful program, deserving of the needed funding, staffing, support by administrators and public officials, training of personnel, and enforcement authority.

This discussion covers aspects of program development and especially emphasizes training for site inspectors. For these purposes it divides the overall program into two components. One covers construction site ESC programs. The second covers permanent drainage practices and facilities, both their inspection at construction and followup inspection and maintenance. In both cases, the paper recommends program structures and discusses some key program elements. It then offers specific examples of inspection checks to perform in the field. The goal of the paper is to give the reader a basis for beginning program design and undertaking the key element of training the staff who will be charged with its performance.

The discussion was derived from two courses developed and offered by the University of Washington's Center for Urban Water Resources Management and Office of Engineering Continuing Education. The course coverage is organized in the same manner as this presentation, and course manuals are available for ESC inspector training (1) and permanent drainage system inspector training (2). Important contributions to the material presented in these courses and in this discussion have been made by local governments and state agencies in the Puget Sound area of Washington state that have been working actively to improve stormwater management through good followup.

Construction Site ESC Inspection Programs

Program Development

Program Elements

The following elements are recommended for a comprehensive construction site ESC program:

- ESC planning
- A plan review process
- Contractor education
- An inspection and enforcement process

The subsections to follow cover two of these program elements in detail, ESC planning and inspection and enforcement. The latter discussion is then extended in the following section to examples of inspection guidelines for common practices.

ESC Planning

ESC planning is an absolute prerequisite for an effective program. A careful site analysis should produce a stand-alone plan (i.e., a plan devoted exclusively to this aspect of the project) developed with the same thoroughness and care as any other plan in the overall construction set. It is intended for use by the plan reviewer, the construction superintendent and other contractor personnel, and the construction site inspector. This subsection outlines the ESC planning process from beginning to end and concludes with an example of a complete plan.

In approaching an ESC plan, the planner must:

- Understand the erosion process, so that it can be controlled.
- Know the site and the construction plan, so that both potential problems and solutions will be apparent.
- Understand the various ways that erosion can be prevented or that eroded sediments can be caught.

The erosion process is first reviewed for the lessons it can offer ESC planning. Erosion has been understood for thousands of years, as is attested by the extensive evidence of terraced farming—some continuing today—in steep terrain in ancient cultures. Figure 1 illustrates the types of erosion and its nature. Soils can be loosened and set in motion initially by the impact of falling raindrops. Erosion progresses, although gradually, as runoff flows in a sheet over a bare surface and exerts shear stress, which is a function of velocity, on soil particles. The rate of erosion increases when flow concentrates and increases in velocity. Channels formed by these flows are known as rills. When rills join and form highly concentrated, rapidly flowing channels, the rate increases still further, a stage termed gully erosion. Erosion can progress still further to mass wasting when a whole area loses stability.

Several factors involving site soils, vegetation, and topography influence the erosion process. Soil erodability is greater in the case of silts and fine sands than clays or soils with a substantial gravel content. Relatively high organic content also offers cohesiveness that resists erosion. Clays tend to produce a larger volume of runoff, however, because of their relatively poor permeability, which exerts more erosive stress on soil. Vegetative cover offers a number of important advantages, including reducing raindrop impact, slowing runoff velocity, helping to absorb water, and holding soil in place. In regard to topography, both slope gradient and length tend to increase velocity and the resulting frictional

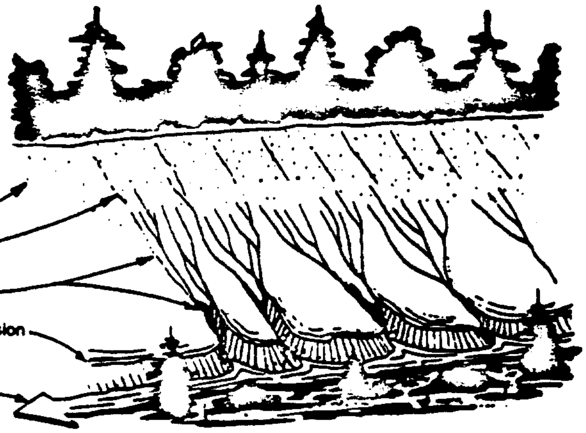

Figure 1. Soil erosion processes (3).

shear stress. Erosion hazards relative to slope gradient and length are listed in Table 1.

Acquiring the familiarity with the site and proposed construction necessary to proceed with the ESC plan involves data collection and analysis. Site data should be collected in regard to:

- Soils
- Vegetation
- Topography
- Ground-water table
- Neighboring water bodies
- Adjacent properties
- Drainage routes and patterns (define subbasins)
- Potential areas of serious erosion problems
- Existing development, utilities, and dump sites

The following construction plan information should be cataloged at the outset of planning:

- Grading (location, amount)
- Topographic changes
- Clearing and grading limits
- Drainage changes

Table 1. Soil Erodability Relative to Slope Gradient and Length

Erosion Hazard	Slope Gradient	Maximum Length
Low	0-7%	300 ft
Moderate	7-15%	150 ft
High	>15%	75 ft

- Materials to be used and locations of use and storage
- Access points

ESC planning should proceed with reference to certain basic principles, as follows:

- First consider all means of preventing erosion; only consider trapping sediments from unavoidable erosion. Prevention has the potential to be more effective in resource protection than later treatment and less costly.
- Phase construction and post clearing limits to maintain as much natural vegetation as possible and for as long as possible.
- Plan construction to fit the site; use terrain advantageously and avoid critical areas.
- Cluster buildings and other developed features, and minimize their impact on impervious area.
- Plan for control of erosion subbasin by subbasin.
- Minimize extent and duration of vegetation removal (especially during wet season) and soil disturbance.
- Stabilize and protect disturbed areas as soon as possible.
- Use natural drainage features, existing vegetation, and materials found on the site.
- Minimize slope length and gradient to control runoff velocities.
- Divert offsite runoff away from disturbed areas.
- Retain any released sediment within the construction area and reduce tracking off site.
- Have a thorough maintenance and followup program.
- Take measures to control potential pollution from construction materials (e.g., paving materials, petroleum

products, other vehicle fluids, fertilizers, pesticides, grinding and sanding debris, wastes).

An ESC plan consists of a narrative and site plans. Points that should be covered by the narrative include 1) a project description, 2) a description of existing and modified site conditions, 3) descriptions of ESC best management practices (BMPs), 4) descriptions of BMPs for pollutants other than sediments, 5) plans for permanent stabilization, 6) calculations, and 7) provisions for inspection and maintenance. Site plans are maps and engineering plans illustrating and specifying the project's location, existing and modified site conditions, and BMPs. The set of site plans should include 1) a data collection worksheet (principally showing topography, soils, and vegetation), 2) a data analysis worksheet (mainly indicating drainage subbasins and primary drainage courses), 3) a site plan development worksheet (showing existing and finished contours, roadways, and permanent stormwater facilities), 4) the ESC plan (showing BMP locations), and 5) diagrams of representative BMPs, as appropriate. The ESC plan (item 4 in the set) is the key element for implementing the plan. BMPs are usually specified on this plan using a system of symbols, which are defined in a legend.

Inspection and Enforcement

The most important general needs of an inspection and enforcement program are a staff dedicated to the function, specific staff training, and administrative support. These needs are best provided for by a dedicated revenue source, such as a stormwater utility assessment. The staff should not have unrelated and distracting duties such as inspection of other facets of construction. Initial training should offer needed background in, for instance, legal and regulatory requirements, water quality, hydrology, soils, and vegetation. Subsequent training should provide detailed coverage of BMP requirements, such as discussed in the following section. Strong support from administrators is essential for a staff undertaking a relatively new function that might be unpopular in terms of economic interests.

Beyond these basic needs are some specific issues to clarify during program development for incorporation as formal program elements. Recommendations on the issues presented in this paper are drawn from experience in the Puget Sound region, especially in King County and the cities of Bellevue and Redmond. One of these issues is the response to a situation in which measures in an approved ESC plan proved inadequate. Strong permit review should normally limit these instances, but unforeseen circumstances can still arise. Inflexible adherence to an ESC plan can be self-defeating when measures prove to be inadequate for whatever reason; thus, the jurisdiction should retain the authority to require additional measures if needed. This option should be noted in a statement on each ESC plan.

A second issue is how field change orders will be handled. The policy should call for careful but expeditious consideration of requests for plan changes, generally after consultation with plan review personnel. Finally at issue is the granting of variances from code requirements. Conditions on granting variances should be strict and specific, such as:

- The expected result should be at least comparable to the outcome expected to be achieved with the approved method.
- Sufficient background information and justification should be presented for adequate assessment of the alternative.
- The ability should be retained with the variance to meet objectives of safety, function, appearance, environmental protection, and maintainability based on sound engineering judgment.
- The variance should be in the public interest.

Enforcement authority must be obtained and the system of enforcement defined and made clear to the regulated parties. A system successfully used by the city of Bellevue has a sequence of three steps, as follows:

- A verbal warning, with a deadline for correction.
- A correction notice (with specifications of corrections), a deadline, and a warning about the consequences of noncompliance.
- A stop-work order, with a warning about the consequences of noncompliance.

ESC Practices and Their Inspection

Categories of Practices

The numerous ESC practices in use can be categorized in various ways. The most basic division is between erosion control practices, which prevent or minimize erosion, and sediment control practices, which attempt to capture soil released through erosion. Within each of these broad groupings are several categories that represent general strategies for achieving either erosion control or sediment control. In addition to sediments, construction sites can generate many other pollutants, such as petroleum products, solvents, paints, sanding dusts, pesticides, and fertilizers. It is most efficient to manage those materials along with sediments and to inspect the management practices for them simultaneously with ESC inspection. Therefore, these practices represent another basic division.

Following is the breakdown of ESC practices used by Reinelt (1), with the number of individual practices in each category. The 29 practices represented are by no means the only ones, but they are the most widely recognized and used. Twenty-two of the 29 (all but the sediment trapping techniques) are preventive and are thus generally the most cost-effective options; however, the straw bale and filter fabric fences and sedimentation ponds among the trapping techniques are most commonly used practices.

1. Erosion control
    1.1. Natural vegetative cover—two practices
    1.2. Temporary cover—three practices
    1.3. Permanent vegetation establishment—two practices
    1.4. Stabilized construction entrance and roads—three practices
    1.5. Runoff control—eight practices
2. Sediment trapping techniques—seven practices
3. Management of other construction site pollutants—four practices

The following passages provide inspection checklists for example practices, generally the most common, in each category and subcategory. The checklists are divided into checks to be made when the practice is implemented and checks to be made on each followup visit to determine the need for maintenance or replacement of the ESC materials. Many of the points are illustrated in diagrams that accompany the checklists.

While much of an inspector's work is performed in the field, it is often advisable or even absolutely necessary to do some background work in the office before going out to inspect an installation. This work mainly consists of consulting the ESC plan to determine the specifications. The plan should be retained on the construction site should the inspector or construction personnel need to refer to it.

1. Erosion control

1.1. Natural vegetative cover

1.1.1. Phasing construction

Phasing construction is a practice in which clearing operations are performed in stages to take advantage of cover that exists on site before construction.

Installation checks:

1. Are areas that will not be cleared set off with plainly visible clearing-limit fencing?
2. Is plainly visible flagging placed at the drip line of trees to be protected (see Figure 2)?
3. Are fills and cuts near protected trees treated as shown in Figure 2?
4. Is final vegetation established as soon as portions of the site can be made ready?

Maintenance checks:

1. Do fencing and flagging need repair or replacement for personnel to see it clearly?
2. Do exposed or injured roots of protected trees need covering or dressing?

1.2. Temporary cover

Temporary cover practices recognize that portions of most construction sites remain unworked for months, during which time very large amounts of erosion can occur unless these areas are stabilized. Stabilization can be achieved with temporary seeding or various kinds of slope coverings, or both. Slope coverings include both mulches and commercial mats and blankets. It is often necessary to apply temporary cover to different areas several times during construction.

Mulches, mats, and blankets can serve several purposes in erosion control: covering the slope temporarily to prevent erosion by raindrop impact and the friction of runoff, holding water to encourage grass growth, protecting grass seedlings from heat, and enriching the soil. Straw, hay, wood fiber, wood chips, and other natural organic materials can serve as mulches. Inspection guidelines for straw and wood fiber are given below as examples. Mats and blankets are manufactured from both natural and synthetic materials. Guidelines are given for several varieties.

1.2.1. Temporary seeding

Installation checks:

1. Is the soil stabilized within the period specified by regulation? (This period varies from place to place, depending on climate patterns. In the Puget Sound area of Washington, which receives most of its rainfall in the winter, the specified periods are within 2

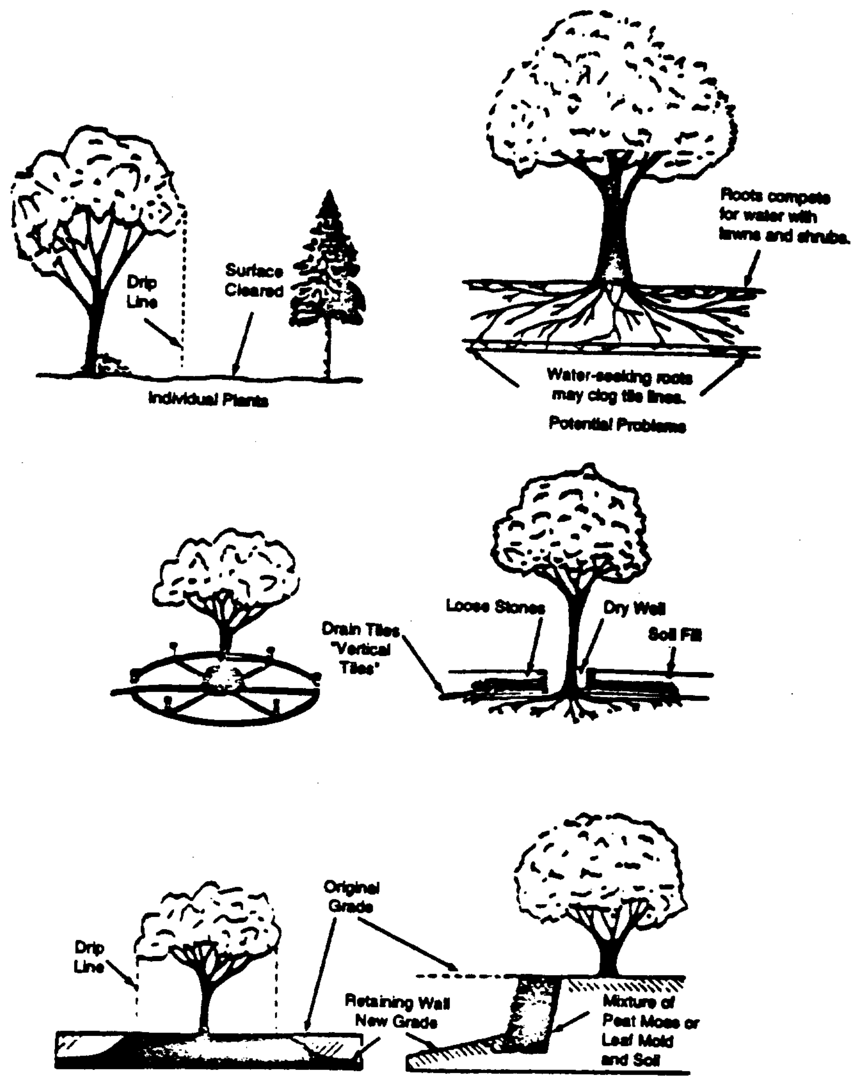

Figure 2. Guidelines for preserving natural vegetation (3).

days during the months October to April and within 7 days during the months May to September.)

2. If used without slope covering practices, is temporary seeding limited to slopes of less than 10 percent and 100 ft in length? If the slope exceeds either limit, is a mulch or mat slope covering used?

3. Has the seedbed been prepared with at least 2 to 4 in. of tilled topsoil?

4. Is fertilizer use limited as much as possible; if used, is it applied in amounts no greater than the needs of the grass for the prevailing soil conditions?

5. Is mulch applied for protection if seeding occurs when temperatures can be high or runoff is likely to occur before the grass is well established?
6. Is irrigation provided if planted when rainfall might be insufficient for good establishment?

Maintenance checks:

1. Is it necessary to irrigate and/or reseed?
2. Is maintenance fertilizer needed?

1.2.2. Straw mulch

Straw mulch can be used without seeding or, for better erosion control, with seeding.

Installation checks:

1. Is the straw spread generally a minimum of 2 in. deep (corresponds to 2 to 3 tons per acre) and greater on very steep slopes, adjacent to sensitive areas, and where concentrated flow passes over the slope?
2. Is the mulch anchored as needed by crimping, disking, rolling, or punching into soil or by moistening, tackifying, or netting?

Maintenance checks:

1. Is replacement needed as a result of blowing away or decomposition over time?
2. Is there any fire hazard requiring moistening?

1.2.3. Wood fiber mulch

Wood fiber mulch should only be used with seeding and generally should be used with a soil bonding agent.

Installation checks:

1. Is the mulch used with seeding and a soil bonding agent? Were the bonding agent distributor's application guidelines followed?
2. Has the wood fiber been applied to cover the soil completely, allowing no bare soil to show through (corresponds to about 1 ton per acre and is adequate for most circumstances)? Are there any special circumstances, such as seeding during hot weather, when the amount should be increased by about 50 percent?

Maintenance checks:

1. Is replacement needed as a result of loss over time?

1.2.4. Excelsior

Excelsior is a product made of fine wood shavings that assume a more-or-less helical form. As a consequence of this form, excelsior does not lie in close contact with the soil and allows runoff to drain beneath it and cause erosion. Therefore, it should be used only with seeding, where it is very useful in holding moisture and providing protection from direct sun in hot periods. Suppliers generally market several grades for sheet and channelized flow and different velocities.

Installation checks:

1. Is the excelsior used only with seeding?
2. Was an appropriate material selected according to manufacturer's recommendations and then placed and stapled as recommended by the manufacturer?
3. On slopes, was it placed 3 ft over the crest or in an anchor ditch?
4. In ditches, was it placed in the direction of water flow with any seams offset 6 in. from the ditch centerline?

Maintenance checks:

1. Is replacement needed as a result of damage or loss over time?

1.2.5. Mats and blankets

Examples of materials produced in a mat or blanket form for erosion control are jute, woven straw, and synthetics. Mats can be used without seeding, or with seeding for better erosion control. As with excelsior, suppliers generally market several grades for sheet and channelized flow and different velocities.

Installation checks:

1. Was an appropriate material selected according to manufacturer's recommendations and then placed and stapled as recommended by the manufacturer?
2. Was it placed in the direction of water flow, in full contact with the soil but not tightly stretched?

Maintenance checks:

1. Is replacement needed as a result of damage or loss over time?

1.3. Permanent vegetation establishment

Permanent vegetation should be established as soon as possible after all construction is completed in each segment of the site. Grass can be established by seeding or sodding. Seeding is generally preferred because of the lower cost and greater flexibility in selecting grass species. Sod is often available only in limited varieties, which may not be the most suitable for erosion control and other purposes unless grown to order. In some cases, overseeding with preferred species is recommended in the spring, when grass must be established with sod in the winter. Species should be selected based on local climatological and soil conditions, with reference to regional guidance documents, and, when necessary, in consultation with regional experts.

1.3.1. Permanent seeding

Installation checks:

1. Has the seedbed been prepared by loosening with a plow if subsoils are highly compacted, spreading 2 to 6 in. of topsoil, and lightly rolling?
2. Is fertilizer use limited as much as possible; if used, is it applied in amounts no greater than the needs of the grass for the prevailing soil conditions?
3. Is mulch applied for protection if seeding occurs when temperatures can be high or runoff is likely to occur before the grass is well established?
4. Is irrigation provided if planted when rainfall might be insufficient for good establishment?

Maintenance checks:

1. Is it nencessary to water, reseed, or add fertilizer?

1.3.2. Sodding

Installation checks:

1. Is the sod placed from the lowest area and perpendicular to water flow?
2. Are sod strips wedged tightly together and joints staggered at least 12 in.?
3. Is the sod stapled if on a steep slope?

Maintenance checks:

1. Is overseeding needed, either to repair damage or to install a preferred grass species?

1.4. Stabilized construction entrance and roads

The entrance is the most important access route to stabilize, since it is the last point at which tracking sediment off site can be stopped. If equipment travels extensively on unstabilized roads on the site, a tire and vehicle undercarriage wash near the entrance will be needed. Perform washing on crushed rock. Wash water will require treatment in a sediment pond or trap.

1.4.1. Stabilized construction entrance (see Figure 3)

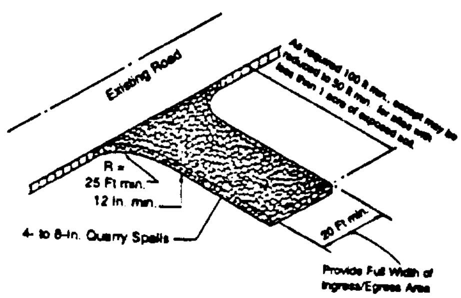

Figure 3. Stabilized construction entrance (from Washington Department of Ecology, 1992).

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Installation checks:

1. Is the entrance constructed with quarry spalls 4 to 8 in. in size and at least 12 in. thick?
2. Is the stabilized entrance sized correctly for the site?
3. If the entrance sits on a slope, is a filter fabric fence in place downgradient?

Maintenance checks:

1. Is the entrance clogged with sediments, requiring top dressing the pad with clean 2-in. rock?
2. Is it necessary to clean up any sediments carried from the site onto the street?

1.5. Runoff control

Runoff control represents various practices designed to keep water from coming in contact with bare soil or controlling its velocity if it does. Included are drains for surface and subsurface water, dikes and swales placed across slopes to interrupt runoff, and roughness created on the surface to reduce velocity. Example guidelines presented below are for a pipe slope drain and surface roughening.

1.5.1. Pipe slope drain (see Figure 4)

A temporary pipe slope drain is an effective technique for preventing erosion on a slope caused by runoff from a higher elevation. Upslope runoff needs to be collected and directed into the drain effectively and then discharged in a controlled way to prevent erosion at the bottom of the slope.

Installation checks:

1. Are no more than 10 acres drained into a single pipe slope drain?
2. Was a minimum 6-in. metal toe plate placed at the entrance to prevent undercutting?
3. Is runoff directed into the pipe with interceptor dikes at least 1 ft higher at all points than the top of the pipe?
4. Is there a slope toward the pipe on a grade of at least 3 percent at the inlet?
5. If the pipe is 12 in. in diameter or larger, was a flared entrance section installed and connected securely to the drain with water-tight connecting bands?

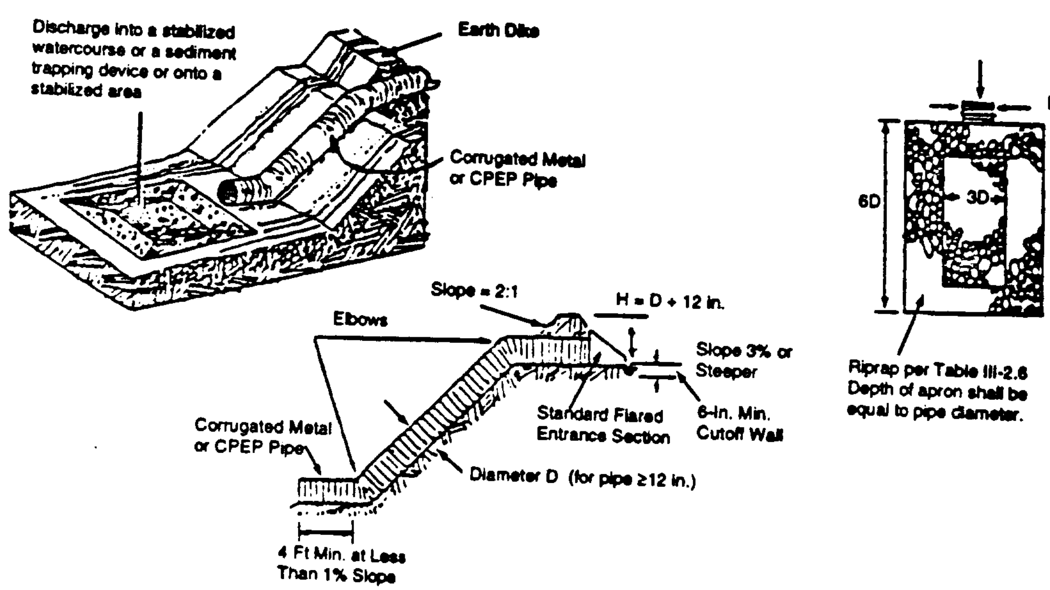

Figure 4. Pipe slope drain details (3).

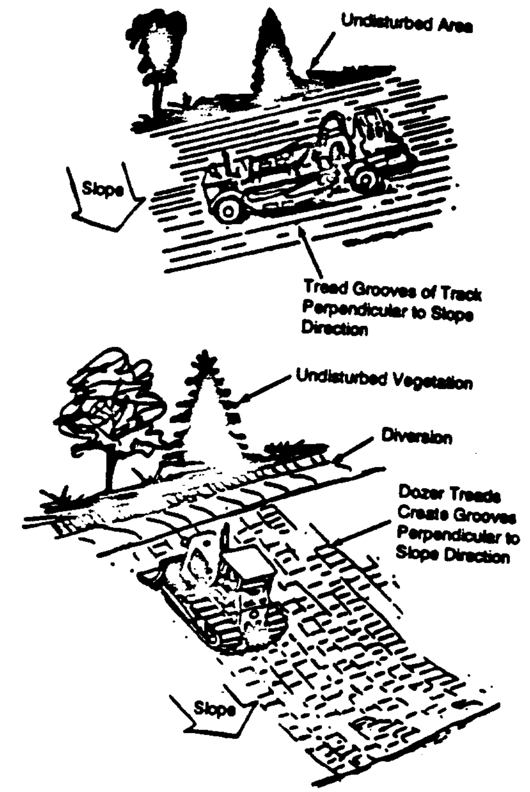

Figure 5. Examples of surface roughening using heavy equipment (3).

6. Was the soil thoroughly compacted at the entrance and underneath the pipe?

7. Were gasketed, water-tight fittings placed between pipe sections, were the sections securely fastened, and was the drain anchored to the soil?

8. Was the area below the outlet stabilized with a riprap apron?

9. If the drainage can carry sediment, is it treated in a sediment pond or trap?

Maintenance checks:

1. Is undercutting or bypassing occurring at the inlet, requiring reinforcing of the headwall with compacted earth or sandbags?

2. Is erosion occurring at the outlet, necessitating rebuilding the apron?

1.5.2. Surface roughening (see Figure 5)

A roughened surface is an easy and inexpensive way to reduce runoff velocity, encourage the growth of vegetation, increase runoff infiltration, and trap some sediment. It is not effective enough to use alone but can reduce the load on sediment trapping installations downstream. Roughening is best used on slopes steeper than 3 horizontal to 1 vertical that do not require mowing. There are several methods of roughening a surface, all of which involve forming horizontal depressions with equipment. Methods include tracking perpendicular to the slope direction, driving treaded equipment along the slope direction to get grooves perpendicular to the slope, or tilling (preferred because it avoids compaction). On steeper slopes (steeper than 2 horizontal to 1 vertical) a stair-step pattern should be formed.

Installation checks:

1. Have all exposed slopes steeper than 3 horizontal to 1 vertical been roughened, with 40- to 50-in. stair-step patterns formed on slopes steeper than 2 horizontal to 1 vertical?

2. Was the soil scarified if it was heavily compacted by the roughening?

3. Was the area seeded as quickly as possible?

Maintenance checks:

1. Have rills appeared that should be regraded and reseeded?

2. Sediment trapping techniques

Trapping sediments once they are released requires slowing the transport velocity sufficiently for soil particles to settle (i.e., reducing the velocity below the settling velocity of the particles). Soil particles range over several orders of magnitude in size, from the small clays to the large sands. Settling velocity is approximately related to the square of the particle diameter; thus, halving the diameter approximately quadruples the time needed for settlement. Therefore, as particles decrease in size, they become

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increasingly difficult to remove from a runoff stream. This fact is largely why preventive techniques are more cost effective than sediment trapping practices and are strongly preferred.

The two basic types of sediment trapping techniques in use are sediment barriers and settling ponds. Sediment barriers include the commonly used filter fabric and straw bale fences as well as brush fences and barriers constructed of gravel. Both types trap sediments in the same way, by ponding water. Although that mechanism is more obvious in the case of ponds than of barriers, practices of the latter type actually provide only a minimum of filtering capability and primarily slow the flow of water long enough for some particles to settle. Thus, they can only trap relatively large particles, generally the larger silts and sands. The trapping ability of settling ponds depends on their size. While they can theoretically be made large enough to trap any size particle, practical sizes generally limit efficient removal to the medium silts and larger.

2.1. Sediment barriers

Several principles apply to the various types of sediment barriers. Maximizing a sediment barrier's ponding volume maximizes the amount of sediment trapped. Therefore, the barriers should be placed away from the immediate toe of slopes in order to increase the area for ponding. It is very important that sediment barriers be aligned on the contour, not up and down slopes. This alignment places them at a right angle to flow paths and also increases ponding volume. Slopes draining to sediment barriers generally should not be more than 100 ft long. Sediment barriers must be trenched in and staked to hold up under the pressure of the wall of water they will dam. Finally, sediment barriers do not provide effective sediment removal from concentrated flows. While straw bales are sometimes used in ditches, rock check dams are really a better alternative for decreasing velocity in channels.

2.1.1. Filter fabric fence (see Figure 6)

Installation checks:

1. Are filter fabric fences used only in the following applications:

   Maximum of 1 acre served by a single fence?

   Maximum 1:1 slope gradient and 100-ft slope length?

   Sheet flow situation (never in concentrated flow)?

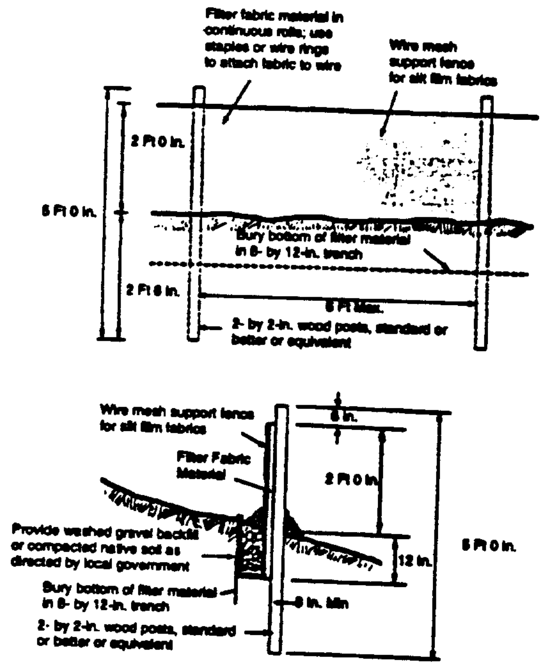


Figure 6. Filter fabric fence detail (3).

2. Is the fence aligned to slope contours as well as possible?

3. Is the fence installed so that its height above the soil is no more than 3 ft?

4. Are posts 2 x 4 in. wood or 1.33 lb/ft steel, or the equivalent?

5. Are posts buried 2.5 ft deep whenever possible and spaced no more than 6 ft apart?

6. Is fabric attached on the upslope side with staples (at least 1 in.), tie wires, or hog rings?

7. Is the end of the fabric buried in a trench sized as shown in Figure 6 and backfilled on both the upslope and downslope sides (as shown)?

8. Is splicing avoided if possible? If impossible, is splicing done only at posts and overlapped at least 6 in.?

9. Nonwoven and woven monofilament materials have the best properties for silt fencing. If a woven slit-film fabric is used, is wire mesh reinforcing (14-gauge rein-

forcing wire mesh with openings no larger than 6 in.) placed on the upslope side and fastened the same as the fabric?

Maintenance checks:

1. Is it necessary to restake, reattach, or replace the fence to maintain all of the above conditions?

2. Is sediment removal needed (before it reaches 1/3 the height of the fence)?

2.1.2. Straw bale fence (see Figure 7)

Straw bale fences tend to swell when they get wet and require frequent maintenance. They are not highly recommended but could be more effective if used according to the following guidelines.

Installation checks:

1. Are straw bale fences used only in the following applications:

   Maximum of 1/4 acre served per 100 ft of fence length?

   Maximum 2:1 slope gradient and 100-ft slope length?

2. Is the fence aligned to slope contours as well as possible?

3. Are the bales bound with wire, preferably, or string placed around the sides of the bale, parallel to the ground?

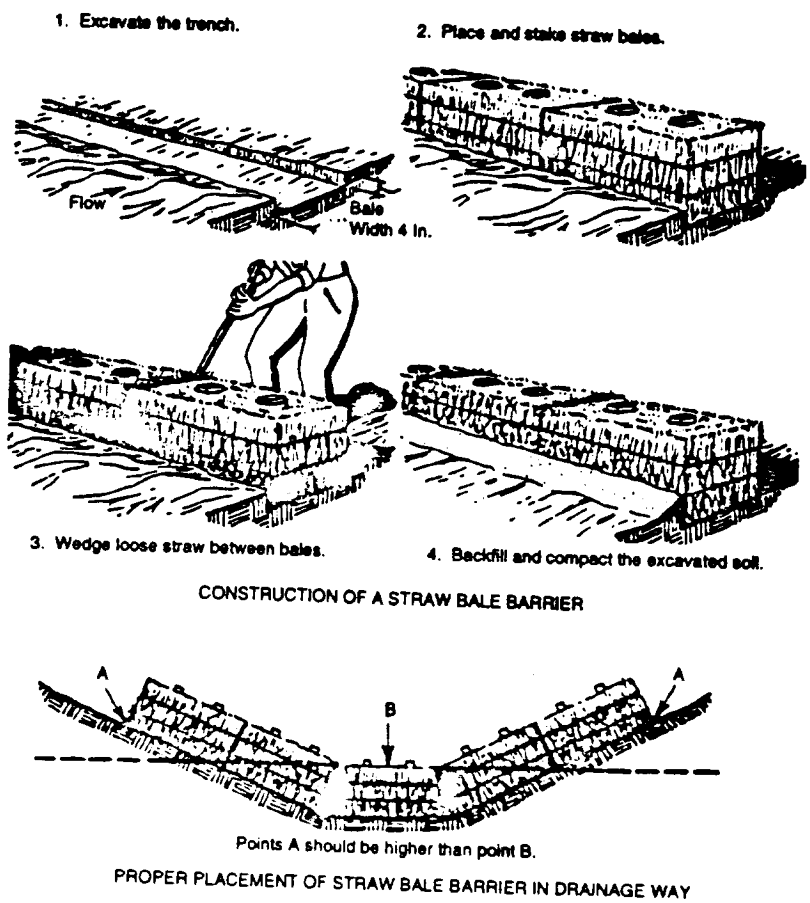


Figure 7. Proper installation of straw bale fences (3).

4. Are the bales installed in a 4-in. trench, as shown in Figure 7, and backfilled with 4 in. of soil on the upslope side?

5. Are the bales forced together as tightly as possible and anchored with at least two stakes or pieces of rebar per bale driven toward the previous bale and flush with the top of the bale?

6. Are gaps wedged with straw, and is straw spread on the upslope side?

7. Are straw bale fences used in channels with concentrated flow only when velocities are low and placed as shown in Figure 7 (perpendicular to flow and extending at least one bale length above the mid-channel bale)?

Maintenance checks:

1. Is it necessary to replace the fence to maintain all of the above conditions?

2. Is sediment removal needed (before it reaches 1/2 the height of the fence)?

2.2. Settling ponds

Settling ponds have several advantages. They can function through all construction phases and have relatively low maintenance requirements. They can also be located to intercept runoff both before and after the onsite drainage system is developed.

The three types of settling ponds in use differ only in their outlet structure. The term sediment basin is used to describe a settling pond with a pipe outlet that generally serves a drainage area of 3 to 10 acres. A sediment trap is a settling pond with a stable spillway outlet and a smaller service area. The third type is a permanent water quantity control pond put in temporary service during construction; such a pond is designed to drain completely between storms in permanent service. This operating mode is not appropriate for ESC application, however, because the residence time is too short for good particle trapping and settled material becomes resuspended during draining. Therefore, a temporary riser outlet needs to be installed for use during construction.

A key point in the design and construction of a settling pond is to avoid short-circuiting by the water. Short-circuiting can cut the actual residence time far below the theoretical value and harm performance. Ways of avoiding it are to divide the pond into two or more cells, locate the inlet and outlet far apart, and install baffling to increase the flow path.

2.2.1. Sediment basin (see Figure 8)

Installation checks:

1. Is the bottom graded to be as level as possible?

2. Is the pond no deeper than 7 ft with 1 ft of freeboard?

3. Are side slopes no steeper than 3 horizontal to 1 vertical?

4. Does the pond have an emergency spillway that is 1 ft deep, with a width two to three times the number of acres served by the pond, and lined with 2 to 4 in. of rocks?

5. Does the pond discharge through a riser pipe having at least two 1-in. diameter orifices at the top of the sediment storage zone?

6. Are inlet and outlet areas protected from erosion with riprap?

7. Is baffling installed if the length-to-width ratio is less than 6 or if the entrance velocity is high?

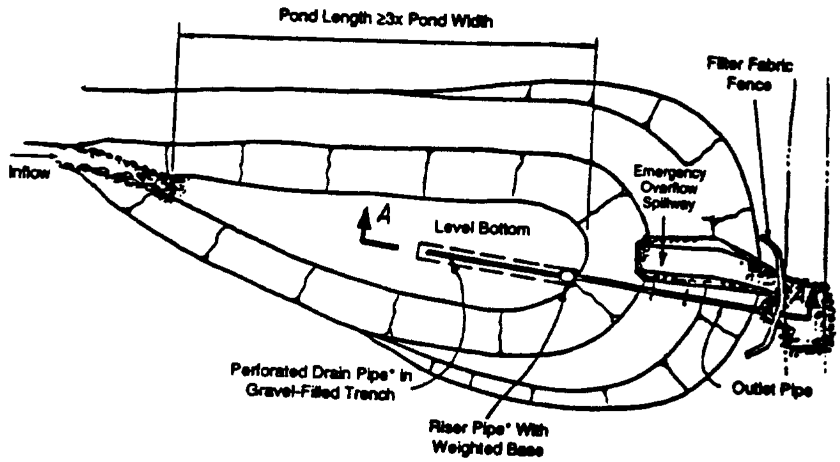
8. A good feature to prevent short-circuiting of flow is a two-celled pond, preferably with cells divided by sandbags or a rock berm and connected by a riser pipe similar to that used for the outlet. A less preferred arrangement is dividing the pond with a filter fabric fence. Is this feature installed if specified in the design?

9. Is the pond fenced if it presents any safety hazard to children?

Maintenance checks:

1. Is sediment removal needed (before 1.5 ft accumulates)?

2. Are any outlet orifices clogged and in need of cleaning?



*Sediment dewatering may be accomplished with perforated pipe in trench as shown or with a perforated riser pipe covered with filter fabric and a gravel "cone." A control structure may also be required; see Conditions Where Practice Applies.

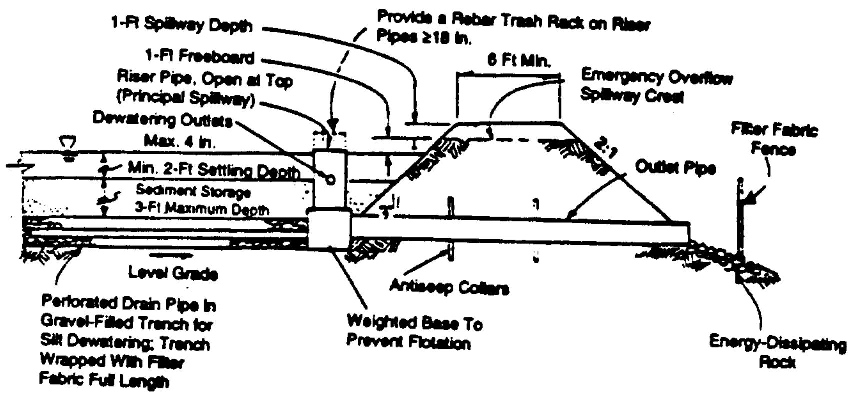


Figure 8. Typical sediment basin (3).

3. Are any embankments damaged and in need of compaction or rebuilding?
4. Has riprap or spillway lining material been lost and need to be replaced?
5. Are there signs of excessive drainage to the pond, requiring rerouting or pond enlargement?
6. Are there signs of excessive sediment loading to the pond, requiring stabilization of the drainage area?

3. Management of other construction site pollutants

Construction sites can create pollution problems over and above erosion and sediments through paving operations, handling and storage of various materials, spills, and waste handling. Inspectors should also be aware of the potential for runoff contamination from these sources and inspect the site according to the following guidelines.

3.1. Handling cement and concrete

Inspection checks:

1. Do concrete trucks have a designated washout area with a sediment trap?

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2. Is exposed-aggregate driveway wash water drained toward a collection point at the side or into a sediment trap, where it cannot get into a street drainage system?

3.2. Material storage and handling

Inspection checks:

1. Are weather-resistant enclosures used for the storage and handling of materials, such as paints, coatings, wood preservatives, pesticides, fuels, lubricants, and solvents, and for potentially polluting wastes?
2. Are there designated and clearly communicated procedures for handling materials and wastes and washing containers?
3. Is a chemical inventory maintained, including Material Safety Data Sheets?
4. Are containers and enclosures inspected periodically for leakage, indicating the need for maintenance?

3.3. Spill containment

Inspection checks:

1. Has a spill control plan been developed, and have supplies been obtained to implement it? Does the plan include:

   Who to notify if a spill occurs?

   Specific instructions for different products?

   Who is in charge?

   Spill containment procedures?

   Easy to find and use spill cleanup kits?

   How a spill will be prevented from getting into a drainage system (e.g., valving, diversion, absorption)?

   A disposal plan?

   A worker education program?

3.4. Waste management

Inspection checks:

1. Have waste reduction practices been instituted (e.g., reusing solvents, substituting for toxic products, minimizing quantities of materials used)?
2. Have recycling practices been instituted (e.g., waste separation for recycling, purchasing recycled materials)?
3. Are hazardous and nonhazardous wastes separated and each disposed of properly and promptly?
4. Has an employee education program on waste management been established?

Inspection Programs for Permanent Drainage Practices and Facilities

Program Development

Program Elements

The following elements are recommended for a comprehensive inspection program for permanent drainage practices and facilities:

- Stormwater management planning
- Plan review process
- Construction inspection and enforcement process
- Followup inspection and long-term maintenance process

The stormwater management planning step ensures that each site considered for a permit receives comprehensive analysis. The extensive considerations in this portion of the recommended program are beyond the scope of this discussion. The third element refers to inspection of the stormwater management facilities themselves when they are built to determine whether installation has been consistent with the approved plans. The final element seeks to ensure that facilities continue to operate properly. The next subsection covers programmatic aspects of the followup inspection and long-term maintenance process. The discussion is then extended in the following section to examples of inspection guidelines for common practices and facilities.

Followup Inspection and Long-Term Maintenance Process

Recommended features for a followup inspection and maintenance program are:

- An ordinance designating public authority and public and private responsibilities.
- A tracking system.
- An inspection schedule.
- A maintenance schedule.
- A safety program.
- A citizen response program.
- A detailing of proper waste disposal practices.
- A maintenance contractor education program.

The discussion below elaborates on several of these features, drawing principally on experience in King County, Bellevue, Olympia, and elsewhere in the Puget Sound region of Washington. The examples in the section that follows this discussion present guidance on establishing schedules for common facilities and the specific checks to be made during inspection visits.

Public Versus Private Responsibilities. Whereas inspection is usually a public function, the question of responsibility often arises with respect to the upkeep of privately owned facilities. One model involves establishing a multiyear bonding period, during which the developer has all responsibility. Often after this period and a demonstration of effective operation, the government agency responsible for stormwater management then takes over operation and maintenance. A second model calls for leaving maintenance as a private function (performed by a commercial property owner or homeowners' association), with inspection by the public agency. In this approach, the government assumes the responsibility and assesses costs if the private party does not meet its responsibility. Effective application of this strategy requires that private maintenance contractors competently perform the needed work. The frequent lack of qualified contractors requires government agencies to consider training and certifying them.

Tracking System. King County, Washington, offers a useful model for a tracking system to organize long-term inspections and maintenance. The King County approach uses a computerized information system. Each inspector is assigned an inventory of facilities to inspect and specify maintenance and is given a laptop computer to use in the field. The information system contains an identification number for each facility, its type (e.g., wet pond, infiltration basin), location, any special needs, and data on previous experiences. At the conclusion of each visit, the inspector enters a maintenance needs assessment in the computer database. The computer then generates a maintenance work order.

Safety. Safety is a major consideration because of potentially harmful air quality in below-ground spaces, corroded supports, traffic, falling objects, sharp edges, poisonous plants and insects, and lifting. The safety portion of an inspection and maintenance program should include:

- Testing instruments for harmful atmospheres (explosive, containing hydrogen sulfide, lacking in oxygen); a tester should be capable of checking all potential conditions of concern, and all enclosed spaces should be tested before an inspector enters.
- Ventilating equipment.
- Checking for structural soundness before entering a manhole.
- Traffic warning devices.
- Ladders, safety harnesses, and hard hats.
- Removing poisonous plants and threatening insect nests.
- Adequate personnel.
- Safety training.

Waste Handling. Major maintenance on large facilities should be scheduled when the least runoff is expected. It is often a good idea to use ESC-type installations such as filter fabric fences, sandbags, grassed drainage areas, and revegetation to prevent escape of sediments during maintenance.

Although the vactor truck is the maintenance workhorse, a problem concerns mixing waste that may be relatively clean with very dirty waste. A solution, but an expensive one, is to have "clean" and "dirty" trucks. Another issue concerns disposal of both solids and separated "decant" water picked up by vactor trucks. The best solution for decant water is to discharge it to a special decant station that has sediment and oil separation equipment, before the water is discharged to a sanitary sewer. Few facilities currently operate this way, and most vactor waste is discharged directly to a sanitary sewer. This practice can result in pollutants entering surface waters because of inadequate treatment at the municipal wastewater plant. It can also deliver toxic materials that can upset biological processes at the treatment plant. Guidelines are needed but generally do not exist for disposing of solids. The best programs now send them to a lined municipal landfill, unless they fail a "looks bad and smells bad" test, in which case they are treated as hazardous waste.

Permanent Drainage Practices and Facilities and Their Inspection

Categories of Practices and Facilities

Following is the breakdown of practices used by Reinelt (2), with the number of individual practices in each category:

1. Stormwater devices—three practices
2. Detention facilities—eight practices
3. Infiltration facilities—five practices
4. Biofilters—three practices

The 19 practices represented include some variations on common devices, depending on their intended function, as specified by the Stormwater Management Manual for the Puget Sound Basin (3). For example, detention facilities include "wet ponds," which have a quantity control function, and "water quality wet ponds," which are treatment devices.

The following passages provide inspection checklists for example practices and facilities, generally the most common, in each category. The practices and facilities themselves are described only very briefly in this section. For detailed descriptions, consult a stormwater management manual or textbook. The checklists are divided into checks to make when the practice or facility is first installed and checks to be made on each followup visit to determine the need for maintenance. Many of the points are illustrated in diagrams that accompany the checklists. Also presented for a number of practices are tables of maintenance standards. These tables have been developed over time in the Puget Sound area, and several jurisdictions have contributed to them.

While much of an inspector's work is performed in the field, it is often advisable or even absolutely necessary to do some background work in the office before going out to inspect an installation. This work mainly consists of consulting the design plans to determine the specifications.

Too infrequent inspection and maintenance is one of the main reasons for poor performance by stormwater facilities. The frequency of followup inspections should be determined based on the type of device and the circumstances where it is installed. An inspection and maintenance plan should be developed before an installation goes into service. As a general rule, surface facilities should undergo a drive-by inspection at least monthly and after any rain totaling 0.5 in. or more in 24 hr.

1. Stormwater devices

This group includes devices used for collection and conveyance of stormwater, as well as special-purpose facilities. Within the category are catch basins, pipes and culverts, and oil/water separators. Inspection guidelines are given for oil/water separators as a complete example. Tables of maintenance standards are included for the other types of facilities.

1.1. Oil-Water separators

Figure 9 illustrates the three basic types of oil-water separators. The spill control unit's purpose is to catch small spills; it is not capable of separating dispersed oil. The American Petroleum Institute (API) separator is a baffled tank that can separate "free" (unemulsified) oil but requires a relatively large volume for effectiveness. The coalescing plate (CP) separator can separate free oil in a much smaller volume because of the large surface area provided for oil collection by the corrugated plate pack. The following guidelines generally apply to all types, except as noted.

Installation checks

1. Is the type appropriate for the service?
2. Is the unit sized and installed as specified in the plans?
3. Are adequate removable covers provided for observation and maintenance?
4. Is runoff excluded from roofs and other areas unlikely to contain oil?
5. Is any pump in use placed downstream to prevent mechanical emulsification?
6. Is detergent use avoided upstream to prevent chemical emulsification?
7. For API and CP separators, is a forebay provided sized at 20 ft^2 of surface area per 10,000 ft^2 of drainage area?
8. For API and CP separators, is an afterbay provided for placement of absorbents?
9. For the CP separator, are the plates no more than 3/4 in. apart and at 45 to 60 degrees from horizontal?

Maintenance checks:

1. Is weekly inspection performed by the owner?
2. Are oil and any solids removed frequently enough (at least just before the main runoff period and then after the first major runoff event)?
3. Are absorbents replaced as needed, but at least at the beginning and end of the main runoff season?
4. Is the effluent shutoff valve operational for closure during cleaning?
5. Are waste oil and solids disposed of as specified by regulations?
6. Is any standing water that is removed discharged to the sanitary sewer and then replaced with clean water?

1.2. Pipes and culverts

Refer to Table 2 for a summary of maintenance standards for conveyance facilities.

1.3. Catch basins

Catch basins are routinely placed between the drain inlets in streets and parking lots and the conveyances that transport water away to settle large solids. Refer to Table 3 for a summary of maintenance standards.

2. Detention facilities

Detention facilities include ponds that are designed and operated either to drain within hours after a

Table 2. Maintenance Standards for Pipes and Culverts

Defect	Conditions When Maintenance Needed	Maintenance Results
Sediment and debris	Accumulated sediment that exceeds 20% of the diameter of the pipe.	Pipe cleaned of all sediment and debris.
Vegetation	Vegetation that reduces free movement of water through pipes.	All vegetation removed so water flows freely through pipes.
Damage	Protective coating is damaged; rust is causing more than 50% of deterioration to any part of pipe.	Pipe repaired or replaced.
	Any dent that decreases the end area of pipe by more than 20%.	Pipe repaired or replaced.
Debris barriers	Trash or debris that is plugging more than 20% of the openings in the barrier.	Barrier clear to receive capacity flow.
Damaged/ Missing bars	Bars are bent out of shape more than 3 in.	Bars in place with no bend >3/4 in.
	Bars are missing or entire barrier is missing.	Bars in place according to design.
	Bars are loose and rust is causing 50% deterioration to any part of barrier.	Repair or replace barrier to design standards.

storm (dry ponds), to drain within a day or two (extended-detention dry ponds), or to retain a permanent or semipermanent pool (wet ponds). These ponds can have water quantity control objectives, or water quality control objectives, or both, although dry ponds offer few water quality benefits. Detention facilities also include below-ground concrete vaults and storage pipes, the latter sometimes referred to as tanks. These devices serve primarily quantity control purposes, although if they have relatively long water residence times they can collect some solids. Other facilities sometimes included in this category are parking lot and rooftop storage. Constructed wetlands can be placed in either this group or with biofilters. Inspection guidelines are given for wet ponds as a complete example. A table of maintenance standards is included for vaults and tanks as well.

2.1. Wet ponds

Figure 10 illustrates a typical wet pond. A wet pond has a "dead storage" permanent or semipermanent pool and a "live storage" zone that fills during runoff events and then drains fairly quickly. Its design basis differs depending on its purpose (quantity control or quality control, or both), but the checks made when it is installed and later while it is operating are

Table 3. Maintenance Standards for Catch Basins

Defect	Conditions When Maintenance Needed	Maintenance Results
Trash and debris (including sediment)	Trash or debris of more than 1/2 ft^3 located in front of the catch basin opening or is blocking capacity of basin by >10%.	No trash or debris located immediately in front of catch basin opening.
	Trash or debris in the basin that exceeds 1/3 to 1/2 the depth from the bottom of the basin to the invert of the lowest pipe into or out of the basin.	No trash or debris in catch basin.
	Trash or debris in any inlet or outlet pipe blocking more than 1/3 of the height.	Inlet and outlet pipes free of trash or debris.
	Dead animals or debris that could generate odors that would cause complaints or dangerous gases.	No dead animals or vegetation present.
	Deposits of garbage exceeding 1 ft^3 in volume.	No garbage in catch basin.
Structural damage to frame or top slab	Corner of frame extends more than 3/4 in. past curb face into the street (if applicable).	Frame is even with curb.
	Top slab has holes larger than 2 $in.^2$ or cracks wider than 1/4 in. (intent is to make sure all material runs in to basin).	Top slab is free of holes and cracks.
	Frame not sitting flush on top slab (i.e., separation of >3/4 in. of the frame from top of slab).	Frame is sitting flush on top of slab.
Cracks in basin walls or bottom	Cracks wider than 1/2 in. and longer than 3 ft, any evidence of soil particles entering catch basin through cracks, or structure is unsound.	Basin replaced or repaired to design standards.
	Cracks wider than 1/2 in. and longer than 1 ft at the joint of any inlet/outlet pipe or any evidence of soil particles entering catch basin through crack.	No cracks more than 1/4 in. wide at joint of inlet/outlet pipe.
Settlement/ Misalignment	Basin has settled more than 1 in. or has rotated more than 2 in. out of alignment.	Basin replaced or repaired to design standard.
Fire hazard	Presence of chemicals such as natural gas, oil, and gasoline.	No flammable chemicals present.
Vegetation	Vegetation growing across and blocking >10% of basin.	No vegetation blocking opening to basin.
	Vegetation (or roots) growing in inlet/outlet pipe joints that is >6 in. tall and <6 in. apart.	No vegetation or root growth present.
Pollution	Nonflammable chemicals of >1/2 ft^3 per 3 ft of basin length.	No pollution present other than surface film.

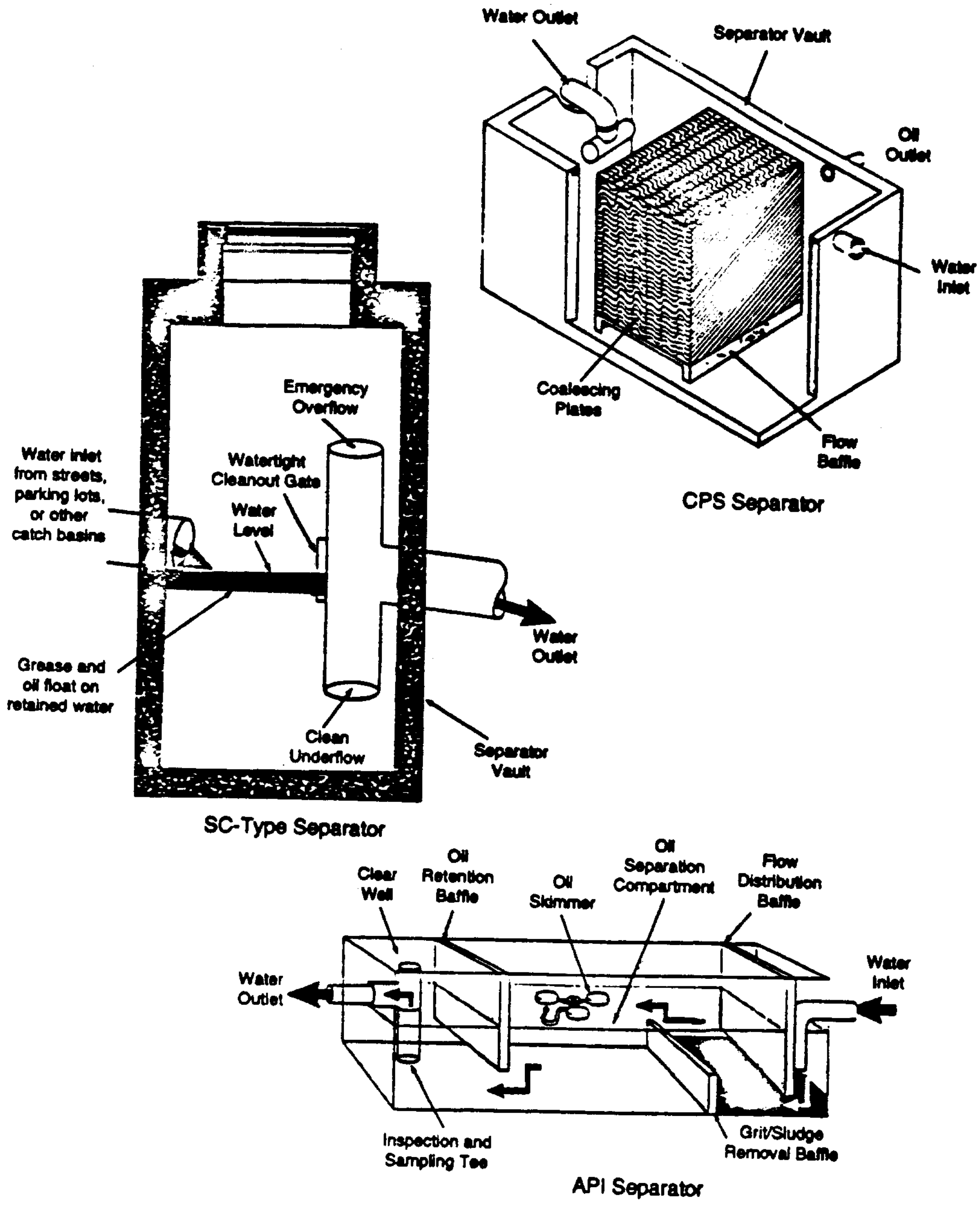

Figure 9. Types of oil/water separators (3).

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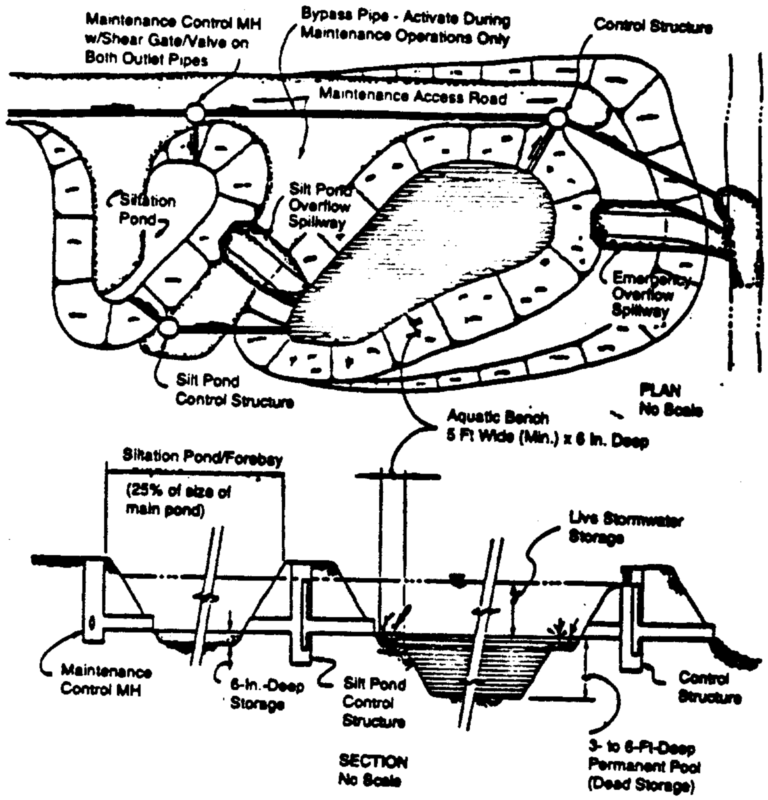

Figure 10. Typical wet pond (3).

generally the same, with the few exceptions noted.

Installation checks:

1. Does construction comply with local requirements for earthwork, concrete, other masonry, reinforcing steel, pipe, water gates, metalwork, and woodwork?
2. Are all dimensions as specified in the approved plan?
3. Are interior side slopes no steeper than 3 horizontal to 1 vertical and exterior side slopes no steeper than 2:1?
4. Is the bottom level?
5. Are the spillways (between cells, if any, and the emergency outlet spillway) sized and reinforced as specified in the approved plan?
6. Is a drain provided that can drain the dead storage zone within 4 hr if necessary?
7. Are inlet and outlet areas stabilized as necessary to avoid erosion?
8. Are safety concerns addressed, for example, with such features as a shallow bench completely around the edge of the pond, barrier plantings to discourage approach by children, and/or fencing (should not be necessary if sloped as recommended and other safety features are provided)?
9. For a water quality pond, is the effective length-to-width ratio at least 3:1 minimum, 5:1 preferably; are the inlet and outlet separated to the greatest width possible?

Maintenance checks:

1. Has a maintenance plan and schedule been developed?
2. Refer to Table 4 for specific checks and maintenance standards (these standards apply to other types of ponds as well).

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Table 4. Maintenance Standards for Detention Facilities

Defect	Conditions When Maintenance Needed	Maintenance Results
Trash and debris	Any trash or debris that exceeds 1 ft^3/ 1,000 ft^2. There should be no evidence of dumping.	Trash and debris cleared from site.
Poisonous vegetation	Presence of any poisonous vegetation that constitutes a hazard to maintenance personnel or to the public (e.g., poison oak, stinging nettles, devil's club).	No evidence of poisonous vegetation. Coordinate with health department.
Pollution	One gallon or more of oil, gas, or contaminants, or any amount that could 1) cause damage to plant, animal, or aquatic life, 2) constitute a fire hazard, 3) be flushed downstream during storms, or 4) contaminate ground water.	No contaminents present other than surface film. Coordinate with local health department.
Unmowed grass/ ground cover	In residential areas, mowing is needed when the cover exceeds 18 in. in height. Otherwise match facility cover with adjacent ground cover and terrain as long as there is no decrease in facility function.	Grass/ground cover should be mowed to 2 in. Maintain dense cover on slopes and in bottom of dry ponds.
Rodent holes	Any evidence of rodent holes if facility is acting as a dam or berm, or any evidence of water piping through dam or berm via rodent holes.	Rodents destroyed and dam or berm repaired. Coordinate with local health department.
Insects	When insects such as wasps or hornets interfere with maintenance activities.	Insects destroyed or removed from site. Coordinate with people who remove wasps for antivenom protection.
Tree growth	Tree growth does not allow maintenance access or interfere with maintenance activity. If trees are not interfering with access, leave trees alone.	Trees do not hinder maintenance activities.
Erosion of pond side slopes	Eroded damage >2 in. deep where cause of damage is still present or where there is potential for continued erosion.	Slopes stabilized with appropriate erosion control BMPs (e.g., seeding, mats, riprap).
Sediment accumulation in forebay/pond	Accumulated sediment 10% of the design forebay/pond depth, or every 3 yr.	Sediment cleaned out to design depth. Reseed if necessary for erosion control.
Dike settling	Any part of dike that has settled >4 in.	Dike is rebuilt to design elevation.
Rocks missing from overflow spillway	Only one layer of rock above native soil in an area of 5 ft^2 or greater, or any exposed soil.	Rock replaced to design standard.
Inadequate spillway size	Emergency overflow or spillway not large enough to handle flows from large storm events.	Increase capacity of spillway to current design standards.
Missing, broken, or damaged fencing	Any defect in fencing that permits easy entrance to the pond.	Fencing repaired to prevent entrance.
	Damaged fencing including posts out of plumb by >6 in., top rails bent >6 in., missing or loose tension wire, missing or sagging barbed wire, missing or bent extension arms.	Repair fencing and barbed wire to design standards
	Fencing parts that have a rusting or scaling condition that is affecting structural adequacy.	Structurally adequate posts or parts with protective coating.
	Opening in fencing that allows passage of an 8-in. diameter ball.	No opening in fence.
Erosion under fencing	Erosion >4 in. deep and 12 to 18 in. wide, permitting an opening under fence.	No opening under fence >4 in.
Missing or damaged gates	Missing or damaged gate, locking device, or hinges.	Gates, locking devices, and hinges repaired.
	Gate is out of plumb >6 in. and out of design alignment >1 ft.	Gate is aligned and vertical.
	Missing stretcher bar, bands, or ties.	Stretcher bar, bands, and ties in place.
Blocked or damaged access roads	Debris that could damage vehicle tires.	Roadway free of debris.
	Obstructions that reduce clearance above road surface to <14 ft (e.g., tree branches, wires).	Roadway clear overhead to 14 ft.
	Any obstructions restricting access to a 10- to 12-ft width for a distance of >12 ft, or any point restricting access to a width of <10 ft.	Obstructions moved to allow at least a 12-ft access route.
	Any road settlement, potholes, mushy spots, or ruts that prevent or hinder maintenance access.	Road surface repaired and smooth.
	Weeds or brush on or near road surface that hinder access, or are >6 in. tall and <6 in. apart within a 400 ft^2 area.	Weeds and brush on or near road surface cut to 2 in.
	Erosion within 1 ft of the roadway >8 in. wide and 6 in. deep.	Shoulder and road free of erosion.

2.2. Vaults and tanks

Refer to Table 5 for a summary of maintenance standards for closed detention systems.

3. Infiltration facilities

Infiltration facilities discharge most of the entering water to the ground. They include surface basins and trenches, below-ground perforated pipes, roof drain systems, and porous pavements. Inspection guidelines are given for infiltration basins as a complete example. A table of maintenance standards is included for infiltration trenches as well.

3.1. Infiltration basins (see Figure 11 for a typical basin)

Installation checks:

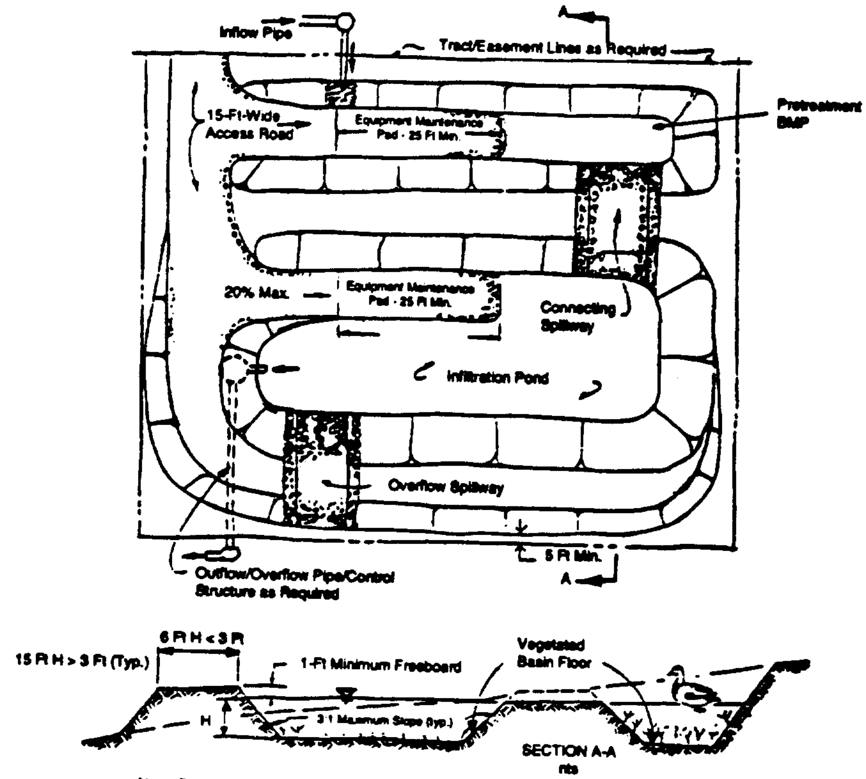
1. Does construction comply with local requirements for earthwork, concrete, other masonry, reinforcing steel, pipe, water gates, metalwork, and woodwork?
2. Are all dimensions as specified in the approved plan?
3. Does the timing of basin construction avoid the entrance of any runoff containing sediment from elsewhere on the site?
4. Is the basin preceded by a pretreatment device (e.g., presettling basin or biofilter) to prevent failure caused by siltation?
5. Is the basin at least 50 ft from any slope greater than 15 percent and at least 100 ft upslope and 20 ft downslope of any building?
6. Is the outlet orifice design consistent with the infiltration capacity on which the facility is based (e.g., to avoid the collection of more water than can infiltrate in 48 hr)?
7. Are the spillways (between cells, if any, and the emergency outlet spillway) sized and reinforced as specified in the approved plan?
8. Are all disturbed areas stabilized to prevent erosion?
9. After final grading, has the bed been deeply tilled to provide a well-aerated, highly porous surface texture?

Maintenance checks:

1. Has a maintenance plan and schedule been developed?
2. Refer to Table 6 for specific checks and maintenance standards.

Table 5. Maintenance Standards for Closed Detention Systems

Defect	Conditions When Maintenance Needed	Maintenance Results
Plugged air vents	Half of the end area of a vent is blocked at any point with debris and sediment.	Vents free of debris and sediment.
Debris and sediment in storage area.	Accumulated sediment depth is >10% of the diameter of the storage area for 1/2 the length of storage vault or any point exceeds 15% of the diameter. Example: 72-in. storage tank would require cleaning when sediment reaches a depth of 7 in. for more than 1/2 the tank length.	All sediment and debris removed from storage area.
Cracks in joints between tank/pipe sections	Any crack allowing material to be transported into the facility.	All joints between tanks or pipe sections are sealed.
Problems with manhole cover	Cover is missing or only partially in place. Any open manhole requires maintenance.	Manhole is closed and secured.
	Locking mechanism cannot be opened by one maintenance person with proper tools. Bolts into frame have <1/2 in. of thread (may not apply to self-locking lids).	Mechanism is repaired or replaced so it functions properly.
	Cover difficult to remove by one maintenance person applying 80 lb of lift.	Cover can be removed and reinstalled by one maintenance person.
Ladder rungs of manhole unsafe	Local government safety officer or maintenance person judges that ladder is unsafe due to missing rungs, misalignment, rust, or cracks.	Ladder meets design standards and allows for maintenance access.
Catch basins	See Table 3.	See Table 3.



Note: Detail is schematic representation only. Actual configuration will vary depending on specific site constraints and applicable design criteria.

Figure 11. Typical infiltration basin (3).

3. In addition, is tilling necessary to restore infiltration capacity (regular annual tilling is recommended)?

3.2. Infiltration trenches

Refer to Table 7 for a summary of maintenance standards for infiltration trenches.

4. Biofilters

The term "biofilter" applies to vegetated land treatment systems. Biofilters can be in the form of vegetated swales, in which water flows at some measurable depth or in a thin sheet across broad surface areas, sometimes called "filter strips." Constructed wetlands are also sometimes put in this category. The guidelines given below generally pertain to swales and filter strips, although some exceptions are noted. Inspection of constructed wetlands should be conducted with reference to both these guidelines and those given above for wet ponds.

4.1. Biofiltration swales and filter strips

Installation checks:

1. Are the dimensions and plantings as specified in the approved plan?
2. Is the vegetation cover dense and uniform?
3. If the biofilter is a swale, is it parabolic or trapezoidal in shape, with side slopes no steeper than 3 horizontal to 1 vertical?
4. Is the biofilter placed relative to buildings and trees in such a way that no portion will

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Table 6. Maintenance Standards for Infiltration Basins

Defect	Condition When Maintenance Needed	Maintenance Results
Sediment buildup in system	Soil texture test indicates facility is not functioning as designed.	Sediment is removed and/or facility is cleaned so that system works according to design. A forebay or presettling basin is installed to reduce sediment transport to facility.
Poor facility drainage (more than 48 hr)	Soil texture test indicates facility is not functioning as designed.	Additional volume added through excavation to provide needed storage. Soil aerated and rototilled to improve drainage.
Sediment trapping area	Sediment and debris fill >10% of sediment mapping facility or sump.	Sediment trapping facility or sump cleaned of accumulated sediment.
No sediment trapping facility	Stormwater enters infiltration area without pretreatment.	Trapping facility (presettling basin, detention pond, biofilter) is added before infiltration facility.

Table 7. Maintenance Standards for Infiltration Trenches

Defect	Condition When Maintenance Needed	Maintenance Results
Sediment and debris buildup in trench	By visual inspection, little or no water flows through the trench during large storms.	Debris blocking infiltration trench is removed. Gravel in infiltration trench is replaced or cleaned.
Observation well	Observation well buried, covered, or inaccessible.	The observation well/cap is accessible to the inspector for opening and inspection.
Water percolates up from trench	Trench water or water with dye percolating to surface.	Gravel and filter fabric in infiltration trench is replaced or cleaned. Trench functions according to design standards.
Filter fabric exposed	Filter fabric is exposed or damaged.	Filter fabric is replaced or repaired and covered with proper backfill material.

be shaded throughout the day and possibly experience poor plant growth?

5. If the longitudinal slope is less than 2 percent or if the water table can reach the root zone of vegetation, is water-resistant vegetation planted to survive a standing water condition or is an underdrain system installed to assist drainage (note: underdrains may not be practical with a large filter strip)?

6. If the longitudinal slope is in the range of 4 to 6 percent, are check dams provided approximately every 50 to 100 ft to reduce velocity (note: check dams may not be practical on a larger filter strip)?

7. If the slope on which a swale is installed exceeds 6 percent, does it traverse the slope in such a way that no reach slopes more than 4 percent, or 6 percent with check dams?

8. Is the lateral slope entirely uniform to avoid any tendency for the flow to channelize?

9. Is flow introduced in such a way that entrance velocity is dissipated quickly, flow is distributed uniformly, and erosion is avoided (e.g., by using a riprap pad or some means of level spreading)?

10. Was construction-phase runoff excluded or was the biofilter reestablished after construction, and are upslope areas stabilized to avoid erosion into the biofilter?

11. Is a bypass in place for flows larger than the flow rate for which the biofilter is designed to provide runoff treatment, or is the facility sufficiently large to pass at least the 100-yr, 24-hr storm without eroding (a bypass is preferred to maintain the treatment function and prevent resuspension of settled material)?

Maintenance checks:

1. Has a maintenance plan and schedule been developed?

2. Refer to Table 8 for specific checks and maintenance standards.

Table 8. Maintenance Standards for Biofilters

Defect	Conditions When Maintenance Needed	Maintenance Results
Trash and debris	Dumping of yard wastes. Accumulation of nondegradable materials.	Remove degradable wastes and compost. Recycle other waste when possible.
Sediment buildup	Accumulation >20% of design depth.	Cleaned or flushed to match design. Vegetation restored as necessary.
Poor vegetation cover	Vegetation sparse and/or weedy. Overgrown with woody vegetation.	Aerate soil and plant. Remove woody growth and replace.
Erosion damage to slopes	Erosion >2 in. deep where cause still present or potential exists for continued erosion.	Find cause and eliminate. Stabilize with appropriate erosion controls (e.g., seeding, mat, mulch).
Conversion to use incompatible with water quality control	Filled, planted appropriately, or blocked.	Discuss with nearby property owners and specify corrections to be made.
Poor drainage	Water stands in swale.	Determine cause. If water table is high, consider rebuilding with liner or underdrain. If slope <1%, use underdrain.

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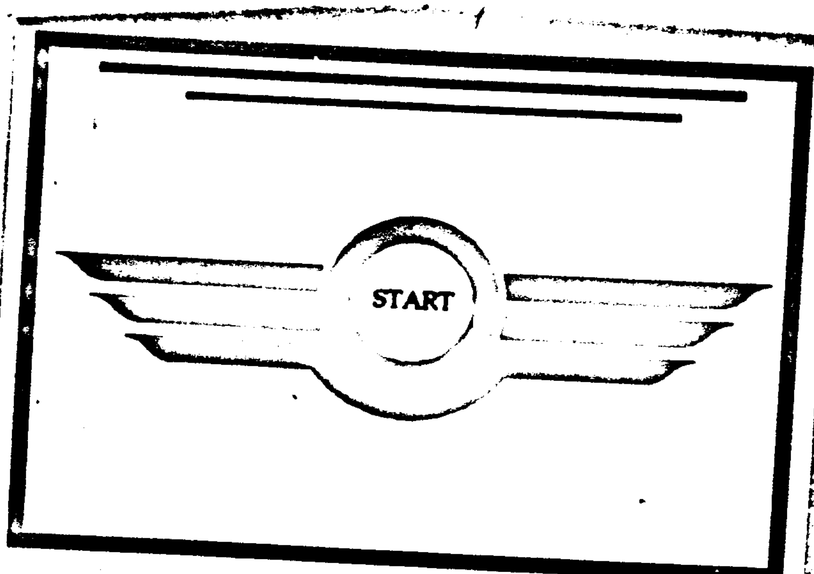

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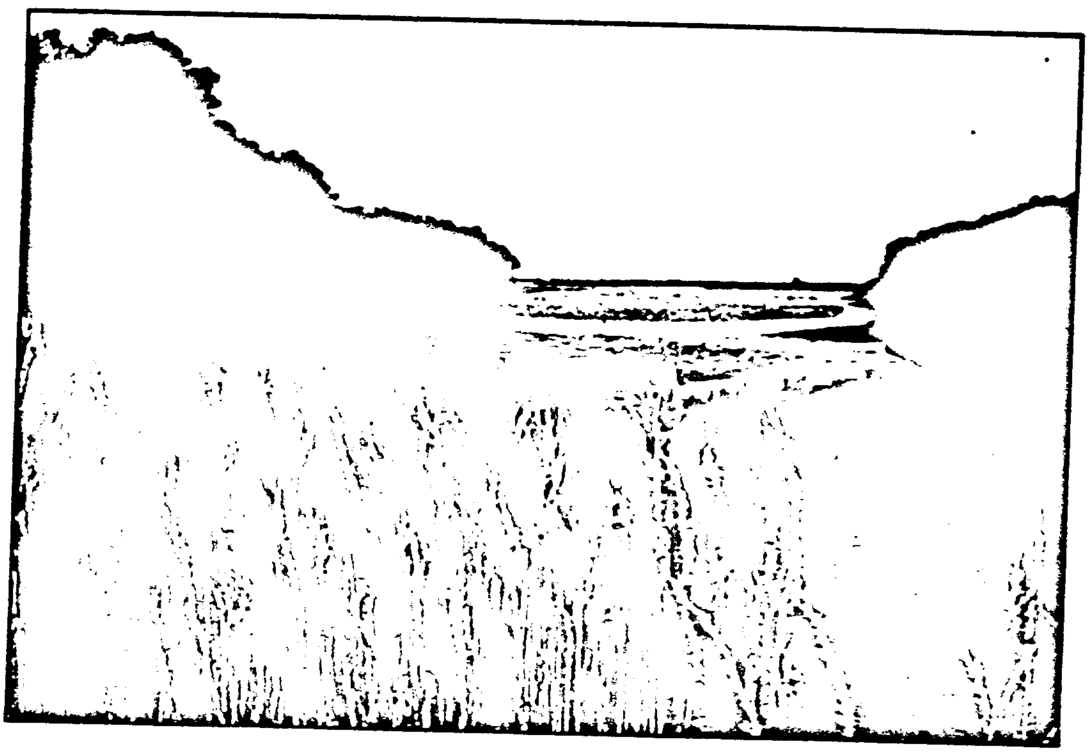
NOAA COASTAL OCEAN PROGRAM
Decision Analysis Series No. 5

ECONOMIC VALUATION OF NATURAL RESOURCES

A Handbook for Coastal Resource Policymakers



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The Decision Analysis Series has been established by NOAA's Coastal Ocean Program (COP) to present documents for coastal resource decision makers which contain analytical treatments of major issues or topics. The issues, topics, and principal investigators have been selected through an extensive peer review process. To learn more about the COP or the Decision Analysis Series, please write:

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Science for Solutions

NOAA COASTAL OCEAN PROGRAM
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ECONOMIC VALUATION OF NATURAL RESOURCES
A Handbook for Coastal Resource Policymakers

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June 1995

U.S. DEPARTMENT OF COMMERCE
Ronald H. Brown, Secretary
National Oceanic and Atmospheric Administration
D. James Baker, Under Secretary
Coastal Ocean Office
Donald Scavia, Director

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Note to Readers

Economic Valuation of Natural Resources: A Handbook for Coastal Resource Policymakers is the outcome of COP-sponsored environmental valuation workshops. As the text to support the teaching in these workshops developed and as the need to transfer this information to a wider audience of coastal managers than workshop attendees became apparent, it was decided to present the Handbook as a stand-alone document. The Handbook is a unique blend of writing by highly regarded experts in the field specifically tailored for the management community and input by managers who have attended the COP workshops. Each workshop participant is asked to provide comments on the curriculum, teaching effectiveness, and materials. Over the past three years, these comments have helped us to improve all aspects of the training.

The NOAA Coastal Ocean Program (COP) provides a focal point through which the agency, together with other organizations with responsibilities for the coastal environment and its resources, can make significant strides toward finding solutions to critical problems. By working together toward these solutions, we can ensure the sustainability of these coastal resources and allow for compatible economic development that will enhance the well-being of the Nation now and in future generations. The goals of the program parallel those of the NOAA Strategic Plan.

A specific objective of COP is to provide the highest quality scientific information to coastal managers in time for critical decision making and in a format useful for these decisions. To help achieve this, COP inaugurated a program of developing documents that would synthesize information on issues that were of high priority to coastal managers. A three-step process was used to develop such documents: 1) to compile a list of critical topics in the coastal ocean through a survey of coastal resource managers and to prioritize and select those suitable for the document series through the use of a panel of multidisciplinary technical experts; 2) to solicit proposals to do research on these topics and select principal investigators through a rigorous peer-review process; and 3) to develop peer-reviewed documents based on the winning proposals. Seven topics were selected in the initial round, but the series is expanding because of the suitability of findings from other COP-funded research to appear in this synthesis format. The documents already published are listed on the inside back cover.

As with all of its products, COP is very interested in ascertaining the utility of the Decision Analysis Series particularly in regard to its application to the management decision process. Therefore, we encourage you to write, fax, call, or E-mail us with your comments. Please be assured that we will appreciate these comments, either positive or negative, and that they will help us direct our future efforts. Our address and telephone and fax numbers are on the inside front cover. My Internet address is DSCAVIA@HQ.NOAA.GOV.

Donald Scavia
Director
NOAA Coastal Ocean Program

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ACKNOWLEDGMENTS

This handbook has grown out of a series of workshops sponsored by the NOAA Coastal Ocean Program (COP). The workshops were developed to meet an expressed priority need on the part of coastal resource managers for more information in the area of environmental valuation. The workshop concept was developed by Rodney Weiher and Katherine Wellman, both at the time in the Economics Group in the NOAA Office of the Chief Scientist, who were asked by COP to formulate a program to meet managerial needs. Nancy Bockstael and Douglas Lipton of the University of Maryland's Department of Agricultural and Resource Economics were brought into the team. Together this team, with coordination from Isobel Sheifer of COP, helped to lay the foundation and framework of the workshops and the handbook that grew out of them.

The handbook contains the written substance of the material being taught at the workshops. The first part of each workshop is devoted to the teaching of a core curriculum by Wellman and Lipton, who have been participating in these workshops beginning with a pilot in Durham, New Hampshire, in summer 1992. The second part of the workshop involves the innovative use of case studies through which workshop attendees get an opportunity to try out these newly studied techniques in actual case situations under the tutelage of a case leader. In addition to individuals already mentioned, case studies have been facilitated by Lewis Queirolo of the NOAA National Marine Fisheries Service, Rebecca Baldwin of the U.S. Forest Service, and Elliot Rosenberg of the Environmental Protection Agency.

Among those making the greatest contribution to the development of this handbook have been the participants in the workshops. By filling out evaluation forms at the end of each session and by their private conversations with teachers and other workshop personnel, participants have helped us improve what we teach, how we teach it, and the sequence of teaching exercises. Participation levels in case study sessions and the kind of discussions that take place have indicated to us which cases were the best tools to promote the learning experience we hoped to achieve.

As the handbook has developed and become refined, we feel it is important to transfer this kind of information to the widest possible audience of coastal managers, regardless of their workshop attendance. To that end, we have undertaken a revision of materials to make the document a stand-alone learning tool and have included cases from many regions of the country to make the scope of this part of the learning truly national. However, it should be noted that a case study for one region can be used by managers anywhere as a guide to understanding environmental valuation. The problems recounted in these cases have general applicability.

Merrill Leffler and Sandy Harpe have been responsible for editing and design of the text.

Economic Valuation of Natural Resources is not a textbook but a guide for policy makers and managers regarding how to assess and understand the economic value of the coastal resources for which they are stewards. We hope it will receive wide distribution and use.

CONTENTS

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PREFACE

Professionals who are responsible for coastal environmental and natural resource planning and management have a need to become conversant with new concepts designed to provide quantitative measures of the environmental benefits of natural resources. These amenities range from beaches to wetlands to clean water and other assets that normally are not bought and sold in every-day markets.

At all levels of government — from federal agencies to townships and counties — decision-makers are being asked to account for the costs and benefits of proposed actions. To non-specialists, the tools of professional economists are often poorly understood and sometimes inappropriate for the problem at hand. This handbook is intended to bridge this gap.

The most widely used organizing tool for dealing with natural and environmental resource choices is benefit-cost analysis — it offers a convenient way to carefully identify and array, quantitatively if possible, the major costs, benefits, and consequences of a proposed policy or regulation. The major strength of benefit-cost analysis is not necessarily the predicted outcome, which depends upon assumptions and techniques, but the process itself, which forces an approach to decision-making that is based largely on rigorous and quantitative reasoning.

However, a major shortfall of benefit-cost analysis has been the difficulty of quantifying both benefits and costs of actions that impact environmental assets not normally, nor even regularly, bought and sold in markets. Failure to account for these assets, to omit them from the benefit-cost equation, could seriously bias decisionmaking, often to the detriment of the environment. Economists and other social scientists have put a great deal of effort into addressing this shortcoming by developing techniques to quantify these non-market benefits.

The major focus of this handbook is on introducing and illustrating concepts of environmental valuation, among them Travel Cost models and Contingent Valuation. These concepts, combined with advances in natural sciences that allow us to better understand how changes in the natural environment influence human behavior, aim to address some of the more serious shortcomings in the application of economic analysis to natural resource and environmental management and policy analysis.

Because the handbook is intended for non-economists, it addresses basic concepts of economic value such as willingness-to-pay and other tools often used in decision making such as cost-effectiveness analysis, economic impact analysis, and sustainable development. A number of regionally oriented case studies are included to illustrate the practical application of these concepts and techniques.

The National Oceanic and Atmospheric Administration's Coastal Ocean Program and its Economics Group participated in the development of the handbook and a series of regional workshops for state and local coastal planners and managers in an effort to relate advances in the physical sciences to modern environmental, economic, management, and policy problems.

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History and Legislative Mandates for Environmental Valuation

In the earliest versions of benefit-cost analysis of federal projects, there was no provision for accounting for economic gains or losses due to environmental benefit or harm. Even when aware of the physical harm a project or policy would have on the environment, decisionmakers were unable to quantify these using the available economic tools of the time. Economic theory has progressed to address the problems of environmental valuation, as have federal environmental laws and regulations.

HISTORY

Environmental valuation has its origin in the River and Harbor Act of 1902. This Act required a board of engineers to report on the desirability of the Army Corps of Engineers' river and harbor projects by accounting for both the costs and benefits to commerce.

In the 1930s, the idea of broader social justification for projects emerged as a theme. For example, the Flood Control Act of 1936 authorized federal participation in flood-control schemes if the benefits of such actions exceeded the estimated costs. The practice of such analyses then spread to other agencies concerned with water development projects. The purpose was both to justify public works projects and to help decide who should pay for these projects.

By the end of World War II, federal agencies had broadened their approach to account for secondary, or indirect, benefits and costs as well as intangibles. Intangibles reflected what are now considered environmental assets. This was really the beginning of benefit-cost analysis (as will be discussed in greater detail in Chapter 3). In the 1950s, a federal interagency committee produced the Green

Environmental Valuation Legislative History

- **River and Harbor Act of 1902**
- **Flood Control Act of 1936**
- **Broadened approach to include *intangibles***
- ***Green Book* published in 1950**
- **Environmental movement of the late 1960s**
- **National Environmental Policy Act of 1969**
- **Clean Air Act of 1970**
- **Clean Water Act of 1972**
- **Comprehensive Environmental Response, Compensation and Liability Act of 1980 and natural resource damage assessment**
- **Executive Order 12291 (Regulatory Iimpact Analysis) issued in 1981**

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Book, an attempt to codify and agree on general principles of project justification. This document was notable for bringing in the language of welfare economics.[1]

In the late 1960s, the environmental movement began. Pollution control was of particular concern and the economics community was ready and willing to play a role. Unfortunately, the economic view had little impact on the initial surge of legislation for pollution control. Two of the cornerstones of federal environmental policy on pollution control — the Clean Air Act of 1970 and the Clean Water Act of 1972 — explicitly prohibited weighing benefits and costs in the setting of environmental standards. Instead, standards were based solely on public health criteria.

While the National Environmental Policy Act of 1969 (as amended through 1982) required the use of benefit-cost analysis in environmental impact statements, environmental valuation did not really come into its own until the 1980s, when Executive Order 12291 (the Regulatory Impact Analysis requirement) was issued.[2] Additional environmental legislation, particularly the Comprehensive Environmental Response, Compensation and Liability Act of 1980 (CERCLA), gave natural resource trustees the right to claim damages for injuries to natural resources that result from the release of oil and other hazardous materials into publicly owned rivers, lakes, estuaries, oceans, or other aquatic or terrestrial habitats. The natural resource damage assessment process explicitly calls for the estimate of interim lost values of injured natural resources and resource services.

During the 1980s, interest in environmental valuation continued to expand, and this attention has continued into the 1990s. This increased attention stems from the implementation of the Oil Pollution Act of 1990 and its subsequent natural resource damage assessment regulations. The Act put pressure both inside and outside of government to improve the decision-making criteria affecting public funds and resources. In addition, relatively recent legislative mandates, through amendments to existing legislation, have strengthened the requirement of net economic benefit analysis as part of management and regulatory programs.

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[1] Interagency River Basin Committee, Proposed Practices for Economic Analysis of River Basin Projects.

[2] Early in the Reagan Administration the President issued Executive Order 12291. This Order requires cabinet-level departments to prepare benefits-cost analyses justifying major rules. These analyses are scrutinized by the Office of Information and Regulatory Affairs within the Office of Management and Budget. Executive Order 12291 has subsequently been superseded by Executive Order 12866.

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LEGISLATIVE MANDATES

The following section provides a summary of legislation which indicates the extent of the applications of environmental valuation in the coastal and marine resource management and policy arena.

▸ **WETLANDS PERMITTING.** Among the many pieces of legislation related to wetlands, the most important is probably Section 404 of the Clean Water Act which is a component of the permit process necessary for wetlands conversion for development. When making a permitting decision, the Army Corps of Engineers is expected to balance the public and private benefits of the project against the costs, and to take into account environmental values. No guidelines are provided on how the Army Corp of Engineers should measure costs and benefits. Nor is there any requirement that an actual study be conducted. However, agencies making recommendations to the Corps can (and occasionally do) make their arguments in terms of costs and benefits.

▸ **NONPOINT SOURCE POLLUTION CONTROL.** Section 319 of the Clean Water Act establishes a national program to control nonpoint sources of water pollution. In addition, Section 6217b of Coastal Zone Act Reauthorization Amendments of 1990 requires that all states with coastal management programs must develop and submit to EPA and NOAA for approval a Coastal Nonpoint Pollution Control Program. Under Section 6217g, EPA is required to publish guidance for specifying economically feasible management measures. All management measures in *Guidance Specifying Management Measures for Sources of Nonpoint Pollution in Coastal Waters* are to be economically achievable and cost-effective. This language does little to aid the coastal manager or planner in actually evaluating which management measures create the greatest welfare to society. In order to determine the depth and breadth of nonpoint source pollution control, the value of the resources (water quality, shellfish beds, recreation) must be determined. Once the value of the resources is established, the costs of such regulations can be weighed against the benefits (i.e., enhanced resource and resource service quality).

▸ **ENVIRONMENTAL REGULATION.** The National Environmental Policy Act (NEPA) requires federal government agencies to conduct an assessment of environmental impacts of proposed legislation and "other major federal actions significantly affecting the quality of the human environment." Over the years this authority has been extended to include any actions funded in part or regulated by the federal government, even though they are carried out by private parties. The result of the assessment is an Environmental Impact Statement (EIS). Under NEPA, benefit-cost analysis is discussed but not required. When a benefit-cost analysis is prepared, a discussion of the relationship between the analysis and any analyses of unquantifiable environmental impacts, values and amenities must be included.

► FISHERIES MANAGEMENT. The Magnuson Fishery Conservation and Management Act of 1976 and its amendments require the preparation of fishery management plans under federal jurisdiction by the Fisheries Management Councils for review by the Secretary of Commerce/National Oceanic and Atmospheric Administration (NOAA). Benefit-cost analysis is required under the regulatory impact review component of the plan. Typical analyses might include determining the value of a recreational fishing day or the value of a sector of the commercial fishing industry to society. The National Marine Fisheries Service (for Commerce and NOAA) has issued guidance from time to time on economic analysis, but the adequacy of these analyses has yet to be challenged in court.

► LITIGATION OF OIL AND HAZARDOUS WASTE SPILLS. The Comprehensive Environmental Response, Compensation and Liability Act of 1980 (CERCLA) mandates the preparation of regulations by which natural resource damages from spills of oil or hazardous substances should be assessed to compensate society for losses before the resources are fully restored. The Oil Pollution Act of 1990 (OPA) also mandates the preparation of regulations by which natural resource damages, specifically from oil spills, will be calculated. Under CERCLA and OPA, in the event of a spill of oil or other hazardous substances, the public must be compensated for natural resource injuries in order to make them as well off as they would have been without the spill. In developing a damage claim, the resource trustees must determine the value of lost resources and service flows pending restoration. In this case, values may include the value of injured marine mammals or seabirds or the value society attaches to just knowing that a natural wilderness area exists. CERCLA and OPA natural resource damage assessment has attempted to incorporate state-of-the-art environmental valuation techniques. Methods for measuring damages are discussed by name in the regulations, in-

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A Sampling of Legislative Mandates

- Wetlands Permitting: Section 404 of Clean Water Act
- Litigation of Oil and Hazardous Waste Spills: The Comprehensive Environment Response, Compensation and Liability Act of 1980
- Oil Pollution Act of 1990
- Coastal Resource Management: Coastal Zone Management Act of 1972 (as amended)
- Marine Sanctuary Designation: Marine Protection, Research and Sanctuaries Act of 1972 (as amended)

cluding travel costs, hedonic valuation, and contingent valuation. Also discussed is the range of types of values, including market-related, nonmarket use values, and nonuse values.

▶ OTHERS. The Coastal Zone Management Act of 1972 (as amended) identifies coastal resource uses subject to management that may require benefit-cost analysis including the siting of major facilities related to energy; fisheries developments, recreation, ports and transportation; and the location of new commercial and industrial developments. In addition, the Act encourages the preparation of Special Area Management Plans (SAMP) for reasonable coastal-dependent economic growth. Net economic benefit analysis, in this case, is prepared by state Coastal Zone Management (CZM) programs and submitted to NOAA, which issues SAMP funds.

The Marine Protection, Research and Sanctuaries Act of 1972 (as amended) requires that public and socio-economic benefits derived from sanctuary designation be assessed as part of the approval process for a proposed site. In addition, an environmental impact statement, fisheries management guidance, and ocean pollution regulations are required.

The National Estuary Program (NEP) was established under Sections 317 and 320 of the Water Quality Act of 1987 (amendments to the Clean Water Act). Under the NEP, the Administrator of EPA is authorized to convene management conferences that represent a partnership across federal, state, and local levels, designed to reach consensus on priority problems of the estuary, the causes of those problems, and the actions that must be taken to correct those problems. The management conference also provides a mechanism for obtaining commitments to take action. These commitments, reflected in the Comprehensive Conservation and Management Plan (CCMP), are the result of the NEP process. Development of the CCMP is critically dependent on the determination of values of estuarine functions and services. Environmental valuation could be an integral part of the scientific characterization process, linking science with policy-relevant issues. Such values could play a major role in the socio-political acceptability of action plan alternatives laid out as a part of the CCMP development and implementation process. Recent guidelines on the role of environmental valuation in NEP planning have been issued by the EPA Ocean Coastal Protection Division.

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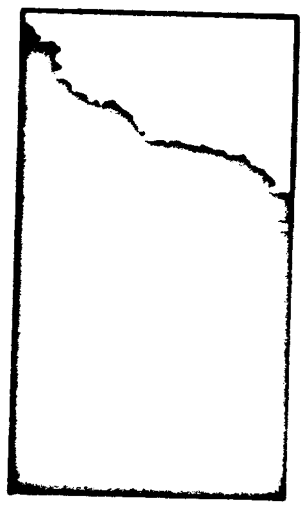
Concepts in Environmental Valuation

The term *value* in economics has a precise definition — it is the price individuals are willing to pay in order to obtain a good or service. The basic economic concepts of supply and demand are employed to estimate willingness-to-pay (called producer surplus and consumer surplus, respectively). This idea of value and its measure remain consistent whether a market good or a state of the environment is at stake.



The term *value*, in the context of coastal issues, can have different meanings to those with different interests. To an ecologist, the value of a salt marsh might mean the significance or importance of the marsh to the reproductive capacity of certain species of fish. To a coastal engineer, the value of a salt marsh may be associated with its contribution to shoreline stabilization. In general, these values are mathematical and functional: mathematical, meaning magnitude, and functional, meaning the physical or biological relationships of one entity to another. These values exist whether or not humans prefer them or are even aware of them.

ECONOMIC VALUE

A fundamental distinction between the way economics and other disciplines such as ecology use the term value is the economic emphasis on human preferences. Thus, the functionality of economic value is between one entity and a set of human preferences. If a coastal area is degraded so it supports a lower abundance of organisms, an ecologist would characterize this degraded area as less valuable for those organisms than a non-degraded area. In economic terms, however, a polluted area only has less value than an otherwise equivalent non-polluted area if some individual members of society prefer non-polluted to polluted areas. If no one cares that there are fewer organisms in the polluted area, then there is no difference in economic value. Typically, some members of society will display a preference for an environment that is less degraded.

Economic value is a measure of what the maximum amount an individual is willing to forego in other goods and services in order to obtain some good, service, or state of the world. This measure of welfare is formally expressed in a concept called *willingness-to-pay* (WTP). Thus, the lost value from the degraded environment is the maximum amount individuals are willing to pay to have a state where that same area is free of pollution.

A common difficulty in understanding economic valuation is distinguishing between what something is valued at by individuals and what its economic value really is. Thus, one can find commercial fish landings in the United States in 1993 *valued* at $3.5 billion and assume that is the value of our commercial fishery. But what is the willingness-to-pay of commercial fishers to be able to land this catch? If all the fisheries were closed tomorrow, would we have to pay $3.5 billion a year in compensation to leave them as well off as if the fishery were open? The answer would be yes only if fishing was a completely costless activity, which we know it isn't. The harvesters have to pay for fuel, gear, and, of course, their time which would have been available for alternative income earning endeavors. The fishery, therefore, is worth somewhat less to the harvesters. Figuring how much it is worth is the subject of Chapter 5, Measuring the Value of Non-Market Goods and Services.

In assessing the value of some policy or management plan, the economist is interested in estimating how much an individual's (or society's) well-being would change: how much it will decrease if a natural resource were lost or increase if a natural resource or resource service were better managed or its quality improved. In other words, when economists try to estimate the economic value of a coastal resource or resource service, they attempt to answer one of two questions:

- How much are people willing to trade (give up) of other goods and services to have some natural resource or resource service?
- How much better off would people be if a policy or management plan action were implemented and the amount or quality of a resource or resource service were improved?

Characteristics of Economic Value

- **Products or services have value only if human beings value them, directly or indirectly.**
- **Value is measured in terms of trade-offs, and is therefore relative.**
- **Typically, money is used as a unit of account.**
- **To determine values for society as a whole, values are aggregated from individual values.**

SCARCE RESOURCES, LARGE DEMANDS

The economic definition of value is rooted in a simple idea: all resoures are scarce, but the demands for those resources are large relative to their availability. There is never enough labor or land or water to do all the things that all individuals might wish. Because resources are scarce, it is necessary to make choices about how society will use what is available. We make choices about the amount of money to devote to schools, roads, libraries, and natural resource protection programs individually and collectively. These choices are often based on complex tradeoffs; thus, value is revealed in decisions about how individuals and society collectively choose to allocate these resources. People may recoil at the notion of placing a value on the natural environment, but there are other uses or alterations of that environment that might be proposed. Society always has to compromise, giving up something to get something else.

The most direct and visible monetary symbol for a good is its market price. The relationship between a good's market price and its value in terms of willingness-to-pay (WTP) can be confusing. We might think, for example, that because an individual buys a certain good at a market price of $8, then $8 is what the individual is willing to pay for this good, and thus $8 is the value to the individual. Such reasoning, however, is not necessarily true. If an individual spends $8 to obtain a good, we know only that the good is worth at least this much to the individual; he or she may also have been willing to spend more, for instance a maximum of $10, to obtain the good. In this case, the $8 market price is only a lower bound estimate of the total value of the good to the individual, that is, the individual's total WTP for the good.

You might conclude from this example that total market expenditures for a good (i.e., price times quantity sold) would constitute a lower bound estimate of its consumer value. The problem with this conclusion is that the appropriate economic measure of welfare or value is *net benefit*, not total value. The net benefits society derives from a good is represented by net WTP, or the amount society would be willing to pay to produce and/or use a good *beyond that which it actually does pay*.

The same principle of economic value holds for *non-market goods*, goods that do not have observable market prices. For example, consider the case of a recreational fisher who would be willing to spend up to $30 a day to use a particular fishing site, but only has to spend $20 a day in travel and associated costs. The net benefit or economic value to the fisher of a fishing day at the site is not the $20 expenditure, but the $10 difference between what that fisher would be willing to spend and what he or she actually has to spend. If a development project eliminated all fishing opportunity at the site, the fisher would lose the satisfaction of fishing there, as represented by $10 a day in net benefits. The $20 a day he or she would have spent to visit the site would not be lost but would be available to spend elsewhere.

Because market expenditures are not measures of net benefits, we cannot use expenditures on the purchase of related goods as a direct measure of the *social value* of the good. Several steps must be taken to provide the information on social value.

Because a market provides a forum for society to express relative preferences in monetary terms, market transactions can be used to infer preferences, and thus economic values. Also, non-market goods can sometimes be valued based on information on preferences provided by market transactions for related products. For example, we

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Economic Value Based on Net Willingness to Pay (WTP)

Consider the case in which only one unit of a certain market good, oysters, is produced at a cost of $1 per dozen and sold at a price of $8. If the purchaser had been willing to pay $10, the net benefit of a dozen oysters to this consumer would be $2 ($10 less $8) — this amount is called consumer surplus. At $8 a dozen, the producer earns $7 from the sale (the selling price minus the production price), so the net benefit of the good to the producer is $7 (called producer surplus). The total economic value of a dozen oysters is thus $9 ($2 net benefit to the consumer plus $7 net benefit to the producer). If for some reason the producer was denied the opportunity to produce and sell oysters (say because of a moratorium on fishing) — and the consumer was denied the opportunity to buy and consume oysters — the total loss to these individuals would be $9.

can estimate the value of a recreational site by travel expenditures (i.e., gas, lodging, meals).

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CONSUMER AND PRODUCER SURPLUS

In measuring the general satisfaction that society as a whole derives from a good or service, economists often use the concepts of *consumer surplus* and *producer surplus* to approximate the net willingness-to-pay (WTP). When a good is exchanged in a perfectly competitive market, its market price measures the consumer demand (marginal WTP) for the last unit of the good purchased. Market price is determined by the equilibrium of demand and supply, i.e., the price and quantity that correspond to the level at which the consumer's WTP for the next unit produced is equal to the cost of producing it. For all other units of the good purchased, however, the consumer marginal WTP for each unit exceeds market price.

Before discussing consumer and producer surplus, it will be useful to first review supply and demand curves. Supply curves describe the relationship between the quantities of a producer's good or service and the price the producer receives. This relationship is shown

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in Figure 2.1. The price for fish and shellfish or whale watching trips, for example, might be represented by the ex-vessel price or fee, respectively. The greater the quantity of whale watching trips or fish produced, the higher the incremental costs (e.g., fuel, ice and crew wages). The producer will produce a higher quantity only for a higher price. Thus, supply curves are upward sloping. Industry supply curves are the aggregation of the quantities of individual firm supply curves.

Demand curves describe the price-quantity relationship for a particular good or service for a consumer (Figure 2.2). They describe what a consumer is willing to pay for various quantities of the good or service, such as whale watching trips or fresh fish. As the number of whale watching trips or fish offered to a consumer increases, satiation sets in and the consumer's WTP for the marginal unit is less. Thus, the demand curve slopes downward to the right. Consumer demand curves are summations of the quantities of individual demand curves.

The excess of what consumers are willing to pay over what they actually do pay for the total quantity of a good purchased is called *consumer surplus* (Figure 2.3); it represents the good's value to consumers in terms of net WTP, and is represented by the area under the good's demand curve, bounded by price (Figure 2.2). Moreover, a good's market-clearing price — the price that satisfies suppply and demand simultaneously, represented by the intersection of the supply and demand curves — also corresponds to the marginal cost of producing the last unit of output. For all other units of the good produced, however, the producer marginal production cost for each unit is less than market price.

The excess of what producers earn over their production costs for the total quantity of a good sold is called *producer surplus* or economic rent. This value represents the production value or net benefit of the good to producers, and it is represented by the area over the good's supply curve, bounded by price (Figure 2.3). While not an exact measure of social welfare, the sum of consumer surplus and producer surplus provides a useful approximation of the net benefit of a good or service.

The concept and measurement of economic value, generally upheld in courts of law, has been evolving. There are clearly issues that have not yet been resolved in this conceptual framework. For example, there is controversy about whether it is appropriate to use a minimal amount one is willing to accept when estimating welfare losses due to environmental damage. Yet, these concepts are useful. They bring us closer than we have ever been before to incorporating some ple, to weigh social benefits associated with a commercial development project against environmental benefits that would be lost should the project be implemented. Such a *social accounting* analysis tallies all real costs associated with an activity, including the cost of lost or damaged environmental assets and quality of life. Desirable characteristics of this social accounting scheme are these: it is internally consistent (i.e., the underlying theory does not change with circumstance), usually intuitively appealing, and acceptable in major courts of law.

The measurement of gains or losses is a *net value* (i.e., the value of a site's services over and above the next best alternative). As we will see, the estimates of benefits are not restricted to losses in commercial enterprises, such as losses to commercial fisheries. Benefit measures attempt to account for the subjective preferences of society regarding the use and existence of coastal or marine resources. For example, in siting a proposed development project, the location should be where the net benefits (commercial gains from the development) minus the costs of production and environmental damages it causes, are maximized. If benefits are negative, then the development would represent an inefficient use of society's resources. For example, a shopping mall built on wetlands provides less net benefits than the same project, just as convenient to shoppers, built on common uplands.

As a general rule, the fewer substitutes available for a good or service, the greater the loss. Thus, a site that provides excellent recreational experiences might be adjacent to another site that provides equally good recreational experiences. The loss to the recreationist from losing one site would be smaller than if there were no close substitute. However, if elimination of one site causes congestion at another site and lowers the quality of the recreational experience for everyone, then those losses must also be taken into account.

Gains from development will be higher where substitutes are fewer and more costly. Take again the simple case of a shopping mall: gains from a new shopping mall would be the extra profits the retail stores could make plus the gains to consumers from having shorter distances to travel to shop. However, if another mall exists nearby, consumers will gain little from the additional mall and the retail stores in the first mall may lose almost as much in profit as those made by stores in the new mall. The net value to shoppers, real estate, and stores owners is the figure that should be compared to the losses from building the mall.

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THE SOCIAL ACCOUNTING SCHEME: A CASE STUDY

Orian Corporation v. State of Washington Department of Ecology illustrates how environmental economists employ social accounting techniques as a first step in doing an economic valuation The case provides an example of the role environmental valuation could play in decisions related to development of environmentally sensitive areas and, potentially, to the determination of compensation in the event of a regulatory taking.

In the 1960s, the Orian Corporation proposed to dredge and fill lands that they owned in the Padilla Bay tidelands of Skagit County in northwestern Washington State to create a Venetian-style community. According to Charles Lean, former Assistant Attorney General and counsel for the State of Washington in *Orian*, the planned community would have been the most populous town in Skagit County.

Padilla Bay is home to the largest contiguous expanse of eelgrass in the state, serves as a salmon and dungeness crab nursery, and is critical habitat to thousands of ducks and geese, as well as endangered bald eagles and peregrine falcons. Recognizing the importance of these natural resources, Skagit County's 1976 Shoreline Master Program (administered by the Washington State Department of Ecology), required by the State's Shoreline Management Act, designated Padilla Bay tidelands "aquatic," which prohibited all uses except nonintensive recreation and aquaculture. The use restrictions in Skagit County's Shoreline Master Program essentially barred Orian's plans to dredge and fill the bay for an overwater housing development.

Orian Corporation argued the shoreline regulations constituted a "regulatory taking" and sued for the right to develop the property. The courts had to determine whether state interference with Orian's use of the property was sufficiently restrictive to deny Orian any reasonable use of the land without offering fair market value. The Washington Supreme Court held that the shoreline regulations did not cause an unconstitutional taking on two grounds.

First, the court held that "the public trust doctrine would have prohibited the intended development anyway, despite the Shoreline Management Act. Therefore, since there was no right to place fills or

Desirable Properties of a Social Accounting Scheme

- **Accounts for all real costs or benefits from an activity**
- **Internally consistent**
- **Intuitive**
- **Accepted in courts**

Figure 2.1. Supply Curve

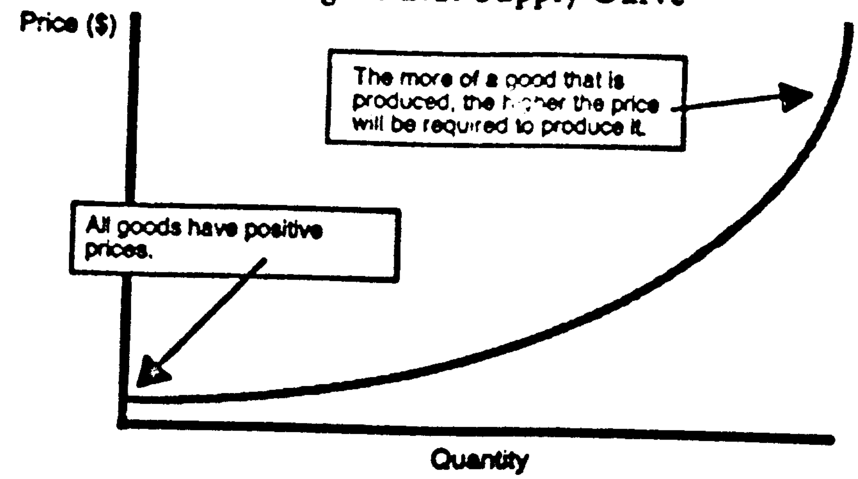


Figure 2.2. Demand Curve

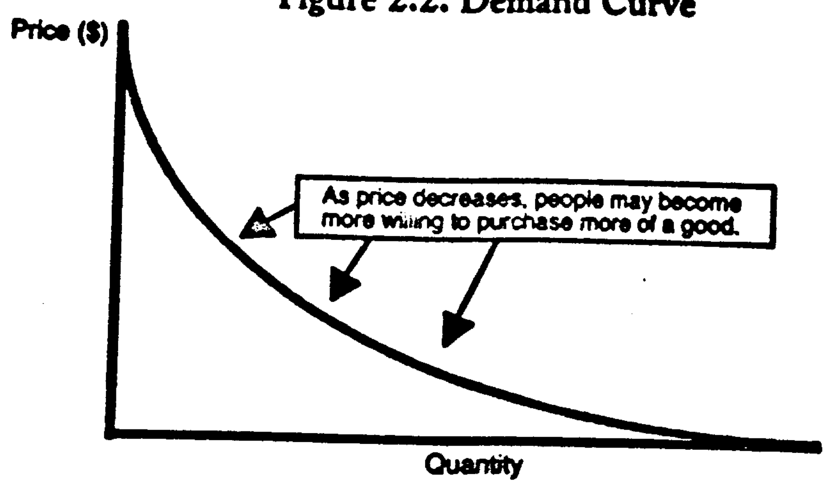
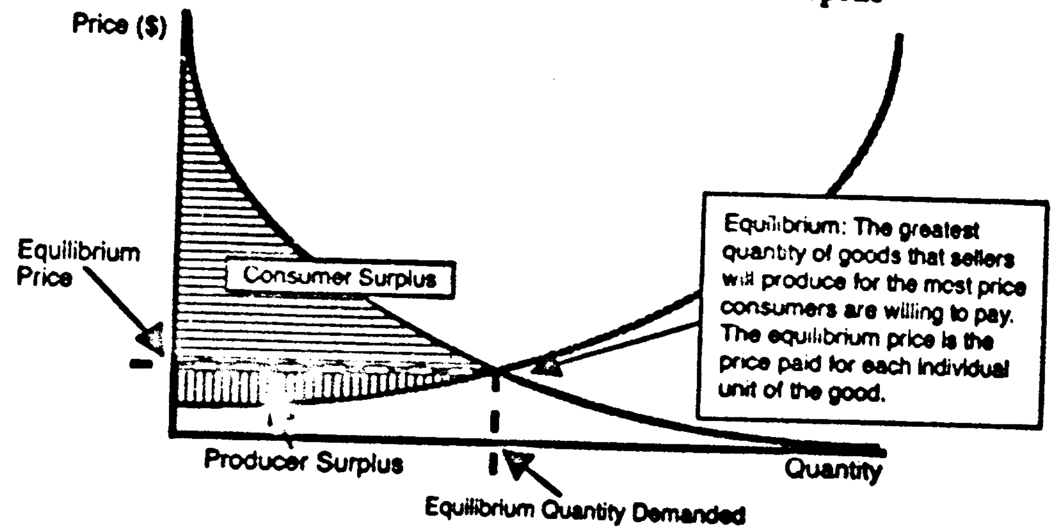


Figure 2.3. Consumer and Producer Surplus



of the natural resource values that we all know exist into the trade-off decisions that are made by government agencies and by courts.

ENVIRONMENTAL VALUATION

Environmental valuation is a series of techniques that economists use to assess the economic value of market and non-market goods, namely natural resources and resource services. It applies the *welfare economics* concepts of producer and consumer surplus to issues involving natural resources and the state of the environment. Welfare economics tries to answer the question "Is society better off?" Environmental valuation is the application of welfare economics when the differences in circumstances relate to the uses or states of natural resources or the quality of the environment.

When economists refer to evaluating societal benefits, it is necessary to recognize two "states of the world": *with* and *without*. *Without* is the base state if an activity, circumstance and policy does not change. *With* is the state when the change occurs. A distinction is made between *with* and *without* and *before* and *after*. *Before* and *after* does not control for changes in the state of the world that do not result from the action or policy in question. Economists try, for exam-build houses in the first place, there was no taking. The state does not have to pay for taking a property right which never existed." Second, the Supreme Court declared that the shoreline regulations did not violate the Constitution because "whenever the state imposes land use restrictions in order to safeguard the public interest in health, the environment, and the fiscal integrity of the area," it is a legitimate use of police power and is "insulated" from takings claims.

The court, however, also recognized that regulations intended to protect the Padilla Bay National Estuarine Research Reserve may have prevented reasonably profitable use of Orian's tidelands. Because the regulations were not intended to protect public health and safety but instead served to enhance the value of the publicly owned Reserve, they could have caused a temporary taking. The Court sent the case back to a lower court to resolve factual issues, where a jury held that the Padilla Bay Reserve caused a temporary taking and Orian was due compensation.

The final settlement included the cost of the acreage plus interest accrued since the creation of the Padilla Reserve in 1980, in addition to attorney fees. In exchange for $3.6 million, Orian released all claims against the Department of Ecology and transferred all rights in Padilla Bay tideflats to the state. Thus in June 1993, the Padilla Bay National Estuarine Research Reserve in Skagit County quadrupled in size with the acquisition of 8,004 acres from the Orian Corporation and its Padilla Bay associates.

Now, suppose Washington wished to assess the potential benefits and costs of allowing the Orian Corporation to proceed with this

Stakeholders in Padilla Bay Development

LOSERS	GAINERS
▸ Commercial Fishers	▸ Orian Corporation
▸ Recreational Fishers	▸ Wildlife Viewers
▸ Fish Consumers	▸ Consumers of Housing
▸ Wildlife Viewers	
▸ Nonusers	

development project rather than incur legal costs and takings compensations. If this situation were analyzed from the environmental economist's perspective, the first step would be to ask: "Who are the players that would be affected by the decision?" That is, "Who are the gainers and losers of limiting Orian's ability to use the tidelands as they wished?" Here is a summary of how some of the stakeholders could be affected. First, the losers.

► COMMERCIAL FISHERS. Development activities on or near the shoreline could destroy salmon and dungeness crab habitat, ultimately resulting in reductions in the stocks of these species and subsequent loss of profit to local harvesters. In this market case, it is the lost profits (lost revenues minus costs) that matter — what harvesters would be willing to pay to avoid the development.

If development occurs unchecked, harvesters may move to other grounds (necessarily less desirable, or they would have already been fishing there) and so they may continue to make some profits (but probably less than they would have made). The appropriate loss to measure takes this move into account. It is a measure of how much worse off fishermen are after they make all the adjustments they can. Additionally, if their adjustments affect others (e.g., deplete other's fishing grounds), then those losses must be counted.

Economics has empirical methods for approximating all of these losses. Commercial harvesters may also have other non-commercial values associated with this environment. Harvesters may value the aesthetic setting, the wildlife they see while fishing, etc. These values are typically measured along with other people's values of this sort.

► RECREATIONAL FISHERS. The same ecological disruptions that harm the commercial fishers may also harm the recreational salmon and crab fishers. As a result of development by the Orian Corporation, the recreational fishers may have fewer grounds to fish and their catch rates may decline.

Substitution is again an issue. Recreational fishermen will have other alternative fishing sites and target species, possibly less desirable. We must measure the net effect of the development on these alternatives as well. Note that if the result makes remaining grounds more congested, this loss must be taken into account.

Unfortunately, there is no market that captures how much worse off recreational fishermen are as a result of the development. The measure we seek is the maximum amount of money recreational fishers would be willing to pay to avoid these damages. How we get this measure will be discussed in Chapter 5, Measuring the Value of Non-Market Goods and Services.

▸ **Fish Consumers.** If Orian's development were to affect the fishery for salmon and crab so that significantly fewer salmon and crab were available in the market, fish prices would rise and the consumers of fish would be negatively impacted.

Here, substitution possibilities are very important. The crab and salmon consumers will substitute other products but will, by definition, be worse off (or they would have made these choices to begin with). In addition, if their substitution causes prices of other species of fish to rise, this rise should also be taken into account.

▸ **Wildlife Viewers.** If the Orian overwater housing development on Padilla Bay were to destroy the critical habitat of migrating shorebirds, bald eagles or peregrine falcons, the available area to view these birds may be reduced, as may the number of birds themselves, thus creating an overall reduction in birdviewing opportunities. There is no market to capture these losses directly and we will need to resort to non-market techniques.

▸ **Nonusers: Naturalists and Others Who Care about the Environment but Don't Use the Tideflats of Padilla Bay.** Padilla tideflats are a relatively rare ecosystem and provide critical habitat to endangered bald eagles and peregrine falcons. There may be individuals who do not visit this area but to whom the existence of these important natural resources is valuable. These people may be willing to pay some dollar amount to prevent the destruction of this habitat. Thus, in the event that the Orian development was allowed to occur and the unique resources of Padilla Bay were impacted or injured, these individuals would experience a loss of value.

If development did occur, the following stakeholders might be gainers:

▸ **Orian Corporation.** Orian Corporation would probably be able to increase its profits from the development over and above what they would have made in the next best alternative (i.e. developing housing somewhere else). Most, if not all, of the gains from development will be measurable in markets.

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▶ WILDLIFE VIEWERS. The Orian development could enhance access to the tidelands and thus improve bird-viewing opportunities. If these prospects were to occur, the benefits to wildlife viewer might increase. Again there is no market to capture these losses directly and we will need to resort to non-market techniques to measure them.

▶ CONSUMERS OF HOUSING. If the Orian development was to have sufficient impact on the Skagit County housing market, the price of housing might drop with the increased availability of housing provided by Orian. Thus, the consumer would gain by the amount of the reduction in housing prices. Again, these gains could be measured using market prices.

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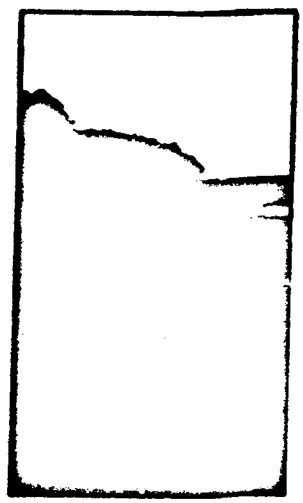
3

Economic Tools for Use in Coastal Management Decisionmaking

Several types of economic information are useful for coastal decisionmaking. Environmental value is important in some of these: benefit-cost analyis, natural resource damage assessments and sustainable development assessment. Other kinds of information such as economic impact analysis are often confused with value measures, but provide different information to the decision process.



Economic Tool Kit

- Economic Impact Analysis
- Cost-Effectiveness Analysis
- Benefit-Cost Analysis
- Natural Resource Damage Assessment
- Sustainable Development

Coastal management and policy decision making requires information that ranges widely from land-use impacts on natural resources to economic implications of changes to terrestrial and aquatic ecosystems. While the availability of accurate information does not mean that such decision making will necessarily be good, it is clear that the lack of accurate information will almost always contribute to uninformed decisions.

While the focus of this handbook is on environmental valuation, namely, determining the dollar value of natural and environmental resources and resource services, it is important for coastal managers and planners to recognize a variety of alternative economic approaches to generating and presenting economic information. Each approach calls for different skills and research procedures, and each is intended to answer a different question.

Which of these economic approaches planners choose depends on what they want to know. This chapter provides a brief review of the most important economic approaches that can be applied to coastal zone planning and management.

ECONOMIC IMPACT ANALYSIS

Economic impact analysis is a methodology for determining how some change in regulation, policy, or new technological breakthrough, or other action affects regional income and other economic activities including revenues, expenditures, and employment. Economic impact analyses can be focused at any level, for example:

- Local environmental groups may want to assess the impact of a wetlands law on the rate of population growth and tax base in their community
- Regional groups might need to understand the impacts of a national regulation on their particular economic circumstances
- International agencies might be interested in how efforts to control CO_2 emissions might impact the relative growth rates of rich and poor countries

To begin with, we must first distinguish economic activity from economic value. Companies supporting the worth of a proposed development plan, for example, will often cite figures on sales volume or increases in jobs. They may claim that the new development will boost sales of other companies. These numbers are measures of economic activity; they are not measures of social value, or what things are worth to people (see Chapter 2, Concepts in Environmental Valuation). Techniques for measuring the economic or market activity that such development generates is sometimes called economic impact analysis.

If a new establishment moves into a region, economic impact analysis would measure the impact or effects of this new establishment on other businesses. Assume the establishment hires local workers, buys products from local suppliers, and purchases transportation facilities or other services. The individuals and firms that the new establishment buys from may then increase their purchases from other suppliers. Economic activity, then, measures the additional income that is generated by the new spending.

Economic impact analysis does not account for social benefit or value. It does not account for what is being given up, nor what alternatives are foregone (i.e., opportunity costs). For example, an impact analysis of recreational fishing does not contain an analysis of what people would do with their time and money if, as the result of a fishery closure or moratorium, they couldn't go fishing. Would they go bowling instead of fishing? If so, would they generate more or less economic activity in the alternative activity? In addition, impact analysis does not take into account anything that is not traded on the market.

Economic Impact Vs. Social Value

Natural disasters offer examples of why economic activity is not a measure of social value. Most people would have considered society better off had Alaska's Exxon Valdez oil spill not occurred. Likewise, society would have been better off had Hurricane Andrew not hit south Florida. However, each of these disasters generated increased amounts of economic activity. A good deal of money changed hands in the form of increased demand for services, oil spill cleanup employment, construction, sales of plate glass and household supplies. While no one would claim that society benefited as a whole (clearly some individuals and businesses did), the economic impact of these events was positive.

While these expenditures represent revenue to a local community, they also represent costs to the recreationists. Furthermore, expenditures do not measure the loss of value to the angler that would result should fishing no longer be available in an area, or the gain in value to the angler that results from establishing a new fishing opportunity. From a broader perspective, increased fishing activity in one area may generate more expenditures within that area but may also mean an offset of activity and, therefore, expenditures in another area. As a result, the net gain in economic activity between areas may be zero, or even negative.

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COST-EFFECTIVENESS ANALYSIS

Cost-effectiveness analysis is a methodology that can be applied whenever it is unnecessary or impractical to consider the dollar value of the benefits provided by alternatives under consideration (e.g., each alternative has the same benefits expressed in monetary terms or each alternative has the same effects but dollar values have not been assigned). A project is cost-effective if it is determined to have the lowest cost of competing alternatives in present value terms for a given amount of benefits.

Suppose a community determined that its current water supply was contaminated with some chemical, and that it had to switch to an alternative supply. Assume there are several possibilities: the community could drill new wells into an uncontaminated aquifer, it could build a connector to the water supply system of a neighboring town, or it could build its own surface reservoir. A cost-effectiveness analysis would estimate the costs of these different alternatives with the aim of showing how they compared in terms of, say, the costs per million gallons of delivered water into the town system.

A cost-effectiveness modeling approach avoids the issue of evaluating benefits by setting desired objectives beforehand and searching for the lowest-cost ways of achieving these. Such an approach can facilitate the comparison among alternative policy or management plans. Cost-effectiveness analysis can help you eliminate those actions that cost more than equally, or less, effective alternatives or those actions that cost the same as more effective options. Such an approach also allows decision makers to build a "frontier" of cost-effective actions that highlights the higher marginal costs associated with different alternatives.

It may make good sense to do a cost-effectiveness analysis even before there is a strong public commitment to the objective you are costing out. In many cases, it may not be obvious how much people value a given objective. Once a cost-effectiveness analysis is done, they may be able to tell, at least in relative terms, whether any of the different alternatives would be desirable. They may be able to say something like: "We don't know exactly how much the benefits are in monetary terms, but we feel that they are more than the costs of several of the alternatives that have been costed out, so we will go ahead with at least one of them."

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BENEFIT-COST ANALYSIS

Benefit-cost analysis is a methodology that compares the present value[3] of all social benefits with the present value of opportunity costs in using resources. It can give valuable insights into the economic efficiency of management and regulatory actions. If the net value (benefits minus costs) of a project or action is greater than zero, then the that project is considered to be economically efficient. The more the benefits exceed the costs, the better off society is in economic terms as a result of the activity.

It is important to note at the outset that the basic benefit-cost framework has limitations, among them, determining the discount rate of future costs and benefits, discounting and future generations, distributional issues, uncertainty and risk, and irreversibility; these factors will be discussed further in Chapter 7, Theory and Application: Reconciling Differences.

Despite these limitations, benefit-cost analysis is the major tool for conducting economic evaluation of public programs in natural resource management, such as flood control, irrigation, hydropower, harbor improvements, and alternative energy supply projects. It is a four-step process that includes the following elements.

▸ **SPECIFY THE PROGRAM.** Benefit-cost analysis is a tool of public analysis, though there are actually many publics. Thus, the first step is to decide on the perspective from which the study is to be done. If you are doing a benefit-cost study for a national agency, the "public" normally would be all the people living in the particular country. But if you are employed by a city or regional planning agency to do a benefit-cost analysis of a local environmental program, you would undoubtedly focus on benefits and costs accruing to people living in those areas. The first step also includes a complete specification of the main elements of the project or program: location, timing, groups involved, connections with other programs, etc.

▸ **DESCRIBE QUANTITATIVELY THE INPUTS AND OUTPUTS OF THE PROGRAM.** For some projects, determining the input and output flows is reasonably easy. in planning a wastewater treatment facility, the engineering staff will be able to provide a full physical specification of the plant, together with the inputs required to build it and keep it running. For other types of programs, such determinations can be much harder. A restriction on development in a particular region, for example, can be expected to deflect development

Benefit-Cost Analysis is a Four-Step Process

- Specifiy the project or program and alternatives.
- Describe quantitatively the inputs and outputs of the program.
- Estimate the social costs and benefits of inputs and outputs.
- Compare benefits and costs.

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[3] Field, B.C. 1994. Environmental Economics. McGraw-Hill, Inc., New York.

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Benefit-cost analysis involves measuring, adding up, and comparing all the benefits and all the costs of a particular public project or program.

elsewhere into surrounding areas. In this step, we first have to recognize the great importance of the time it can take to complete large undertakings: environmentally related projects or programs may require years. Therefore, the job of specifying inputs and outputs involves predictions of future events, sometimes many years after a project begins. Consequently, having a good understanding of factors such as future growth patterns and future rates of technological change and possible changes in consumers' preferences is important.

► ESTIMATE SOCIAL COSTS. Assigning economic values to input and output flows is to measure costs and benefits. The methods for such measurements are the subject of Chapter 4, Measuring the Value of Goods and Services Traded in Markets and Chapter 5, Measuring the Value of Non-Market Goods and Services.

► COMPARE BENEFITS AND COSTS. In this final step, total estimated costs are compared with total estimated benefits. Table 3.1 illustrates the estimated benefits and costs associated with a regulatory program to control various airborne and waterborne pollutants coming from a group of marinas.

Table 3.1. Results of a Benefit-Cost Analysis of a Proposed Emission Reduction Program for a Group of Marinas

	Totals over life of the program ($ millions)
Costs	
Private compliance	
Capital equipment	580
Operating	560
Public monitoring and enforcement	96
Total	$1,236
Benefits	
Increased benefits to recreators from improved water quality	1,896
Increased property value from reduced air emissions	382
Nonuse value increase related to ecological integrity	749
Total	$3,027
Net benefits	$1,791

Guidelines for Benefit-Cost Analysis that Incorporate Environmental Valuation

While legislation requires net economic benefit analysis, and there are clear applications for environmental valuation, the guidelines for actually doing such an analysis are limited. The two most widely referred to guidelines are the following:

- WATER RESOURCES COUNCIL. *The Economic and Environmental Principles and Guidelines for Water and Related Land Resources Implementation Studies*, 1983, is the latest in a series of guidelines published by the Water Resources Council under the Water Resource Planning Act. It provides the required guidelines to be used for estimating the benefits and costs of constructing a public works project. The early versions of these guidelines first codified the use of applied welfare economics in evaluating public projects. The guidelines establish the elements that need to be taken into account when assessing the benefits and costs of a project, and incorporate the concepts of consumer and producer surplus measures in markets, as well as their counterpart in non-market settings. Unfortunately, the methodological prescriptions are somewhat out of date.

- ENVIRONMENTAL PROTECTION AGENCY. The Environmental Protection Agency's *Guidelines for Performing Regulatory Impact Analysis*, 1991, provides the latest set of guidelines for performing benefit-cost analysis on proposed environmental regulations, as mandated by Executive Order 12291. These guidelines are, for the most part, quite good and are continually being revised to reflect methodological advances. The focus is on measuring and valuing both health and environmental effects. Techniques for valuing the benefits of environmental improvements include travel cost, hedonics, and contingent valuation. The guidelines show an awareness of distributional considerations, both across the current population and between generations.

These emissions reduce the water quality in the bay on which they are located and contribute to air pollution in the vicinity of the marinas. The dollar values are totals of various cost and benefit categories over the life of the regulatory program. Compliance costs in the industry consist of $580 million of capital equipment costs and $560 million of operating costs. Public-sector monitoring and enforcement required to achieve an acceptable level of compliance total $96 million. There are three major benefit categories: recreationists (fishers and boaters) benefit from improved water quality at an estimated value of $1,896 million; property values of local homeowners are expected to increase to $382 million because of improved air quality and visibility resulting from reduced airborne emissions;

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nonuse values associated with the general improvement in the ecological integrity of the bay are estimated at $749 million.

We can compare total benefits and costs in several ways. One way is to subtract the total costs from total benefits to get "net benefits." In Table 3.1, the net benefits are $1,791 million ($3,027 minus $1,236). Another criterion is the benefit-cost ratio, found by taking the ratio of benefits and costs. This shows the benefits the project will produce for each dollar of costs; the benefit-cost ratio is 2.5 ($3,027 divided by $1,236)

NATURAL RESOURCE DAMAGE ASSESSMENT

Natural resource damage assessment is a methodology for determining the liability for injury to natural assets that results from release of oil or hazardous substances. Three federal statutes — the Clean Water Act, CERCLA, and the Oil Pollution Act — all impose liability assessments for injury to natural assets that result from oil spills or hazardous wasters and other substances. Under these acts regulations for comprehensive natural resource damage assessments have been developed by the Department of the Interior and NOAA. The process includes three steps: (1) injury determination; (2) quantification of service effects; and (3) damage determination. Environmental valuation plays a role in the latter step. Natural resource damages are the sum of:

- Restoration costs
- Compensable value (diminution in value of foregone natural resource services prior to restoration)
- Damage assessment costs

► RESTORATION COSTS (which also include costs of rehabilitation, replacement, and/or acquisition of equivalent resources) include both direct and indirect costs. Direct costs are costs charged directly to the conduct of the selected alternative, such as staff time, materials, equipment, and the like. Indirect costs are costs of activities or items that support the selected alternative but cannot be directly accounted for, such as overhead.

► COMPENSABLE VALUE is the amount of money required to compensate the public for natural resource services losses between the time of the release and the time when these services are fully restored to their baseline condition. Compensable value excludes any losses associated with secondary economic impacts resulting from the release, such as losses incurred by businesses patronized by users of the injured resources (e.g., bait and tackle shops).

▸ DAMAGE ASSESSMENT COSTS are the costs of peforming the studies to determine the other costs mentioned above.

SUSTAINABLE DEVELOPMENT ASSESSMENT

Sustainable development — development that meets the economic needs of the present without compromising the ability of future generations to meet their economic needs — links two basic ideas: ecological sustainability, which implies that biological elements (including humans) and processes that keep ecosystems productive and resilient, should be maintained; and economic development, which seeks to maintain economic growth or expansion, should be undertaken.

Ecological sustainability and economic development must be linked when implementing policies that would lead to sustainable development. The ability to implement such policies requires multidisciplinary approaches which blend the perspectives, the goals, and objectives of disciplines such as ecology, social science, and economics.

Determining the value of natural resources and environmental assets in the sustainable development framework is useful in a number of ways, including:

- National and regional income accounting
- Strategic benefit-cost analysis
- Project level benefit-cost analysis

▸ NATIONAL AND REGIONAL INCOME ACCOUNTING. Environmental values may be used to modify national income accounts so that they reflect improvements and declines in environmental resources. The objective is to obtain a better index of economic well-being and avoid net loss transfers of wealth between the market and non-market sectors. Standard gross domestic product (GDP) accounts reflect only a portion of a nation's economic productivity (the portion traded in ordinary markets). Using standard accounts, a

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county or region could destroy its resource base but show an increase in wealth. For sustainable development to be operational in economic policy, environmental accounts and standard economic accounts must be integrated.

▸ STRATEGIC BENEFIT-COST ANALYSIS. The objective of strategic benefit-cost analysis is to set priorities and make trade-offs across a range of alternative policies. Such analysis is motivated by the economic consequences of environmental investments. For instance, strategic analysis may assess the benefits of investments in salmon habitat restoration relative to nonpoint source pollution controls. Alternatively, such an analysis may respond to questions such as, "How much should we clean up? What level of investment should we make in nonpoint source pollution control or salmon habitat restoration?" Beneficial policies are selected and put together to construct an overall policy package or agenda.

▸ PROJECT-LEVEL BENEFIT-COST ANALYSIS. Examines the benefits and costs of specific policy actions and controls and extends conventional benefit-cost procedures to the non-market sector. This extension is increasingly common in development decisions. For example, a study might estimate a household's willingness to pay to hook up a centralized sewer system in order to reduce nonpoint source pollution. In controlling nonpoint source pollution, project-level analysis examines the benefits and costs of specific actions. It addresses the means and methods of control once the general direction of policy is set.

4

MEASURING THE VALUE OF GOODS AND SERVICES TRADED IN MARKETS

If goods or services are traded in the market, there are well established and accepted empirical techniques for measuring welfare changes. For measuring producer surplus, it is not necessary to estimate the supply curve. For measuring consumer surplus, it is essential to estimate the demand curves. These conventional techniques of measuring changes in value serve as a springboard for understanding non-market techniques of economic valuation.

To estimate use values, economists employ market resource valuation methodologies. For those resources for which markets exist, economists typically rely on directly observable behavior in the form of market transactions to reveal preferences or the value that individuals place on goods and services and their willingness to pay to avoid loss of such goods and services. The standard method for measuring the use value of resources traded in the marketplace is the estimation of producer and consumer surplus using market price and quantity data.

MEASURING PRODUCER SURPLUS WITHOUT ESTIMATING SUPPLY

Sometimes the measurement of changes in producer surplus does not require complicated econometric modeling to estimate the supply curve (see Chapter 2, Concepts in Environmental Valuation). Careful measurement of all the opportunity costs of production in alternative situations can be used to estimate the change in producer surplus. Consider the hypothetical case in which habitat degradation results in a reduction of striped bass available to the commercial fishery in Chesapeake Bay, a reduction in catch from 8,000 to 5,000 pounds a day. The ex-vessel price, below, refers to the price paid directly to the harvesters for whole fish.

Prior to the reduction in stock size the state of the fishery was estimated as follows:

Catch rate per day (pounds) = 8,000
Ex-vessel price = \$0.70/pound
Variable costs per pound = \$0.40
Total days fished in season = 16
Total revenue = 16 x 8,000 x 0.70 = \$89,600
Total variable cost[5] = 16 x \$0.40 x 8,000 = \$51,200

Producer surplus = Total revenue minus total variable cost
= \$89,600 – \$51,200 = \$38,400

To simplify the analysis, we assume that the harvesters will not change their fishing behavior, at least in the short run, due to the

[5] Variable costs or costs which vary with output. Fixed costs are not included because, by definition, they do not change in the two scenarios. Thus, even if we bothered measuring them, they would be netted out when comparing the two scenarios.

decrease in stock size. However, reduced stock size can affect harvesters by lowering their catch rate and increasing their variable costs of production. After the reduction in stock size, the state of the fishery is:

Catch rate per day = 5,000
Ex-vessel price = $0.70 (note: for simplicity we assume no price change)
Variable costs per pound = $0.50 (uses more fuel searching for fish)
Total days fished in season = 16
Total revenue = 16 x 5,000 x $0.70 = $56,000
Total variable cost = 16 x $0.50 x 5000 = $40,000

Producer surplus = $56,000 – $40,000 = $16,000

The estimated change in producer surplus is $38,400 – $16,000 = $22,400

Advantages of This Technique. We have a number that can be compared against the producer surplus created by the activity that resulted in the habitat degradation. For the average fisher, the degradation of striped bass habitat has created a welfare loss of $22,400 per year. If there are 100 fishers, the estimated welfare loss would be $2,240,000. In practice the calculation would be more complicated. What will be the predicted response of harvesters due to the reduction in stock size? Will some harvesters drop out of fishing or go after a different species? If so, what is their producer surplus in these alternative activities?

Disadvantage of This Technique. Such an analysis may be problematic because of difficulties in accurately predicting the changes in cost and earnings due to environmental change and in fisher behavior. Also, the prices and cost of inputs and outputs (true opportunity costs) may diverge from accounting costs. This is particularly a problem with fisheries because of the common property nature of the resource. The intricacies of that problem are beyond our study of environmental valuation.

Data Needs. The data required for such an analysis include detailed costs and earnings for a representative fisher. Such information could be obtained from an industry survey.

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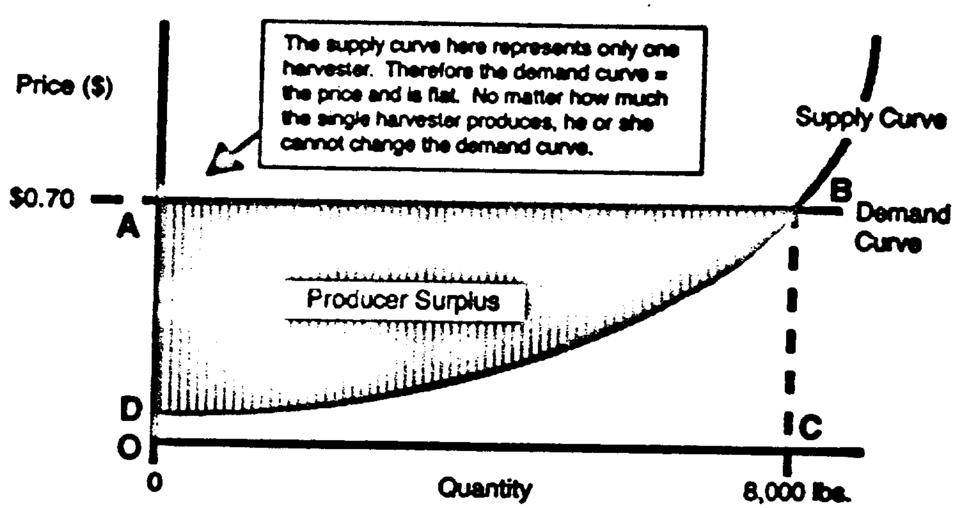
MEASURING PRODUCER SURPLUS BY ESTIMATING SUPPLY

Econometric (statistics of economics), techniques can be used to estimate the industry supply curve — these techniques are an alternative to the previous methods for directly calculating changes in producer surplus. The method is directly linked to the previous approach for measuring producer surplus because the industry supply curve is another way of representing the variable costs of production that that method employs. The area under the industry supply curve (to any given quantity) is equal to the industry's total variable cost to produce that quantity.

From Figure 4.1 we can geometrically determine the producer suprlus: draw a rectangle connecting the price of striped bass (Y-axis) and the quantity caught (X-axis) through its point on the supply curve (OABC). The area of this rectangle is simply price times quantity or total revenue, the same as in the previous example. If we subtract from this rectangular area, the area under the supply curve (area of ODBC, equal to total industry variable costs when producing

Figure 4.1. Chesapeake Bay Striped Bass: Measuring Producer Surplus



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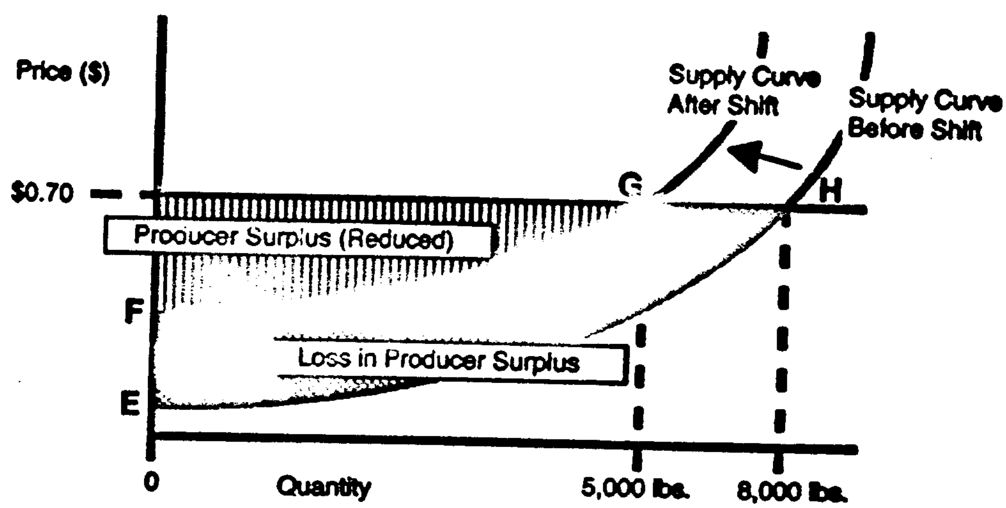
that quantity), the remaining area (ABD) is equal to the producer surplus from the previous method.

The same exercise can be done to describe the situation after the decrease in the size of Chesapeake Bay striped bass populations. The reduction in stock size causes a shift left in the industry supply curve because supply is dependent on the size of the stock. The difference between the areas of the producer surplus triangles with and without the environmental impact is the change in producer surplus (Figure 4.2) or welfare loss (area EFGH).

Disadvantage of This Technique. The major problems associated with this technique include the need to account for all the factors that affect the supply curve over time (e.g., technical change in fishing and regulations) to isolate the effect of the environmental welfare loss.

Data Needs. The data required for this analysis include time series data on input and output prices, landings, and stock abundance.

Figure 4.2. Chesapeake Bay Striped Bass: Measuring Change in Producer Surplus



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EMPIRICAL TECHNIQUES FOR MEASURING CONSUMER SURPLUS

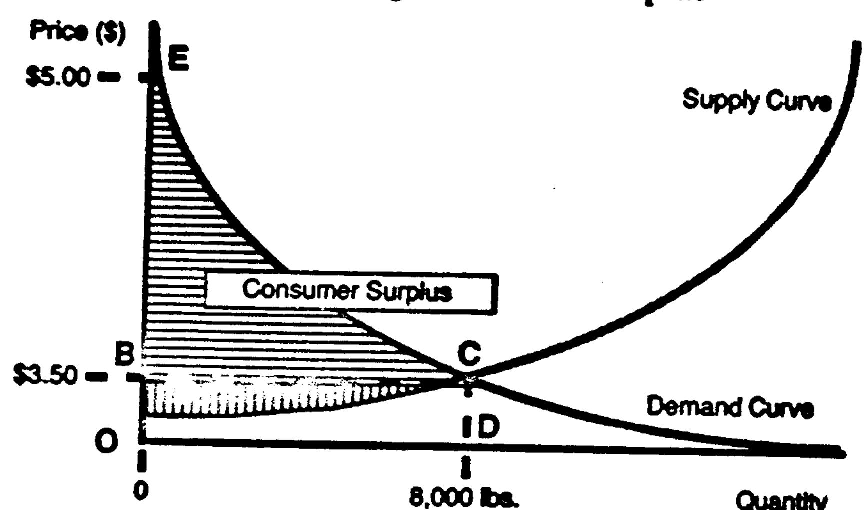
As in the case of producer surplus, econometrics can also be used to estimate consumer demand and thus changes in consumer surplus. The area under the demand curve is equal to the consumer's total willingness-to-pay. Suppose that initially fish consumers must pay $3.50 per pound at the retail fish market. At that price 8,000 pounds of fish are purchased. A simple calculation tells us:

consumer expenditures = $3.50 x 8,000 = $28,000

From Figure 4.3 we can draw a rectangle (area OBCD) connecting the price of striped bass (Y-axis) and the quantity demanded (X-axis) through its point on the demand curve. The area of this rectangle is simply price times quantity or total expenditure, the same as calculated above.

Some consumers may be willing to pay more than $3.50 per pound for their fish, but everyone pays the same price in the store. The area under the demand curve captures the information about the total amount consumers would be willing to pay for the various quantities offered. By subtracting what they actually pay, we obtain an es-

Figure 4.3. Chesapeake Bay Striped Bass: Measuring Consumer Surplus



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timate of their net welfare from the consumption of striped bass. In our example, the total area under the demand curve (area OECD) out to 8,000 pounds is the consumer total willingness-to-pay ($34,000). Subtracting what the consumers must pay ($28,000) from their total willingness-to-pay, the consumer surplus is equal to $6,000 ($34,000 – $28,000) — this is the area BEC.

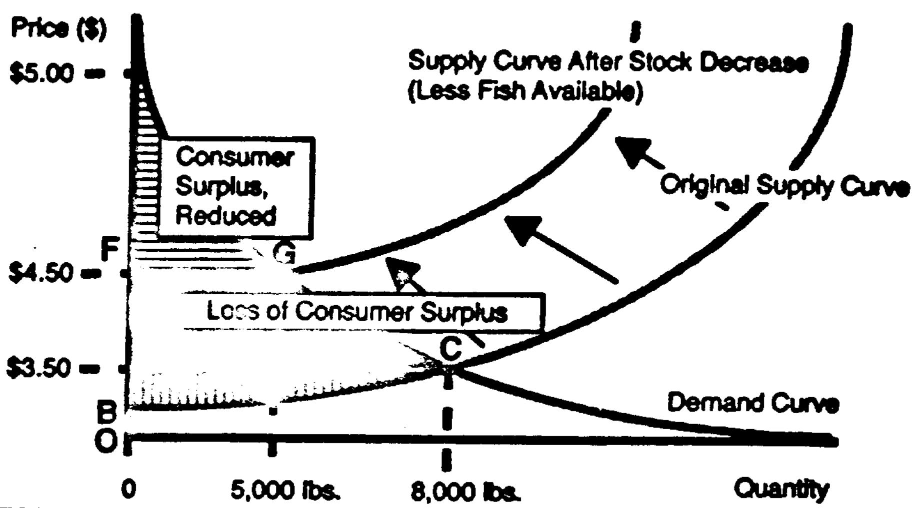
This same exercise can be done to describe the situation after the decrease in the size of Chesapeake Bay striped bass populations. As outlined previously, the reduction in stock size will cause a shift left in the industry supply curve, causing the price of striped bass to rise (Figure 4.4). The difference between the areas of the consumer surplus triangles with and without the environmental impact is the change in consumer surplus (area BFGC).

Suppose now that with the decrease in stock size and subsequent reduction (8,000 to 5,000 pounds) of striped bass being harvested consumers see an increase in the retail price from $3.50 to $4.50 per pound. A simple accounting shows:

consumer expenditures = $4.50 x 5,000 = $22,500

In this new situation, the total area under the demand curve out to 5,000 pounds is the consumer total willingness to pay ($23,750). Subtracting what the consumer must pay ($22,500) from their total

Figure 4.4. Chesapeake Bay Striped Bass: Measuring Consumer Surplus



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willingness to pay, the new consumer surplus is equal to $1,250. The estimated change in consumer surplus is then:

$6,000 – $1,250 = $4,750

or a loss of $4,750 to society.

Disadvantage of This Technique. The major difficulty with this approach is that effects from changes in supply must be separated from the effects on demand; and shifts in demand, if any, must be accounted for over time.

Data Needs. The data required for this analysis are time series information on market price for the product and quantity consumed, along with measures of other factors that affect demand.

SUMMARY

For environmental goods or services traded in markets, standard economic techniques of measuring supply and demand and determining changes in producer and consumer surplus can be applied using market price and quantity data. There is no difference in the techniques suggested here and measuring the economic value of any non-environmental good or service. In the next chapter, we demonstrate techniques economists have developed to deal with the situation when goods and services and other benefits do not result from market transactions.

5

Measuring the Value of Non-Market Goods and Services

Without the observable price and quantity data that are available when goods or services are traded in the market, economists have devised innovative techniques for measuring changes in value for natural resources and the environment. Three of the techniques, travel cost, random utility and hedonics use information to indirectly determine what a market might reveal in value if it did exist. The contingent value technique attempts to measure the change in value directly.

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Some goods and services like recreational fishing and wildlife viewing are not traded in a well functioning, traditional market. That is, they are not supplied by private firms and consumers do not pay market prices. Nonetheless, indviduals benefit from their use and, therefore, the loss of such environmentally related goods signifies welfare losses to these individuals. Conceptually, the same measure of benefit applies to market and non-market goods, that is, the maximum amount an individual would pay to avoid losing, or gaining, access to the good. Since these are non-market benefits, typically, there is no producer, or the consumer is both the producer and consumer. Thus, measures of non-market benefits are concerned with estimates of consumer demand and consumer surplus. There are a variety of methods that have been developed to measure this value concept in the absence of markets.

Non-Market Valuation Techniques

In the absence of ownership and efficient pricing, we need special techniques to place consumer preferences for natural resources and environmental goods and services on common ground with the demands for more conventional commodities. Three types of procedures have been employed to measure these demands.

- **Travel cost and random utility models, which are based on expenditures and travel behavior for recreational opportunities**
- **Hedonic methods of decomposing prices of market goods to extract embedded values for related environmental attributes**
- **Experimental methods for eliciting preferences, either by using hypothetical settings, called contingent valuation, or by constructing a market where none existed**

Travel cost models, random utility models, and hedonic methods are indirect measures based on observable behavior. Experimental methods, or contingent valuation, are based on direct surveys of individuals.

INDIRECT MEASUREMENT TECHNIQUES

Indirect techniques rely on observable behavior to deduce how much something is worth to an individual even though it is not traded in markets. These methods produce value estimates that are conceptually identical to market values, but they must be measured more creatively since market data are not available. Indirect techniques include travel cost models, random utility models, and the hedonic pricing method.

▸ Travel Cost Model

Overview. The travel cost method is, in general, employed to estimate recreational values. This technique assumes that visitors to a particular site incur economic costs, in the form of outlays of time and travel expenses, to visit the site. In effect, these economic expenditures reflect the "price" (albeit implicit) of the goods and services provided by the site, and are an indirectly observable indication of the minimum amount that a visitor is willing to pay to use the site (with all its associated attributes).

By observing the characteristics of individuals visiting the site — for example, the specific attributes of their trip to and from the site as well as the total number of visits — economists are able to estimate the "derived demand" for the site. That is, for any given or implicit price, the derived demand relationship will determine the number of visits consumers will "purchase" at that site.

The travel method technique has a number of applications — it can be used, for example, to measure the effects on a consumer's willingness-to-pay because of changes in access costs to a recreational area, or the elimination of a site, or changes in environmental quality.

Issues that Require Attention in Travel Cost Modeling

- **Costs, because time costs are often critical in recreational consumption**
- **Characterizing the quality dimensions of the site and taking proper account of substitute sites and their characteristics**
- **Estimating both the individual's decision as to whether to use the site and his or her decision as to how much to use it**

Advantages of This Technique. The travel cost technique is relatively uncontroversial because it mimics empirical techniques used elsewhere in economics. Economists generally tend to prefer techniques of this sort because they are based on actual behavior rather than verbal responses to hypothetical scenarios. In the travel cost model, individuals are actually observed spending money and time, and their economic values are deduced from their behavior. In appropriate circumstances, this model can often be applied without enormous expense.

Disadvantages of This Technique. The greatest disadvantage of travel cost and other indirect techniques is that they can not be employed unless there is some easily observable behavior that can be used to reveal values. Thus, in the case of measurement of nonuse values these methods are inappropriate. In the case of nonuse values, there is no observable interaction between the individual and the resource in question

Travel cost models are also technically and statistically complicated. Understanding the conceptual measure requires understanding the connection between consumer surplus (measures of changes behind demand curves) and the "maximum willingness to pay" concept. In addition, data must be employed to statistically estimate increasingly sophisticated econometric models that take into account such factors as sample selection problems and non-linear consumer surplus estimates. Finally, the resulting estimates sometimes have been found to be rather sensitive to arbitrary choices of the functional form of the estimating equation and the treatment of time. Though much technical work has been dedicated to improving these methods, they will continue to be subject to the problems that plague all empirical economic estimation.

Data Needs. While the early travel cost models used information on the proportions of visitors from increasingly distant zones of origin from which their travel occurred (called "zonal models"), current methodology requires data on individual travelers. Typically this information is collected through surveys. On-site surveys can provide heavy sampling of users, but these need to be augmented with surveys of the general population in order to learn what proportion of the population uses the resource. A survey of the general population also provides data on the characteristics of the resource users as well as information that helps the economist estimate the participation decision.

Unfortunately, a travel cost study is best at assessing the current situation. To analyze the gains or losses from changes in the recreational resource, economists need to conduct travel cost studies under varying circumstances or they need a way of extrapolating the effects of change. Ideally, an important recreational resource could be subject to periodic travel cost studies, so that the effect of differing conditions of the resource could better be estimated. This is especially true if one is measuring the damages from a disaster such as the effects of an oil spill on recreational boating. Economists would find invaluable a travel cost study that had been completed before the disaster.

Estimating the Value of Recreational Bird-watching: Travel Cost Model

Suppose a development project calls for filling a wetlands area, an area that is a major bird-watching site for the region. In this case the valuation question might be: What would be a money measure of the lost value of observing birds in this area due to the development? The answer could be used as input to a benefit-cost analysis of the proposed development.

The first step in such an analysis is to survey participants on bird-watching trips about trip expenses. The second step would examine the relationship between the number of participants and trip expenses such as in the table.

Table 5.1. Travel Cost Data.

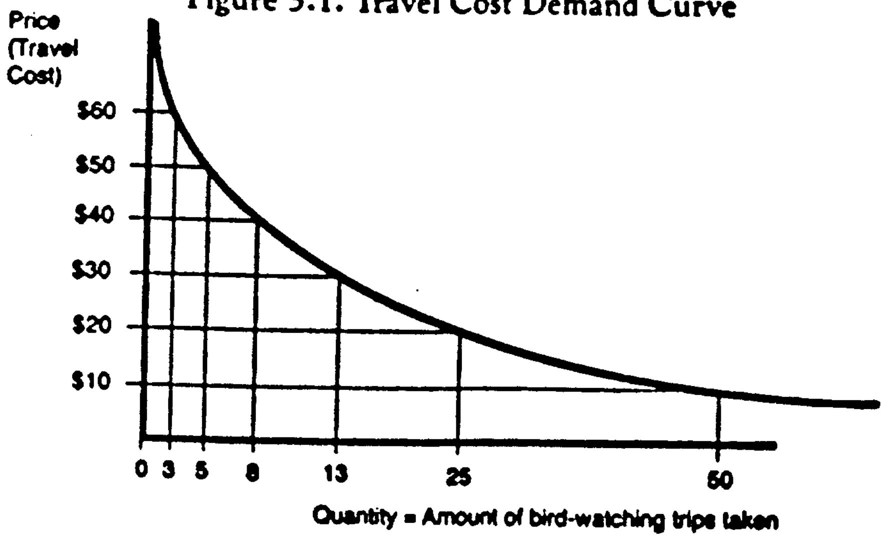
Trip Expense Range	Number of Trips
< $10	50
$10-$19	25
$20-$29	13
$30-$39	8
$40-$49	5
$50-$59	3

In the absence of such ideal studies, researchers would find any information on the level of use of the resource beneficial (e.g., historical information on number of users, their location of residence, and frequency of use). Moreover, any information that would help shape the sampling method would be valuable (e.g., when the resource is most heavily used and by whom).

As with all environmental valuation, the researcher's most difficult job is connecting the environmental event with the effect on the user. Any insights here are invaluable. In the development case, the analysis would need to be accomplished as a hypothetical case. To use results from a travel cost model, researchers need to know how recreationists would be affected by the development activity and how that effect would translate into changes in behavior.

From this and other data collected about the individual participants, we can estimate a travel cost demand curve with the travel cost as the price and the number of trips as the quantity shown in Figure 5.1. This demand curve will also be a function of other information collected from the individuals that help to explain their bird-watching behavior (e.g., income, ethnicity, education, etc.). We must also make adjustments econometrically

Figure 5.1. Travel Cost Demand Curve



for the non-participants, the people who might go bird-watching in the area under different circumstances (e.g., if they had lower travel costs).

The travel cost demand curve applies to a representative individual from a particular geographic region or socio-economic class. It is not the aggregate demand curve. To get an aggregate value measure, individual consumer surplus must be augmented by a population expansion factor which this individual represents.

This curve represents the recreational demand for bird-watching prior to the development. If bird-watching is completely eliminated at this site, then the total consumer surplus is lost. However, the more likely consequence is that the quality of the bird-watching trip will be lowered. We will need to predict how the demand curve will shift, and then measure the consumer surplus with and without the shift.

▸ Random Utility Models

Overview. Though conceptually similar to travel cost models, random utility models do not focus on the number of trips recreationists make to a given site in a season; rather, they focus on the choices of recreationists among alternative recreational sites. This type of model is particularly appropriate when substitutes are available to the individual so that the economist is measuring the value of the quality characteristics of one or more site alternatives.

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Advantages of This Technique. The same advantages that apply to travel cost models are applicable with random utility models. Many economists consider this method as the state-of-the-art in recreational demand modeling. Relative to the travel cost model, this approach deals well with substitute sites and environmental quality considerations.

Disadvantages of This Technique. The approach has all the disadvantages of the travel cost method, though it is much more data intensive.

Data Needs. Because a researcher needs to know what alternative sites are considered by recreationists, as well as recreational behavior with respect to all these alternative sites, the data requirements are greater. In addition, accurate measurements of the characteristics of alternative sites are important.

Estimating the Value of Recreational Bird-Watching: Random Utility Model

The superiority of the random utility model approach over the standard travel cost method will be evident. In a hypothetical example (Table 5.2), suppose Site I is the birdwatching area proposed for development. However, there are two other relevant sites in that area, each having its own characteristics with regard to the experience the bird-watcher will have. These experiences are represented in the example by a species diversity index and a

Table 5.2. Multiple Sites with Quality Differences.

Site Attributes	Site I Proposed Fill Site	Site II	Site III
Species Diversity Index	5.2	4.8	3.6
Bird-Spotting Index	8.7	5.9	6.3

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bird-spotting index. The greater the diversity of species and the more likely the individual will see unusual birds, the greater the value of the recreational experience. Because of locational differences and the value of time, each individual will incur different costs to go to each site. Table 5.3 summarizes the pattern of visits to the different sites by three different individuals. The data in these two tables are the type typically used to determine the value of access to the site, or changes in quality at a site. These data provide us with observable information about how individuals make tradeoffs between the quality of the site and the cost of accessing it. In the travel cost model, we only have one site, so it is difficult to determine how individuals respond to quality changes unless the quality of that site has changed over time.

Note that the random utility model requires data about participation at the study site as well as relevant alternative sites. Site characteristics are also implicitly considered in the decision model. In the example, we looked at a species diversity index and an index of number of bird spottings per hour as the relevant characteristics that vary across sites.

Table 5.3. Trip Expenditures and Number of Trips Taken (Example of data from three individuals in our sample).

	Individual	Site I	Site II	Site III
1	Travel Costs	$10	$20	$30
	Number of Trips	4	2	0
2	Travel Costs	$15	$8	$40
	Number of Trips	0	5	1
3	Travel Costs	$20	$20	$20
	Number of Trips	5	2	3

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▸ Hedonic Pricing Methods

Overview. The hedonic pricing method is another technique to determine environmental value. In its earliest applications, these techniques were intended to capture the willingness-to-pay measures associated with variations in property values that result from the presence or absence of specific environmental attributes, for instance, air pollution, noise, or water views. By comparing the market value of two properties which differ only with respect to a specific environmental attribute, economists may assess the implicit price of that amenity (or its cost when undesirable) by observing the behavior of buyers and sellers.

A variation on the approach of comparing the effects of an environmental attribute would involve comparing the price of a single piece of property over successive sales. By correcting for other factors that might influence the value of the subject property, economists are able to isolate the implicit price of some amenity or bundle of amenities which have changed over time. The price of a house may be affected by factors such as the number of bedrooms, the square footage, the existence of a pool, the proximity to local schools, shopping, highways. The price may also be affected by the proximity to, or quality of, environmental amenities. Air quality has been found to be a determinant of housing prices in Los Angeles; whether or not a property abuts a woodland may also matter. Hedonic methods can also be used to estimate the effect of certain disamenities on the price of a house, for instance, the impact on the price of a residential property adjacent to an area affected by a spill or some proposed unfavorable development.

The process for estimating an hedonic price function that relates housing prices to the quantities of various characteristics is reasonably straightforward. However, it is much more difficult to derive value measures from these estimated functions. Only under very restrictive assumptions can values be obtained directly from these estimated functions. In most cases, a two-stage procedure that depends on information from multiple markets is necessary.

Advantages of This Technique. The hedonic techniques, like travel cost and random utility models, depend on observable data resulting from the actual behavior of individuals. Market data on property sales and characteristics are available through real estate services and municipal sources and can be readily linked with other secondary data sources.

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Disadvantages of This Technique. Most environmental incidents will have only small, if any, effects on housing prices. Even where effects do exist, it may be difficult to estimate them using econometric methods because many factors, many of which are correlated, influence housing prices. For example, a house located near a factory with emissions that reduce air quality may be in a poorer section of town where schools are not as good and there are few other amenities like parks. Even when implicit prices for environmental amenities can be estimated, it is usually very difficult to obtain measures of value from these models. The connection between the implicit prices and value measures is technically very complex and sometimes empirically unobtainable.

Data Needs. Data needs include prices and characteristics of houses sold in the housing market of interest. In particular, a measure or index of the environmental amenity of interest is needed.

DIRECT TECHNIQUES

▸ *Contingent Valuation Method (CVM)*

Overview. The most obvious way to measure nonmarket values is through directly questioning individuals on their willingness-to-pay for a good or service. Called the contingent valuation method, it is a survey or questionnaire-based approach to the valuation of non-market goods and services. The dollar values obtained for the good or service are said to be contingent upon the nature of the constructed (hypothetical or simulated) market and the good or service described in the survey scenario.

The contingent valuation technique has great flexibility, allowing valuation of a wider variety of non-market goods and services than is possible with any of the indirect techniques. It is, in fact, the only method currently available for estimating nonuse values. In natural resources, contingent valuation studies generally derive values through the elicitation of respondents' willingness-to-pay to prevent injuries to natural resources or to restore injured natural resources. Since the first published contingent valuation study on valuing outdoor recreation appeared in 1963, more than 1,400 related documented papers, reports, and books have been published.

In contingent valuation methods, randomly selected samples or stratified samples of individuals selected from the general population

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are given information about a particular problem. They are then presented with a hypothetical occurrence such as a disaster and a policy action that ensures against a disaster; they are then asked how much they would be willing to pay — for instance, in extra utility taxes, income taxes, or access fees — either to avoid a negative occurrence or bring about a positive one. The actual format may take the form of a direct question ("how much?") or it may be a bidding procedure (a

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A Sampler of Contingent Valuation Questions

- **Would you approve of the wetlands protection program if it reduced your income by some dollar amount ($5-1500, posted price varied on questionnaires) per year in order to have your bag or catch preserved at current levels (or 50% or 25%), rather than have your bag or catch reduced to zero because of continued marsh loss? (Circle one letter.)**

  a. Yes **b. No**

  Source: Bergstrom, J.C. et al. 1990. Economic Value of Wetlands-Based Recreation. *Ecological Economics* (2):129-147.

- **Suppose that the Terrebonne wetlands were to disappear tomorrow and that persons like yourself had a chance to save this particular area. What would you reasonably estimate to be the maximum you would be willing to pay each year in order to guarantee the use of this area for you and your household?**

$0-$15 _	**$45-60 _**	**$90-100 _**	**$200-250 _**
$15-30 _	**$60-75 _**	**$100-150 _**	**More than $250 _**
$30-45 _	**$75-90 _**	**$150-200 _**	

  Source: Farber, S. 1988. The Value of Coastal Wetlands for Recreation: An Application of Travel Cost and Contingent Valuation Methodologies. *Journal of Environmental Management* (26):299-312.

- **What amount on the payment card, or any amount in between, is the most you (your household) would be willing to pay in taxes and higher prices each year to continue to keep the nation's freshwater bodies from falling below the boatable level where they are now? In other words, what is the highest amount you (your household) would be willing to pay for Goal C each year before you would feel you are spending more than it's really worth to you (all members of your household)? (Note: Payment card is income dependent and shows average household public expenditures on various public programs such as roads, education and defense.)**

  Source: Mitchell, R.C. and R.T. Carson. 1989. *Using Surveys to Value Public Goods*. Baltimore. Johns Hopkins University for Resources for the Future.

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ranking of alternatives) or a referenda (yes/no) vote. Economists generally prefer the referenda method of eliciting values since it is one most people are familiar with. The resulting data are then analyzed statistically and extrapolated to the population that the sample represents.

Contingent valuation studies are conducted as face-to-face interviews, telephone interviews, or mail surveys. The face-to-face is the most expensive survey administration format but is generally considered the best, especially if visual material needs to be presented. Non-response bias is always a concern in all sampling frames. In other words, people who do not respond have, on average, different values than people who do respond.

Pros and Cons of Contingent Valuation

Pros

1. Based in economic utility theory and can produce reliable estimates.
2. Most biases can be eliminated by careful survey design and implementation.
3. Currently the only method available to measure important nonuse values associated with natural resources.
4. Has been used successfully in a variety of situations.
5. Is being constantly improved to make the methodology more reliable.

Cons

1. Estimates of nonuse values are difficult to validate externally.
2. Stated intentions of willingness to pay may exceed true feelings.
3. Results may appear inconsistent with tenets of rational choice
4. Respondents may be unfamiliar with the good or service being valued and not have an adequate basis for articulating their true value
5. Respondents may express a value for the satisfaction ("warm glow") of giving rather than the value of the goods or service in question
6. Respondents may fail to take questions seriously because the financial implications of their responses are not binding.

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Advantages of This Technique. In principle, contingent valuation methods can be used to estimate the economic value of anything, even if there is no observable behavior available to deduce values through other means. It is the only method that has any hope of measuring "existence values," i.e., the value that individuals place on simply knowing the natural resource exists in an improved state. This is because since existence values are not connected with use and all other methods depend on observing actual behavior associated with the resource.

Though the technique requires competent survey analysts to achieve defensible estimates, it is not difficult to understand. The responses must be statistically analyzed, but require no more than the understanding of a mean or median value.

Disadvantages of This Technique. When conducted to the exacting standards of the profession, contingent valuation methods can be very expensive because of the extensive pre-testing and survey work. In addition, while this technique appears easy, its application is fraught with problems, for example, the possibility of strategic bias by respondents or structural problems in questionnaire design. Moreover, question framing, mode of administration, payment formats, and interviewer interactions can all affect results.

Many questions have been raised about the reliability of the contingent valuation method for the calculation of nonuse values particularly in regard to natural resource damage assessment under OPA. Because this subject is complex and contentious and has ramifications not applicable to the use of CVM in applications other than damage assessment, it is not discussed here.

Data Needs. The quality of a contingent valuation questionnaire depends upon the amount of information that is known beforehand about the way people think about the resource in question. Information on who uses the resource and who knows about it are critical. When the contingent valuation method is applied to use values, the economist undertaking the survey will want to sample populations most likely to use the resource. The key point is that while all the information necessary for assessing an individual's value of the resource is collected in the survey, the economist needs help in identifying a representative sample and information to allow extrapolation to the population.

Illustration of Contingent Valuation Methodology

Suppose development along the coast of New Jersey would result in impacts to coastal waters that will lower the quality of recreational activities. It is estimated that such development might lower recreational fish catches by (100, 50, 25%), increase beach closings, and lessen the quality of the recreational boating experience. A number of environmental groups have proposed a program that will mitigate impacts of the development on recreation. It is to be funded by a tax on individuals such as yourself and would be ($5-1,500) per year. Given that the development will occur, and specifically relating to fishery catch, are you willing to fund the mitigation program at this cost to you? (A "yes" answer requires respondent to specify the amount of his/her willingness-to-pay for mitigation to prevent various levels of catch reduction.)

a. yes
b. no

Table 5.4. Willingness-to-Pay for Mitigation.

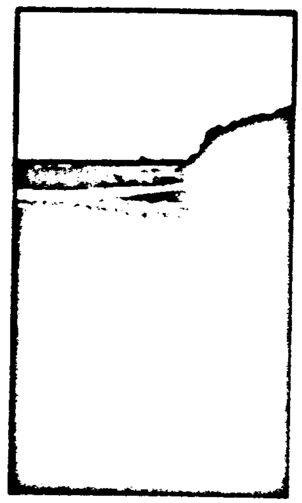
Individual's cost for mitigation	Percent Responding Yes to Reduction in Catch		
	100% Reduction	50% Reduction	25% Reduction
$5-25	100%	100%	95%
$25-50	88%	78%	65%
$50-75	51%	45%	40%
$75-100	22%	15%	12%
$100-200	8%	6%	4%
$200-300	7%	7%	6%
$300-400	5%	2%	1%
$400-500	2%	1%	1%
$500-750	1%	1%	1%
$ 750-1000	0%	0%	0%
>$1000-1500	0%	0%	0%

This data can be used to econometrically determine the mean willingness-to-pay for the mitigation program (mean=$160). The aggregate measure would be determined by multiplying the mean willingness-to-pay by the appropriate sample size. In this case, we might only be interested in fishers, beach goers, or boaters (n=10,000): Willingness-to-pay = $160 x 10,000 = $1,600,000 per year.

6

BENEFIT TRANSFER

Application of environmental valuation techniques may be expensive, particularly for local decision-making where research budgets are limited. Benefit transfer offers a lower cost alternative to performing a full-scale study for any particular issue.



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Benefit transfer is an application of a data set developed for addressing one particular environmental or natural resource valuation question to another context. Given the expense and time associated with estimating values of non-market natural resources and services, benefit transfer can be a reasonable method for determining such values. Benefit transfer applications can be divided into three classes:

- Estimates based upon expert opinion (e.g., the transfer of average net willingness-to- pay or proxy values)
- Estimates based on observed behavior (e.g., transfer of the entire demand equation)
- Estimates based upon preference elicitation mechanisms, i.e., the contingent valuation method

Benefits transfer are considered to be valid under well-defined conditions. Factors to consider in conducting a benefit-transfer decision include some of the following considerations:

GENERAL ASSUMPTIONS

- For what purpose were the original value estimates generated?
- What user group(s) were considered in generating the initial estimate (e.g., duck hunters versus all citizens in an area)?
- Did the existing study address a specific or unique problem that may have influenced the magnitude of the estimates obtained (e.g., during a period of heightened concern for the resource in question)?
- Have general attitudes, perceptions, or levels of knowledge changed in the period since the existing study was performed in a way that would influence the value of the benefit estimate? Are these values likely to be consistent over time?
- If the value being considered is for a generic resource category (e.g., common songbirds), are the species considered in the original study relevant to the case at hand?

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- Were adjustments to the data made in the existing study? For example, were outliers deleted? Were any adjustments made for perceived biases?

- Does the existing study consider the same or a similar geographic area? Are the demographic and socio-economic characteristics of the two areas similar?

METHODOLOGY

- If the source being used presents a composite of existing values based on an earlier literature review, what methods were used to derive these composite values and what was the nature of the underlying studies?

- Were baseline conditions (e.g., ambient water quality) in the existing study similar to baseline conditions in the case at hand?

- Were variables omitted from the original study that are believed to be relevant to the case at hand? To what extent does such omission prohibit the transfer?

- If current best research practices were not used to generate the value estimate(s), can the estimate(s) be adjusted to reflect changes in the state-of-the-art?

ECONOMIC METHODS/EVALUATION

- Was the study used to generate the value estimate published in a peer reviewed journal, or did it receive other forms of peer review?

- How is the original study viewed in the professional community? How was the study viewed by its sponsor?

RESOURCE

- How does the resource that was affected compare to that considered in the referenced study (e.g., is the species of concern

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more common in the policy study area than in the initial study area)?

- What was the nature of substitutes in the initial study area, and how does this compare to the policy study area (e.g., are alternative recreational opportunities more or less available in the policy study area)?

- Was the original analysis conducted to value all organisms of a given species, a sub-population, individual members of the species, or some other grouping?

Decision-makers should consider all available estimates, each based on the factors described above. Once a final set of values has been chosen, consideration should be given to their general magnitudes. If the existing value estimates differ significantly, or if values generated using alternative models differ significantly from one another, consideration should be given to whether they differ in a predictable and consistent manner. In some cases it may be possible to combine these estimates formally through meta analysis.[5] In all cases, more defensible benefit estimates will result from comparative analysis.

In many cases the defensibility of the transferred economic benefit estimate will depend on the quality of the underlying research. However, no globally accepted, standard criteria are available to judge the quality of existing studies. The professional and academic community can provide guidance with regard to the current minimum conditions for quality assurance of the benefit transfer.

The Economic Analysis and Research Branch of the U.S. Environmental Protection Agency, Office of Policy Planning and Evaluation has prepared *The Environmental Economics Database*, a collection of references for national resources and environmental amenity valuation studies collected over several years. Computer disks of the database are available.

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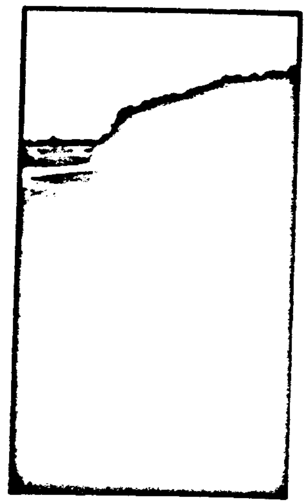
[5] Smith, V.K. 1992. On Separating Defensible Benefit Transfers from "Smoke and Mirrors." *Water Resources Research*, 28(3):685-694.

7

Theory and Application: Reconciling Differences

In the practical application of environmental valuation, issues such as choosing a discount rate, dealing with intergenerational transers and equity, and decision-making under risk and uncertainty can become important to the outcome and interpretation of the analysis. This chapter provides a brief introduction to these topics. Arguments about the appropriate discount rate can unduly obscure the underlying message that there is an economic value to natural resources and the environment.



Valuation of natural resources and environmental amenities can meet with difficulty under certain conditions. For example, if the use of a particular resource is impossible to reverse, the economic and social impacts over a long period of time must be considered. Such a consideraton in turn raises the question of discounting or, more generally, the efficiency and equity of resource use in the long run. Moreover, where information about the costs and benefits of alternative uses is particularly poor, perhaps because of the long period to which it must apply and the non-market character of some of the uses, decisions should take this uncertainty into account.

This section briefly examines these issues from a conceptual view. Unfortunately, theory does not spell out the precise quantitative adjustments that would be required in applying these issues to estimate benefits and costs in empirical work. The major point is this: the traditional benefit analysis of resource use and allocation as a basis for public decision-making is only one part of the decision process which must be accompanied by subjective notions of risk-taking and equity. A benefit-cost analysis in isolation should not be the sole basis for decision-making.

DISCOUNT RATES

When gains or losses from either a program or action accrue to individuals over time, discounting methods are typically used. Discounting is a procedure that deducts future values of a particular good — the aim is to determine the present value of the stream of benefits or costs in relation to the benefit or costs at different times in the future, i.e., benefits or costs occurring in different magnitudes at different dates in the future.

The basic principle of discounting is that a dollar received or paid next year is worth less than a dollar received or paid this year. For example, a dollar received this year may be deposited in a savings account earning, for example, 5 percent interest. On the one hand, at 5 percent interest, the dollar will be worth $1.05 the next year. Looked at from the discounting perspective, one dollar received or paid next year is only worth approximately $0.95 today. The *discount rate* in this situation is 5 percent, the interest on savings accounts. Other market interest rates, such as interest on bonds or corporate portfolios, may be used as discount rates as well. Such rates are based on the *private opportunity cost principle* or *private time preference*.

Discounting may reflect other social or psychological considerations. For example, many people exhibit "impatience." Understandably, they may value recreational experience more highly now than if they were promised the same experience ten years from now. The reasons are many — the immediate desire for pleasure and the relief from stress are only two. The result of preferring present consumption or change in the state of the world is positive discount rates. Alternatively, a concern for future generations might lead to the opinion that values in the future are worth as much as values today, implying a zero discount rate.

In general, the application of discounting in a social value context incorporates the more complex concept of *social time preference* and is often very difficult to determine. The problem of measurement parallels that of market and non-market goods. The private rate of time preference is revealed in markets, but the social rate is not. With respect to natural resources, the fundamental issue is one of defining a discount rate which reflects society's collective preferences regarding resource utilization or retention. The discount rate in the natural resource or environmental arena can be thought of as a measure of the opportunity cost of not having immediate access to a resource.

Suppose a decision must be made on whether or not to implement an oyster reef program in Chesapeake Bay. Assume a one-time startup cost of $100,000 (Table 7.1). The benefits associated with the program are projected for three years in increased returns to the local oyster industry: $15,000 in 1994, $80,000 in 1995, and $25,000 in 1996. Discounting will be crucial in determining whether the reef program is an efficient use of society's resources.

Table 7.1. Discounted Net Present Value (NPV) of Oyster Reef Program.

Year	1993	1994	1995	1996	NPV
Benefits of Reef Program	$0	$15,000	$80,000	$25,000	-
Reef Development Cost	-	$0	$0	$0	-
0% Discount Rate	-	-	-	-	$20,000
3% Discount Rate	-	-	-	-	$14,041
5% Discount Rate	-	-	-	-	$9,775
7% Discount Rate	-	-	-	-	$5,269
10% Discount Rate	-	-	-	-	-$1,950

Without discounting (or a zero discount rate), the net present value of the reef program is $20,000 and the program may be consid-

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ered economically efficient. With a 5 percent discount rate, the net present value is $9,775. However, with a 10 percent discount rate the program results in a net loss of $1,950, suggesting an inefficient use of resources. Which discount rate is "correct"? The answer depends.

Difficulties arise in choosing the "correct" rate of discount. From the example, it is clear that the larger the discount rate, the more weight that is put on the present relative to the future. Large discount rates give less weight to environmental benefits or damages that don't accrue immediately but only in the long term. Real rates of between 0 and 8 percent appear regularly in the economics literature. Some have even argued for negative discount rates to reflect the implicit interest of future generations in resource management decisions.

Despite the extensive literature, a consensus does not yet exist on an appropriate procedure for discounting costs and benefits of public programs and regulations. It is clear, however, that the characteristics of natural resources (e.g., slow-growing, renewable, and typically held in public trust) necessarily imply that they should be treated differently than other private capital assets.

IMPACTS ACROSS GENERATIONS

We referred earlier to distributional implications of different outcomes. What happens when the distributional implications span generations? How do we compare situations when one generation gains and another loses? Discounting at some market-based rate of interest is commonly used to express future costs and benefits in terms of present monetary value, assuming that a value received now is worth more than the same value provided at some future date. Obviously, standard discounting procedures will weight the effect on the current generation far more heavily. Thus, some critics feel that discounting results in greater resource exploitation or use of natural capital now, at the expense of future generations. Is there an ethical basis for this discrimination against future generations?

Some economists have proposed that decisions affecting the future should be made with decision-makers placed behind a "veil of ignorance" about which generation they belong to. This impartiality criterion suggests equal use of irreplaceable resources across generations, implying a zero discount rate. But with a zero discount rate, if enough generations are involved, use of non-renewable resources (such as oil) approaches zero for any given generation. Likewise, irreversible development (such as building a dam in a unique natural area) is essentially precluded. Furthermore, a zero discount rate may foreclose future options by undervaluing investments that produce wealth and new technology that would be of great value to future generations.

Clearly, some compromise is needed between a zero discount rate, which would preclude many resource uses and perhaps prevent valuable technological advances, and a typical market rate that reflects only the atomistic time preferences of the current generation. This compromise has been called a *social rate of discount*; its argument is that the government in this role should consider the wishes (the values) of both current and future generations. Because the welfare of future generations depends on current consumption patterns, the government should assure protection of future welfare by policies that force sufficient resource conservation. In essence, the government would proclaim what it deemed to be an appropriate discount rate.

Another argument takes a more democratic approach, recognizing that the government is run by and for the current generation; thus, any saving for the future must rely on the values of the current generation. The basis of this argument is that most citizens have a set of held values that include a concern for the larger group (including the future) as well as concern for self. If people do value the welfare of the future, then what is needed is a way for that value to be expressed and measured — a way that avoids the singular context of the marketplace.

UNCERTAINTY AND RISK

In practice, environmental valuation must contend with a great deal of uncertainty. One source of uncertainty is in the problem of predicting the consequences of today's environmental policies and actions. Will the reduction in nutrients that enter coastal waters lead to increased fish populations? Will controls on development lead to cleaner estuaries? Another source of uncertainty results from the increasing use of models, both biological and economic, to predict outcomes. Modeling is inherently a source of error, as is the measurement error of data used to calibrate the models.

There is a branch of economics that deals with decision-making under uncertainty that should be an integral part of any environmental valuation exercise. Uncertainty surrounding environmental mea-

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Models are like maps that try to chart a complex territory in which the landscape cannot be completely known — they depend on variabilities in human nature and ecosystems themselves.

surements can be introduced explicitly into background analyses by three methods:

- Direct enumeration, which requires us to list all possible outcomes
- Probability calculus, which employs formulae for the computation of such statistics as the means and variance of a probability distribution
- Stochastic simulation, which is also known as Monte Carlo simulation or model sampling

While it is clear that the decision-maker should be given as much information as possible about the probability distribution of potential outcomes of environmental actions, there are no hard and fast rules as to the "correct" way to incorporate this information.

Risk is closely related to the notion of uncertainty, focusing on the outcome that is affected by uncertainty. Every project or policy decision has risk associated with it. There is always some probability that costs and benefits will not be exactly what are expected. For example, the major risk factors inherent in coastal wetlands projects are attributable to imperfect scientific knowledge of biophysical relationships, such as uncertainty about salinity effects on cordgrass growth, and probabilistic natural phenomena, such as varying meteorological and hydrological events.

A typical method of accounting for risk is to adjust discount rates upward for projects or decisions with more risk. An alternative is to establish risk rankings of projects or decisions, along with other measures of anticipated benefits. Decision-makers may select actions with lower net benefits, if they are more certain of the outcome. This is an example of risk aversion which enters into the decision process.

IRREVERSIBILITY

For many environmental risks, the possible negative impacts are irreversible in the sense that they cannot be undone by subsequent actions, for instance, the possible ecological effects of global warming and species extinction.

The possibility of irreversible effects makes current policy decisions particularly important, since recovery from poor decisions is not possible. In other words, we must live with the consequences of current policy choices without the possibility of future rectification. In general, the benefits of risk reduction are likely to be greater, if the possible negative effects of a risky activity are irreversible, than they would be if those effects could be offset, or reversed, by subsequent actions. For example, the introduction of a non-indigenous species such as the Pacific oyster to an estuary or bay in the Mid-Atlantic is riskier when the consequences are irreversible than when they are not.

The major implications of the existence of intertemporal conflict and uncertainty with respect to the use of the natural environment is that it will be most efficient to proceed very cautiously with any irreversible action.

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CASE STUDIES

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ABOUT THE CASE STUDIES

The case studies in this section represent a unique learning tool for applying the economic valuation techniques presented in the text of this handbook to real-world situations. Although some of the cases have been modified and have been placed in a hypothetical context, they closely mimic actual scenarios. In reading and responding to the exercises that follow each case study, the users of this handbook can apply what they have already learned or return to the text to refresh their understanding of the techniques to be used. Typically, at the workshops where facilitated training has been given, a participant will take part in two case-study sessions on the second day of the training. These case-study sessions are conducted by a workshop leader or by other individuals with particular subject matter expertise.

In putting together this handbook, the authors have been guided by the need to make it truly national in scope. We have included cases dealing with questions that might arise in all regions of the Nation. While the cases deal with a specific state or regional context, they can be applied throughout U.S. coastal areas. In fact, we have learned that workshop participants sometimes learn more easily from materials with which they do not have familiarity. We hope you will use all of these case studies to expand your understanding of the economic value of natural resources. The authors are grateful to the following people for assisting in the development of these materials:

Case Study 1: Oyster Restoration in Chesapeake Bay
Douglas Lipton, University of Maryland

Case Study 2: Salmon Habitat Restoration in Alaska
Rebecca Baldwin, formerly regional economist with the U.S. Forest Service, Alaska Region

Case Study 3: Florida Keys National Marine Sanctuary
Benjamin Haskell, Florida Keys National Marine Sanctuary Program

Case Study 4: Coastal Barrier Island Preservation in North Carolina
William Zieburtz, CH2M Hill

Case Study 5: Artificial Reef Program in Lake Erie, Ohio
Leroy Hushak, Sea Grant Associate Director, Ohio State University, and David Kelch, District Specialist, Ohio Sea Grant College Program

Case Study 6: Red Snapper Fishery Management in the Gulf of Mexico
Wayne Swingle, Gulf of Mexico Fishery Management Council

Case Study 7: Wetland Restoration in Louisiana
Katharine Wellman, Battelle

Case Study 8: Nonpoint Source Pollution Control in California
Leigh Taylor Johnson, San Diego Area Marine Advisor, and Erika McCoy, Program Representative, University of California Sea Grant College Program, Cooperative Extension Service

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Oyster Restoration in Chesapeake Bay

Background

Since the mid-1800s the Chesapeake Bay has been a major producer of oysters to an extended market reaching as far away as California and England. During the 56-year period after 1834 when the business of packing oysters for shipment to the interior was established in Baltimore, Maryland, the average annual harvest from the Bay was 7 million bushels per year, or 392 million bushels for the period. This massive yield from both the Maryland and Virginia portions of the Bay was almost entirely the result of natural production, that is, there was little farming of oysters.

Sometime after the turn of the century, Maryland's oyster harvests dropped below that of Virginia. This change in comparative productivity may have resulted from several factors: development of widespread private leasing of Bay bottom grounds in Virginia while in Maryland public grounds remained the primary source of harvesting; growth of power dredging in Virginia, which was highly restricted in Maryland; overfishing of public beds in Maryland; and increasing destruction of oyster reefs and their consequent smothering by siltation. In the early 1900s, Virginia became the largest producer of oysters in the Chesapeake Region and on the entire Atlantic seaboard.[1]

Situation

The near-decimation of oysters in the Chesapeake Bay by protozoan diseases has stirred interest in importing a disease-resistant species of oyster for restoration of the fishery. Historical differences between the Maryland and Virginia oyster industries, however, complicate the problem of restoration. Competing interests between the commercial fisheries of both states as well as considerations of the role oysters play in the Bay's ecological health must be taken into account.

[1] Hargis, W.J. and D.S. Haven. 1988. The Imperilled Oyster Industry of Virginia. Special Report No. 290 in Applied Marine Science and Ocean Engineering. Virginia Sea Grant Marine Advisory Services.

In 1954, Chesapeake harvests rose dramatically in response to a 15 percent increase in ex-vessel price, which was itself the result of a decrease in mid-Atlantic harvests. However, this boom did not last for long. In 1959, the protozoan pathogen *Haplosporidium nelsoni* (MSX) invaded the Chesapeake Bay and, soon after, *Perkinsus marinus* (Dermo) — both have been responsible for catastrophically killing most of the oysters in high-salinity regions of the Bay. In Virginia, leaseholders, or private growers, hold a majority of their leased bottoms in the high salinity areas affected by MSX and Dermo — public grounds are in the lower-salinity waters. Unlike Maryland watermen, who have depended for their harvests primarily on publicly open grounds, Virginia's private industry has been virtually decimated.

In spite of the MSX invasion in the Bay, oyster production in Maryland in the 1960s increased for a short period. A major reason for that increase was the discovery of pre-historic fossil shell sources and the development of a dredge to extract the shell for use as a substrate to "catch" natural oyster seed. Subsequent employment of these resources by the State of Maryland was commonly referred to as the "repletion program."[2]

Prior to the repletion program, state legislation had required processors to make 10 percent of their shucked shell available for purchase by the state in order to ensure the availability of substrate for future oyster production. The legislation also provided funds for state shell-planting activities. The discovery of additional shell sources provided a cheap alternative to freshly shucked shell and yielded significant production increases. Maryland's oyster production doubled from around 1.5 million bushels to some 3 million annually. The increase in importance of the repletion program relative to natural oyster set helped transform the oyster fishery from traditional natural resource gathering into a "put-and-take" state fishery.[3] Watermen were temporarily relieved of the constraints of nature alone and no longer solely dependent on the "recycling" of processed oyster shell.

The use of relatively inexpensive dredged shell also changed the philosophy of oyster management in Maryland from maintenance of a collapsing industry to revitalization, through repletion, of a potentially valuable one. The state switched from its regulatory role of oyster manager to a champion of production growth. Although production began to wane in the late 1960s and has continued to do so, until about 1981 Maryland oyster production remained over 2 million bushels. During this time there was concern that the market could not absorb, at an acceptable price, more than about 2.5 million bushels. In this new scenario, the market, not nature, became the constraining element.

Since the 1980s oyster production has been suffering from the reappearance of MSX and, especially, Dermo. Maryland's harvest has declined from over 2.5 million bushels during the 1980-

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[2] The nature of oyster reproduction is such that young larvae require a hard substrate on which to attach; oyster shell provides such a material. However, if the harvested shell is not replaced in the Bay by a suitable substrate, there is a strong likelihood that the future availability of oysters will be reduced.

[3] Lipton, D.W., E.F. Lavan, and I.E. Strand. 1992. Economics of Molluscan Introductions and Transfers: The Chesapeake Bay Dilemma. Journal of Shellfish Research 11(2):511-519.

1982 season to under 250 thousand bushels in the early 1990s. As a result of the decline in supply, ex-vessel prices have risen.[4] In spite of the increased ex-vessel prices, the effect of the loss of production on the income of the Chesapeake watermen has been significant. Unlike past battles with MSX and Dermo disease, this most recent outbreak has not been relieved by the repletion program. Lipton, Laval and Strand explain that the sporadic nature of the protozoan infections have made it difficult to develop a comprehensive strategy for oyster repletion.

Proposal to Revitalize Oyster Production

In contrast to the steep decline of oyster landings in Chesapeake Bay, oyster production on the west coast of the United States grew between 1982 and 1988 by 600 thousand pounds. The source of this production increase is hatchery production of the introduced species *Crassostrea gigas* (originally from Japan). Because of evidence that C. *gigas* is more resistant to MSX and Dermo, there has been strong interest in introducing this species into the Chesapeake Bay to test its hardiness. Virginia growers, in particular, are interested in introducing such a non-native species of oyster into their waters in an effort to revive their leased grounds and their processing industry. Maryland watermen, who harvest public grounds, have generally opposed introductions even though public grounds are not nearly as productive as they once were. In the meantime, harvesters in both Maryland and Virginia have turned to alternative resources — in Maryland, to softshell clams; in Virginia, to hardshell clams; in both states, to more intensive fishing effort for blue crabs, beginning earlier in the season and lasting later. Other watermen have left commercial fishing entirely.

The decision on whether or not to introduce C. *gigas* or some other non-native oyster into the Chesapeake Bay is not as straightforward as it may appear. Several factors must be considered including the costs and benefits of such an action. The net benefits to the different groups affected by the introduction must be estimated. These benefits may be economic or ecological in nature. Other significant considerations in the decision process are the uncertainties involved.

Benefits of an Introduction

Among the expected benefits from the introduction of C. *gigas*. are those to commercial harvesters and consumers. From the Virginia industry's perspective, the argument in favor of introducing a non-native species is based on the expected economic benefits, for instance, increases in income levels and employment, as well as in increases in producer surplus or economic rent.

The measurement of producer surplus is assessed as the revenue net of costs. In this case, culturing, processing, and harvesting costs are taken into account as well as the opportunity cost of a

[4] Harvest prices are strongly influenced by the supply of the oyster yields. When both Maryland and Virginia harvests were low prior to 1960, real prices, the actual prices adjusted for the general level of inflation, were high. The tremendous increase in Maryland's production in 1966 caused real prices to drop by as much as 40%.

producer's labor — what he or she could earn in the next best employment opportunity.

As Lipton, Lavan and Strand point out, if the introduction of C. *gigas* is for the purpose of restoring a public fishery, the net benefit to producers will also depend on how the resource is managed. If an open access management regime is maintained, then net benefits to producers will be less than if a bottom leasing program or limited entry program on public grounds is instituted. Simply replacing one species with another does not necessarily eliminate the human-induced factors that caused the decline of the native species.

Consumers of oysters may also benefit from the introduction of C. *gigas* or some other non-native molluscan into the Chesapeake Bay implying further increases in social welfare. Increases in consumer surplus may occur with expected increases in the quantity of oysters available and decreases in price. Consumer welfare measures are assessed based on the demand for the introduced oyster. It is questionable, however, to what extent consumers are aware of or care about the oyster species they consume. It is entirely possible that the introduction of C. *gigas* into the Chesapeake will have negative net benefits: one reason is the negative publicity surrounding the health and safety aspects of eating molluscan shellfish. Consumer demand for the product may be highly inelastic so that a slight increase in the available quantity will be accompanied by a large decline in price.

In addition to market-oriented benefits from oyster introduction, there are potentially significant ecological functions and services that oysters may enhance, ultimately leading to long-term benefits to society. Historically, the oyster was the dominant benthic organism in the Chesapeake Bay: according to many ecologists, as reef-forming organisms, oysters played a major role in ecosystem dynamics.[5] Restoration of the oyster is seen therefore as highly desirable from an environmental perspective. The oyster's filter feeding functions could serve to filter the Bay's large amounts of algae, which could perhaps help reverse eutrophication of the Chesapeake ecosystem. Related improvements in water quality might ultimately provide ecosystem benefits in terms of improved fisheries, aesthetics and recreation and could lead to avoided costs of sewage treatment or depuration facilities.

Costs of a Species Introduction

The costs of introducing C. *gigas* or any other non-native mollusc into the Chesapeake Bay include direct costs such as the actual costs of performing the introduction, monitoring, and maintenance. In addition, there are costs associated with the introduction in the form of research dollars. That is, before an introduction is implemented, research must be conducted to determine the impact and probability of success of such an action.

Another critical cost is the risk of environmental injury resulting from species introductions. The history of molluscan introductions demonstrates that they can ferry in unintended or nuisance species that could potentially outcompete or displace a desirable native species. There are numer-

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[5] Newell, R.I.E. 1988. Ecological changes in Chesapeake Bay: Are they the result of overharvesting the American Oyster, *Crassostrea virginica*? In Understanding the Estuary: Advances in Chesapeake Bay Research Consortium. Newell estimated that prior to major harvesting (pre-1870) of oyster beds, oysters filtered the entire water column in 3.3 days, while in 1988, the turnover time would have been 325 days. He further estimated that the pre-1870 populations may have been capable of removing 23-41 percent of the 1982 phytoplankton carbon production, but by 1988, they could remove only 0.4 percent.

ous examples in terrestrial and aquatic environments.[6] In addition, the introduction of a non-native species such as C. *gigas* could have unforeseen, detrimental ecological impacts.

The magnitude of the risks involved in introducing a non-native species into the Chesapeake Bay is as yet undetermined. However, it is clear that an introduction poses fewer risks for Virginia's oyster fishing industry than for Maryland's. Unlike Maryland's oyster fishery, which though much diminished is still viable, Virginia's oyster industry is failing. Thus, Virginia's industry does not risk the devastation of native species with the unintended, negative ecological consequences of an introduction. An introduction in Maryland's waters, on the other hand, puts the native *Crassostrea virginica* potentially at risk.

Dealing with Risk and Uncertainty

Compounding the debate over C. *gigas* introduction into the Chesapeake Bay is the natural ecological connection between the industries of the two states. It is likely that introductions in Virginia waters will eventually affect Maryland waters. The decimated state of Virginia's fishing industry compels its oyster producers and managers to pursue the introduction or transfer of a molluscan species in an effort to save the industry. The less urgent circumstances surrounding Maryland's industry impels its producers and managers to act more cautiously. These contrasting agendas inhibit consensus among the two states as to the appropriate course of action. The use of economics in the decision process could enhance the possibility of a resolution; towards this end, the uncertainties of an introduction can be considered within the benefit-cost framework.

Two principle methods of doing a benefit-cost analysis are through *expected net benefits* and *game-theoretic* approaches. In the expected net benefits approach, the distributions about the costs and benefits are used and the value of net benefits are calculated. Conceptually, the procedure is straightforward. However, the distributions about net benefits are not easy to ascertain, particularly when considering future events. As a result, a higher discount rate is often used with more risky selections.[7]

Game theory[8] can also be applied to the uncertainty involved in the decision on whether or not to allow an introduction. The game theory method is based on the two choices presented — to allow or not to allow an introduction. The approach offers the option of taking either a conservative or a more risky position with regard to possible damages from unintended negative consequences or environmental costs. The conservative position utilizes the minimax principle in which the strategy that minimizes the maximum possible losses is chosen.[9] The more risky position

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[6] Rosenfield, A. and R. Mann. 1992. *Dispersal of Living Organisms into Aquatic Ecosystems.* Maryland Sea Grant College, College Park, Maryland.

[7] Lipton, D.W., E.F. Lavan, and I.E. Strand. 1992. Economics of Molluscan Introductions and Transfers: The Chesapeake Bay Dilemma. Journal of Shellfish Research 11(2):517.

[8] Bishop, R.C. 1978. Endangered Species and Uncertainity: The Economics of a Safe Minimum Standard. American Journal of Economics 60(10):10-19.

[9] Ciriacy-Wantrup, S.V. 1968. Resource Conservation: Economics and Policies. Berkeley and Los Angeles: University of California Division Agricultural Sciences.

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makes use of probability distributions of net benefits and compares the expected value of the introduction and no-introduction scenarios, choosing the action with the greater expected value. Clearly for each strategy, measures of the consequences of introductions and damages must be made. This procedure must determine how the stream of net benefits should be discounted over time and the characteristics of the uncertainty of these measurements.

Exercise

The debate over the introduction of *C. gigas* or some other non-native oyster into Chesapeake Bay waters is highly political and full of uncertainties. Watermen are unwilling to abandon an industry that has been a fundamental element of the region's economy and culture for over a century. Virginia watermen, in particular, see molluscan introductions as a means to revitalize the failing industry. However, the uncertainty of the effects of an introduction clouds the issue. Another complication is the fact that the decision will have effects that cross jurisdictional boundaries.

The decision whether or not to allow an introduction is not isolated to the specific, individual oyster beds within the two states of Maryland and Virginia. The Chesapeake Bay ecosystem is not confined, of course, by political boundaries. Any decision that is made must take a multi-jurisdictional approach that transcends artificial divisions.

Suppose that you are a member of a Chesapeake Bay economic development council. You are tasked with developing recommendations on a Bay wide oyster development plan. Consider the role of environmental valuation in your analysis. Using the following questions as a guide, outline the study you would request of a local economist.

1. What values associated with oyster resources and services should be analyzed?

2. What techniques would you recommend in order to determine the values of these resources and services?

3. What are the limitations to the existing methodologies in this case?

4. What additional information do you need in order to determine the expected net economic benefits of a *C. gigas* introduction plan?

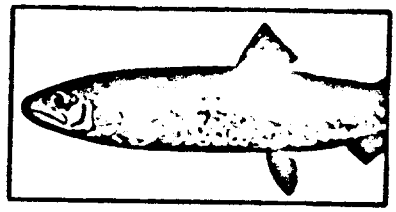
5. What discount rate would you recommend in a benefit-cost analysis of a *C. gigas* introduction plan?

6. Suppose that new technological developments offer alternative methods of oyster enhancement (e.g., bio-technological or bio-engineering of a native species immune to MSX or Dermo). What role can environmental valuation play in assessing these alternatives?

SALMON HABITAT RESTORATION IN ALASKA

Background

Alaska's salmon fisheries account for sizeable contributions to the state's economy. In 1990, commerical harvests, which were 94 percent of the 733.1 million pounds landed in the United States, were valued at $546.7 million. This amount does not account for the added value of its recreational and subsistence fishing. The health of the salmon fishery, then, is vitally important to economic health. The salmon fishery is influenced by many factors, environmental and human — from highly variable ocean conditions to the timing of harvesting, the levels of that harvesting, the impact of land-use practices on freshwater and estuarine habitats, which can be critical for spawning.



Situation

Harvesting of Alaskan forests can impact salmon habitats and lead directly to reduced spawning of smolts. A hypothethical example is presented in which a proposed regulation calls for a riparian buffer zone along critical stream habitat.

Pacific anadromous salmonids include five species of salmon that are comprised of a large number of stocks originating from specific watersheds. Salmon juveniles or smolts spawned in streams migrate to the ocean and then generally return to their natal streams to spawn. Because forestry practices can directly influence the quality and quantity of freshwater habitat, primarily through harvesting of timber and associated road building activities, their management is particulalry important for the health of salmon returning to their home streams.

Even with salmon health generally high, with record harvest levels, and with a large proportion of the land base relatively undisturbed, specific stocks could still be in decline if forest practices remove too much of the riparian vegetation or degrade channels. Under certain conditions, a given run of salmon could be considered for listing as endangered under the Endangered Species Act, which includes provisions for listing "distinct population segments."

Hypothetical Alaskan Watershed

The following example provides a set of assumptions about the economics of logging and salmon harvests — the exercise then poses a number of questions that consider issues of value. To begin with, suppose that harvesting within the Tough Choices watershed would generate 6,700 million board feet of timber with a pond log value of $401 per million board feet — pond log value reflects not just the price of the standing timber but also the costs incurred in bringing the timber to the mill, for instance, logging, road construction, and transport. Assume that by building the access roads across the watershed and by removing the trees, this timber sale will fragment the riparian habitat into patches and cause a reduction in the full capacity of the spawning ground for the coho stock that inhabits the creek. This stock of salmon would show an expected decline relative to the amount of habitat lost.

The impact of tree clearance would also affect the food web, for example, local bear and eagle populations that depend on salmon stocks could be adversely affected. Such impacts could have ripple effects, for instance, declines in recreational viewing which might be impacted because of tree harvesting and road-building. We will suppose that the only functions attributed to these trees is either commercial harvest or as an input into stream integrity and fish production, or negative effects. The value of the salmon consists of its commercial and recreational value (in current and future fisheries), as well as its subsistence and cultural value to the residents of the State of Alaska.

As part of this hypothetical example, we assume that biologists have developed an expected relationships between land clearance and the capacity of the spawning ground associated with the stream. If all the commercial timber proposed is harvested, then the spawning capacity will be reduced by 90 percent of its original capacity. If only 20 percent of the trees are harvested, a 10 percent reduction in fish capacity is expected. For every 10 percent increase in timber harvest from that level on, there will be a corresponding drop of 10 percent in fish spawning capacity. In addition, consider the following information:

Spawning capacity: 9000
Smolts per spawner: 106
Ocean survival to maturity: 43%
Commercial harvest rate: 47%
Freshwater recreational harvest: 16%
remainder available to spawn for future cycles

Ex-vessel Price: $1.42/lb
Average weight of salmon harvested: 12 lbs
Anglers' WTP: $15.92 per additional fish caught

Exercise

Given the background and information provided above and keeping in mind the various perspectives regarding "value," analyze a proposed regulation calling for a 300-foot riparian buffer zone along critical salmon streams.

Questions to consider include:

1. Are there any additional value associated with the timber and salmon resources not mentioned?

2. What measurement techniques would you employ to determine relevant values?

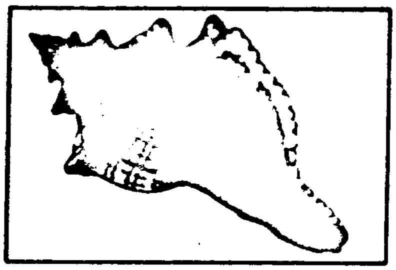
3. What additional data (aside from that provided) might you need to carry out empirical analysis?

4. What discount rate would be appropriate in the determination of net present value?

5. Society involves many individuals, and projects such as this often affect the welfare of individuals differently. The implicit assumption in constructing the estimates of costs and benefits in this example is that the welfare of all individuals is weighted equally. What if you were to eliminate this assumption and address the issues of equity and fairness? How might your decision change if you take future generations explicitly into consideration? How might you go about doing this?

6. Consider the issue of irreversibility. How might the potential for species extinction change your decision process and recommendation? How might you integrate the potential risk of irreversible outcomes into your analysis?

Florida Keys National Marine Sanctuary



Situation

With the Florida Keys ecosystem threatened by point and non-point source pollution, alternative management strategies outlined in the Florida Keys National Marine Sanctuary Plan have focused on the cost-effectiveness of different issues or activities for achieving sustainable use of the Florida Keys National Marine Sanctuary: boating, fishing, recreation, land use, water quality, zoning, and education. This case study focuses on different strategies of zoning.

Background

The marine ecosystem of the Florida Keys is the only complete tropical marine ecosystem in the continental United States. It includes extensive aquatic habitats such as coral reefs and seagrass beds. Ninety percent of the region's commercially important species use these habitats for shelter, food, or nurseries during at least one stage of their life history. Several species of threatened and endangered sea turtles are found in the Keys, including hawksbill, loggerhead, leatherback, green, and Kemp's ridley. In addition, dolphins and endangered manatees frequent the area, as well as countless species of sea and shore birds. Another aspect of the area's marine environment is the submerged cultural and historic resources, for example, submerged Paleo-Indian sites, nationally registered lighthouses, and wrecked ships going back several hundred years.

The Keys ecosystem is threatened by impacts from a number of different sources, indirect and direct. Indirect impacts contributing to the decline of the reefs and seagrass beds include polluted runoff from over-developed islands; heavy metals and other toxins which contaminate the reefs; excess nutrients from human sewage, fertilizers, detergents, and animal wastes which create algal blooms; pesticides; offshore oil and mineral mining; and saltwater/freshwater imbalances. Direct impacts include vessel groundings, diver damage to coral, and boating traffic (anchor and prop dredging) which destroys seagrass beds, and destructive fishing methods.

To protect the Keys marine ecosystem, Congress enacted the Florida Keys National Marine Sanctuary and Protection Act of 1990.[1] The legislation to provide comprehensive protection to the Keys' marine environment was prompted by recognition in the late 1980s of human impacts that threatened sanctuary resources. The sanctuary area extends approximately 220 miles southwest from the southern tip of the Florida peninsula and encompasses a 2,600-square nautical mile area of submerged lands and water surrounding Monroe County, Florida.

Protected areas and marine sanctuaries are not new to the Florida Keys area. The Key Largo and Looe Key Marine Sanctuaries were established in 1975 and 1981, respectively, and according to the Act, they will be incorporated into the new Florida Keys Sanctuary when the management plan is adopted. Numerous State and Federal parks and reserves are also located within the boundaries of the Sanctuary.

The existing regulations of current jurisdictional responsibilities allow sport and commercial fishing with hook and line; taking of spiny lobsters and stone crabs in accordance with the fishery management plan; and swimming, snorkeling, scuba diving, photography, and recreational boating. Regulations prohibit removing or damaging natural features, non-permitted marine life, or archaeological and historical resources; dredging, filling, excavating, and building; anchoring in a manner that damages coral; discharging harmful substances into the water; spear fishing or using wire fish traps; and handling or standing on coral formations. Specific regulations already in place as a result of the Florida National Marine Sanctuary Protection Act prohibit all oil drilling and exploration within the Sanctuary and the operation of tank ships or other vessels greater than 50 meters in Areas To Be Avoided, which were designated in response to the region's many historical groundings.

In addition to creating one of the largest national marine sanctuaries, the Act also requires the National Oceanic and Atmospheric Administration (NOAA), which administers the National Marine Sanctuaries program, to prepare an environmental impact statement and a comprehensive management plan for the Sanctuary with implementing regulations to govern the overall management of the Sanctuary and to protect Sanctuary resources and qualities.

The Local Economy

The Florida Keys economy is dependent on a healthy ecosystem. In 1991, Florida Keys' and Monroe County's gross earnings were $853 million. The activities that contributed most to those earnings were recreation and tourism, commercial fishing, and retirement communities. These activities combined make up more than 80 percent of the local economy. Over three million tourists visit the Keys annually, participating principally in water related sports such as fishing, diving, boating, and other ecotourism activities. In fact, 61 percent of the recreation and tourist activities are water-related — the Keys have been hailed as the most important dive destination in the world. In addition, multi-million dollar fisheries for spiny lobster, stone crab, grouper, and snapper have supported local and regional economies for generations. Commercial fishing is the fourth-

[1] The information presented in this case study was obtained from existing sources, primarily from NOAA's Florida Keys National Marine Sanctuary, Draft Management Plan/Environmental Impact Statement. While the Draft Management Plan/EIS examines several issues, this case study gives particular emphasis specifically to zoning issues and de-emphasizes other issues that were addressed in the Draft Management Plan/EIS.

largest industry in the Florida Keys region and represents 9 percent of Monroe County's private-sector employment. Case Table 3.1 provides more information about the value of specific services provided by the ecosystem and economic impacts.

Case Table 3.1. Overview of Economic Situation.

Economic Value of Florida Keys		Economic Impacts	
Service	**Value**	**Activity**	**Impact**
Annual non-market user value of water-related activities	$660 million	Gross earning provided by tourism industry	35% ($309 million)
Asset vlue of the Keys for water related activities (1990 dollars)	$22 billion	Gross earnings provided by retail trade	18.7% ($160 million)
1990 ex-vessel value of commercial fishing in sanctuary	$46 million	Population with jobs that either directly or indirectly support outdoor recreation	51%
1986 ex-vessel value of Monroe County's seafood landings	$27.4 million	Monies provided by commercial fishing	$17 million
Value of seafood landings at the harvesting, wholesale, retail and restaurant levels	$14.8 million		

NOAA's Proposed Alternative Management Plans

In fulfillment of the mandate to prepare an environmental impact statement and a comprehensive management plan for the Sanctuary, NOAA developed and assessed five alternative management plans. These plans represent different levels of regulatory control over Sanctuary resources and restriction of uses, with Alternative I being the most restrictive (total restriction of uses, except for research) and Alternative V the least restrictive (no action). The purpose of NOAA's proposed Alternative Management Plans is to ensure the sustainable use of the Key's marine environment by achieving a balance between comprehensive resource protection and multiple, compatible uses of those resources.

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Each of the five alternative plans are comprised of a series of management strategies that focus on the pertinent issues or activities considered to have potential resource impacts, positive or negative. These issues or activities include:

1. Boating
2. Commercial and Recreational Fishing
3. Recreation
4. Land Use
5. Water Quality
6. Zoning
7. Education

For each issue, the potential impact themes of habitats, species, use and users, and water quality were examined.

Economic Impact Assessment

The purpose of the of the Florida Keys National Marine Sanctuary and Protection Act is to provide for multiple uses of the Sanctuary as well as to ensure that its natural resources are protected for the future.[2] However, due to the implementation of management strategies, such as zoning, the Act may also result in the displacement of some Sanctuary users and consumers. Because the numerous users, consumers, and administrators of the Sanctuary have diverse and sometimes contradictory interests, a thorough examination and comparison of the Management Plans under consideration is essential. NEPA requires the assessment of environmental impacts in an Environmental Impact Statement. An analysis of the economic impacts, costs, and benefits of the proposed plans is an important part of this assessment, especially in light of the Keys' economic dependence on revenue generated from marine-related activities, and the value of the services provided by the ecosystem.

An economic impact assessment was conducted as part of the Draft Management Plan/Environmental Impact Statement. However, a net economic benefit analysis, examining the socio-economic implications of proposed actions by comparing economic costs and benefits, was not conducted. The economic impact assessment summarizes the potential impacts of proposed management strategies on various user groups and the local economy, for example, sales, employment, income. The socioeconomic impacts associated with the management strategies were assessed by issue, as outlined above and discussed in qualitative terms. The key strategies within each issue were assessed in terms of impact on user groups and expected socioeconomic costs and benefits.

Cost information for the analysis was based on negative impacts such as expected losses in user values, income, or employment. The cost information used in this assessment was provided by federal, state, and local officials with responsibilities in the Keys. Low- and high-range estimates were given for both capital and annual operating costs and costs for each proposed manage-

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[2] The Coral Reef Coalition. Inside the New Florida Keys National Marine Sanctuary.

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ment strategy. Information on the effects of proposed actions on human activities was also derived as part of the process to develop a Sanctuary resource protection zoning scheme.

Resource Protection Zones — Zoning Categories

This section describes the findings of the assessment of social and economic implications for zoning strategies proposed in the Alternative Management Plans. Zoning, as noted in the previous section, is one of the issues that has potential resource impacts.

The development of a management plan, then, provides the opportunity to establish different regulations for separate areas within the Sanctuary. Thus, one of NOAA's tasks under the Act is to consider temporal and geographic zoning to ensure protection of Sanctuary resources.

Zoning schemes were developed to ensure the protection of Sanctuary resources. The intent was to reduce both damage to those resources and threats to environmental quality, while allowing uses that are compatible with resource protection. The zones are intended to protect habitats and species by limiting consumptive and/or conflicting user activities, thus enabling resources to evolve in a natural state with minimal human influence.[3] Zoning will permit customary activities to continue in some areas, while other areas will be designated for preservation, research, or restoration. The resource protection zoning scheme proposes five types of resource protection zones (these are then described briefly):

1. Wildlife Management Zones
2. Sanctuary Preservation Areas (SPAS)
3. Existing Management Zones
4. Special-Use Zones
5. Replenishment Reserves

WILDLIFE MANAGEMENT ZONES. This strategy would affect user groups participating in wildlife observation or seeking access to these areas. Users participating in wildlife observation would see a small socio-economic benefit due to greater assurances of continued wildlife and habitat protection. However, most of these zones are already within national wildlife refuges and are under restrictions established by the U.S. Fish and Wildlife Service. As a result, the strategy is likely to have minimal socio-economic impacts on Sanctuary users.

REPLENISHMENT RESERVES. These reserves will encompass large diverse habitats and are intended to provide genetic protection for marine life. The goal is to increase the productivity in adjacent marine areas and enhance biodiversity. Sanctuary regulations will strictly limit resource use and consumption in these habitats. Some users, such as commercial lobster fishers, sport fishers, and tropical fish collectors will be displaced. However, compatible recreational activities will be permitted. Although these zones would prohibit commercial and recreational fishing, they are expected to have an overall benefit by protecting spawning and recruitment stocks from overfish-

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[3] National Oceanic and Atmospheric Administration. (December 1994). Florida Keys National Marine Sanctuary, Draft Management Plan/Environmental Impact Statement. V2, pp. 194.

ing, promoting genetic diversity within the fishery, producing "spill-over" benefits to other non-protected areas through the migration of organisms across boundaries, and providing important baseline data for use in managing fisheries in other areas. The zones become slightly larger and/or more numerous moving from Alternative IV to Alternative II.

SANCTUARY PRESERVATION AREAS (SPAS). These zones will focus on the protection of shallow, heavily used reefs where user conflicts occur and where concentrated visitor activity leads to resource degradation. As with Replenishment Reserves, the groups that will benefit are those that value an abundance and diversity of marine wildlife, including commercial and recreational fishers and participants in water-related recreation activities. However, tropical fish collectors, lobster fishermen, recreational fishers and spear fishers displaced from these areas will be negatively impacted.

EXISTING MANAGEMENT AREAS. Because these areas are already established by federal, state, or local authorities with competent jurisdiction in the Sanctuary, this strategy will have minimal socio-economic impact.

SPECIAL-USE ZONES. This strategy will have negligible socio-economic impacts on users because only a small number of areas will be established. Academic and scientific communities will be the primary beneficiaries of this zone type.

The socio-economic information generated by this analysis was used along with the environmental impact assessment data in the selection of a Preferred Management Alternative.[4]

Exercise

While an economic impact assessment does provide some useful information in the evaluation of management alternatives, it does not provide more comprehensive information about the overall result of a given project or policy change. All of the proposed management strategies assessed in the NOAA plan affect some aspect of Sanctuary resources, either directly or indirectly.

Sanctuary resources (both natural and historic) can be considered assets that produce a flow of goods and services with both market and non-market values to users and non-users. The concept of non-market value is significant to the Keys and its economy. The area's natural resources are considered public resources, not common property or privately owned. Tradeoffs between the effects of strategy implementation on economic values and economic impact are also pertinent to the Keys. Restrictions may increase the costs of consumptive use; however, protecting a resource may not only increase its quality and value but also have a long-term economic benefit to both consumptive and non-consumptive users.

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[4] Alternative III was chosen as the Preferred Management Plan. Volume I of the Florida Keys National Marine Sanctuary, Draft Management Plan/Environmental Impact Statement provides a description of the strategies recommended in the Management Plan. According to the selection committee, the positive environmental impacts and associated beneficial economic impacts of the Preferred Alternative (Alternative III) outweigh any potential negative impacts. Of the five alternatives, the one selected most closely meets the resource protection goals, while facilitating current Sanctuary users and user activities.

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Some of the proposed Sanctuary Preservation Areas will displace current commercial and recreational fishers as well as tropical fish collection to non-zoned areas. This displacement may result in increased costs to fishers and consumers as well as decreased sales, employment, income, and tax revenues for the local economy dependent on this activity. However, the protection provided to these areas may have economic value to non-consumptive users. Furthermore, if resource degradation can be halted or reversed, there may be long-term benefits for consumptive users. While the existing economic assessment attempted to take these types of tradeoffs into account for each management strategy, it would be more informative to carefully consider how such an analysis is in fact operationalized. Such a consideration is one to examine in this exercise.

Reread this case study noting the economic values and costs that could be compared in a benefit-cost analysis.

1. What techniques would you recommend be used to measure the value of services identified above?

2. What types of resource values are missing?

3. What data would you need to conduct these studies?

4. Give particular attention to the effects on displaced fishers versus fishers who are not displaced, as well as to the various other tradeoffs that are made.

5. How does this information differ from the impact assessment on Resource Protection Zones provided by NOAA?

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Coastal Barrier Island Preservation in North Carolina

Situation

A barrier island with a small year-round population and a large number of seasonal home owners has the potential of greater development. The island is also home to a unique forest community as well as other rare fauna. State plans to purchase large tracts of the island for preservation must consider the economic impact of shutting down further development that such preservation would entail and the alternative of purchasing a similar tract for preservation on another island.

Background

Old Baldy Island is a coastal barrier island in North Carolina.[1] It is situated at the mouth of the Cape Buffalo River, approximately three miles off the coast of Northport and about 30 miles south of Wilmatown, the fourth largest city in the state. Old Baldy Island is the largest and southernmost of a series of small islands connected by extensive salt marshes that form an area known as Smith Island. It comprises approximately 13,000 acres including upland, tidal marshes and creeks, shallow bays, and marshland. The island is 3-1/2 miles long and 1-1/2 miles wide and features a moderate climate often referred to as subtropical. The Old Baldy Island Lighthouse, built in 1817, serves as the Island's landmark — it is North Carolina's oldest lighthouse.

Located on the island is the Old Baldy Planned Unit Development, primarily a second home development; it is somewhat of an island retreat in that its access is limited to a privately operated ferry system which provides access to the mainland. While there are a limited number of year-round residents (approximately 60 at present), some 1,200 families have homes there. The neighborhood is less than 50 percent developed.

THE MARITIME FOREST. Old Baldy Island is home to a maritime evergreen forest. It is a globally imperiled forest community located on old stabilized dunes and flats protected from saltwater flooding and the most

[1] While this case study is based on a real situation, place names and some facts have been modified for the purposes of the example.

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extreme salt spray. Encompassing approximately 355 acres, it is the largest in the state and still has undeveloped, natural transition zones from ocean to sound. The topography is that of a dune ridge and swale system: the ridges are broad and they slope gently into even broader swales, which can be wet or dry, depending on local drainage patterns. The natural communities associated with the Phase I site include salt marsh, interdunal ponds, pine lowlands, palmetto lowlands, and non-forested freshwater wetlands.

While the State has been working closely with local officials to minimize impacts from development on the maritime forest, even low-intensity development on Old Baldy Island will tend to fragment the high-quality maritime forest communities. The proposed actions would preclude even lower density development.

A special Maritime Forest Advisory Committee, set up by the North Carolina Coastal Resources Commission in 1990, recommended that the few remaining high quality tracts of maritime forest be acquired and managed for conservation purposes. The committee ranked the undeveloped maritime forest on Old Baldy Island among the top two or three maritime forests in North Carolina in terms of natural area values such as ecological integrity, uniqueness, diversity, rare species, size, and historical significance. Nags Head Woods and Buxton Woods are the two other areas of significant natural value and these two areas have already been acquired for conservation purposes.

VEGETATION. The Island is home to several species of plants that are unique. One of these is a plant commonly known as the Old Baldy Blue Curl, a small indigenous plant in the mint family. A significant feature of the forest is the many extremely old trees; they include palmettos, pines, cedars, oaks, and dogwoods. The undergrowth throughout the forest is quite dense with many vine species. The most common of the understory shrub layer are Red Bay, Wild Olive, *Prunus caroliniana*, and French Mulberry. The Island also harbors two moss species, Beach Moss and Cuban scheliessmund that are recognized as "critically imperiled species." Other plants that fall within the "critically imperiled species" designation are the Tough Bumelia and the Piedmont Flatsedge. Finally, the dunes and cape at Old Baldy are host to a newly identified species, Dune Blue Curl, which is a candidate for state and federal protection.

WILDLIFE. Old Baldy Island is North Carolina's most popular nesting area for the endangered loggerhead sea turtle, which lays its eggs along the island's 14-mile oceanfront. The Old Baldy Conservancy has a successful sea turtle conservation program which claims a 95 percent hatch rate. Other fauna of the island complex include alligators, raccoons, large numbers of tern and gulls, over-wintering brown pelicans, and migrating peregrine falcons. The freshwater ponds and marshes are used heavily by water birds, as are the extensive marshes, tidal creeks, bays, and mudflats. Nearby Battery Island is North Carolina's largest breeding rookery for egrets, herons, and ibises.

Proposal for Preservation

To preserve maritime forest, the state of North Carolina is considering purchasing land currently scheduled for development. In Phase I of the proposed preservation plan, the State will acquire approximately 125 acres of the remaining core maritime forest. In Phase II, the State will work to acquire as much of the remaining undeveloped maritime forest and associated wetlands as possible. It is anticipated that Phase II will include the purchase of additional areas along the undeveloped estuarine shoreline. North Carolina is also considering acquisition of an ocean front section that would protect a portion of the island from ocean to sound.

The Old Baldy Phase I Purchase Tract is an irregular shaped area of 96.80 acres. The Purchase Tract can be generally characterized as a gently rolling and heavily wooded maritime forest. The plan would include a Maritime Forest Protection Overlay District, protective salt spray shear zone vegetation, forest wetlands, and relic dunes and dune ridges. In addition, there would be a prohibition against the removal of trees and shrubbery (except as necessary), the filling of wetlands and ponds, and on-street parking. In addition, all construction would need to be contained to prevent runoff. To protect against the potential of introducing harmful exotic plants, only permissible plants would be allowed. The maximum lot coverage for structures, including all impervious surfaces, would not be allowed to exceed: (1) 25 percent of a building lot less than 9,000 square feet; (2) 50 percent of a lot less than 9,000 square feet in residential lots; (3) 60 percent of a commercial service or multi-family lot.

Economic Considerations

Implementing the proposed Old Baldy Island Phase I purchase would reduce the community's ad valorem tax base by approximately $10 million, the purchase price of the land. Based on the current rate of development and the type of development that has occurred, approximately 50 housing units with property values of approximately $7.5 million would be added per year, if there are no restrictions. Because of the seasonal nature of most of these residences, each of the additional residential units, if developed, would be anticipated to result in $250 per month in direct expenditures in the local community during the winter season (October-February) and $1,000 per month during the summer season. It has been estimated that the addition of more than 200 new residential units would result in the need for increased local public servants including one additional police officer, one fireman, and several municipal maintenance staff persons.

Exercise

The Old Baldy purchase is only one active maritime forest preservation option available to the State of North Carolina. Another is to purchase a similarly sized tract of maritime forest land on Little Barrier Island, also in North Carolina. The purchased land would become a nature preserve protected from development. The Old Baldy Little Barrier Islands are very similar — the main differences are smaller loggerhead sea turtle nesting areas and the absence of palmetto palm trees and beach moss on Little Barrier Island. Little Barrier Island also lacks the historical significance of Old Baldy Island, home of the Old Baldy Island Lighthouse and Captain Charlie's Station cottages built in 1903.

Little Barrier Island has extremely limited development, with no existing plans for additional construction activity. For this reason, purchasing the land is estimated to cost $2 million. Since the land on Old Baldy Island is scheduled for development, its purchase price is expected to be roughly $10 million, the appraised value of the land. Given this information consider the following questions:

1. Suppose your agency is trying to decide between purchasing the land described above on Old Baldy Island and the similarly sized tract of maritime forest land on Little Barrier Island in North Carolina. Which tract of land would you recommend trying to purchase?
   a. What additional information would you want?
   b. Does the schedule for development affect your decision?
   c. What operations other than purchase might be available (zoning, legislation, takings)?

2. Which economic approach in this handbook would you typically use in evaluating the Old Baldy Island maritime preservation proposal?

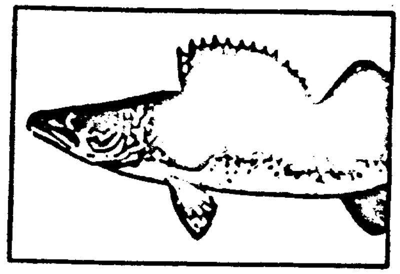
3. How would the various economic approaches be of use to others in the decision process?
   a. Developers
   b. Local agencies making decisions regarding supporting public investment decisions
   c. Interest groups
   d. Public at large
   e. Federal regulators/decision-makers

4. The residential development on Old Baldy is "upscale," but is protected by covenants and zoning restrictions. Transportation around the island is restricted to electric golf carts. Plants may not be introduced unless they are on a list of permissible shrubbery. Restrictions also exist limiting all impervious structures. You have responsibility for the enforcement of zoning laws related to the environment. Two homeowners have approached you with a proposal. One, for aesthetic reasons, prefers not to pave his driveway. The other wishes to purchase her neighbor's "right to pave" in order to build a tennis court on her property. Proponents of this proposal applaud the flexibility that allowing "tradable paving rights" affords. Property values could rise if residents are permitted to build tennis courts and other amenities on their land. They also note that less pavement would exist than if the two homeowners had paved driveways. Those opposed to the change argue that existing residents originally did not have a choice between paving a driveway, building a tennis court, and selling their rights. Further, they argue, the right to pave is an intrinsic part of the property and cannot be transferred. Finally, they fear that this is an attempt to abolish paving limitations altogether.
   a. Should residents be allowed to sell paving rights?
   b. How would you deal with the right of a future homeowner to pave his driveway if the previous owner has already sold the rights?
   c. Should your agency attempt to regulate the price for which paving rights will sell? If so, what will you consider in setting that price?
   d. What problems might arise from setting such a price?

Artificial Reef Program in Lake Erie, Ohio

Background

Artificial reefs are synthetically constructed underwater structures — they may be rock, sunken ships, auto bodies, rubber tires, and wood. Designed for structureless bottom areas in either fresh or salt water environments, they provide habitat for fish, habitat that includes food, shelter, protection, and spawning areas. Drawn by the new habitat, fish concentrate in these areas. Often artificial reefs are strategically placed at various depths and are built to particular heights to attract a specific species of fish.



Situation

Artificial reefs can be used for enhancing fisheries and economic activity by providing the structure for new fish habitats. Reefs placed in different locations in Lake Erie are demonstrating that improved fisheries habitats lead to increased recreational fishing.

Artificial reef construction may be a community effort, with technical assistance provided by state and federal agencies. Recreational fishing reefs are placed near access areas such as launch ramps and marinas and in locations where they will not interfere with navigation and commercial fishing activities.[1] Artificial reefs have been constructed all along the U.S. coast in salt water and in many inland lakes and reservoirs. Artificial reef programs have been implemented in many coastal states, e.g., Georgia, Florida, California, Texas, Alabama, Virginia, New Jersey, South Carolina, and Delaware.

Studies indicate that when artificial reefs are constructed with proper materials, placed in good locations, and developed with a specific purpose and plan, they can enhance sustainable fisheries. Research in South Carolina, for example, attributes increases in time spent fishing and catch rates to the presence of artificial reefs. In many areas, new aquatic communities created by the artificial reefs draw increased numbers of recreational and commercial fishers and scuba divers — one result is travel and tourism dollars brought in by visiting anglers and their families, thus leading to positive economic impacts to local communities.

[1] Kelch, D. O. and J.M. Reutter. 1991. Lake Erie's Artificial Reef Program. Ohio Sea Grant Program, OHSU-FS-021.

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Artificial Reef Program

Ohio's Lake Erie is the warmest, shallowest, and most productive of the Great Lakes; its western basin is known as the "walleye capital of the world" and produces more walleye per hectare than any other lake in the world. Historically, the western basin walleye fishery has made up the major component of Ohio's primarily recreational sport fishery.[2] As a result, Ohio's north coast has developed into a major recreational economy. The historical predominance of the walleye fishery within the western basin of Lake Erie is also the result of easy access to areas where the fish congregate.

Unlike the western basin, the central basin is deeper and larger — it also lacks the productive bottom structures that provide habitat for fish. These features, combined with the fact that schools of walleye are often located further from shore, make the walleye more difficult to locate in the central basin. Access for boat anglers is another difficulty: the rocky bluff and high bank terrain of the central basin impedes the construction of marinas and launch ramps, which are readily available to boat anglers in the western basin. As Kelch and Reutter point out, while there are many excellent fishing areas in the central basin, not all are within safe running distance for smaller boats. Fishery managers have recognized that construction of artificial reefs strategically located in areas easily accessible to boat anglers could attract greater numbers of anglers in the central basin. Furthermore, if the artificial reefs yield the expected results — attracting fish and thus increasing angler participation and catch rates — the fishery's role in helping develop a recreational economy in the Central Basin communities could be enhanced.

Ohio began an artificial reef project in 1986. While artificial reefs have been planned for the entire shoreline of Ohio, the central basin presently is the key area of development for reasons outlined above. The U.S. Army Corps of Engineers has granted permits for five sites. To date, two reef structures have been constructed — the Lorain County reef and the Cuyahoga County reef. The purpose of the reef project is to create a demonstration project to evaluate the productivity and feasibility of reef construction in other areas of Lake Erie and the other Great Lakes. Evaluation of the demonstration project's effects on recreational activity and the expected effects of similar reef structure in other coastal areas are priority needs for sustainable coastal development policy of the central basin.

The Lorain County reef consists of two reef structures, one about 370 meters long and the second about 183 meters long. The Cuyahoga County reef, also known as the Cleveland site, is made up of one reef structure 213 meters long in 8.5 meters of water and a series of unconnected sandstone "rubble piles" in deeper water. The reefs were constructed from scrap rock and concrete and are located within close proximity to ports of shelter, an advantage for smaller vessels.

The Ohio artificial reef project plans to construct additional reefs in Lake and Ashtabula Counties, but the construction is awaiting scientific evaluation of the completed structures. The only evidence available regarding the ecological and economic benefits of the artificial reefs has been anecdotal information from various anglers who report successful fishing within proximity to

[2] Lake Erie's total 1993 fish harvest yielded 12.9 million pounds of fish, only 4.3 million pounds of which were caught by commercial fish producers. The bulk of the harvest (8.6 million pounds) were caught by recreational sport and charter boat anglers.

the reefs and some underwater videos taken in 1989 and 1990. No formal scientific data demonstrating the success of the structures has been gathered. According to Dave Kelch, District Specialist with The Ohio State University's Sea Grant Program and the project's director, research is needed for both the scientific community's acceptance of the artificial reefs and for interested shoreline communities.

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Costs and Benefits of the Artificial Reef Program

COSTS. Ohio's Artificial Reef project has been financed by the local communities, fishing public, local government, local business and industry, and fishing tackle companies. Donations exceeded $100,000, the majority of which has been used to pay marine contractors for materials placement (more than 7,000 tons of material were used to build the reefs at the Lorain site and a total of about 6,800 tons were used to construct the reefs at the Cleveland site). Much of the project supervision, fund raising and donation procurement, and materials site inspection was conducted by volunteers from the North Central Sea Grant Advisory Committee. Overall project supervision and monitoring was the responsibility of the Sea Grant District Specialist, which resulted in no monetary outlay for these services.

According to Kelch and Reutter, only $10,000 of state and federal dollars were made available. Because of the donation of material, dollars, services, and labor, exact costs for the construction of artificial reefs are difficult to assess. Estimates are that the cost of placement varied from $6 to $14 a ton (based on 1984 to 1989 costs) depending on the contractor. Small, non-union contractors fees averaged $7.50 a ton, while unionized contractor fees were as much as $14.8.

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BENEFITS. One rationale for the Ohio Artificial Reef project is to improve the integrity of the central basin area. In the past, eastern Ohio waters have been plagued by heavy pollution. At one time the situation was so bad that the surface of the Cuyahoga River ignited. Since then, environmental enhancement measures have significantly improved water quality. Residents of the central Lake Erie region wanted assurance that the central basin could provide water-related recreational pleasures similar to those available in the western basin. The construction of artificial reefs has been perceived as an effective strategy to improve the area's character.

Additional gains to local small boat anglers are also expected: anglers should experience increases in recreational fishing value as a result of the new, productive, quality fishing sites within close proximity to sheltered ports. In addition, communities as a whole should benefit from some increases in tourist-related activities resulting from improved sportfishing opportunities.

Preliminary Analysis and Evaluation of the Artificial Reef Program

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While scientific analysis of the effects of artificial reefs on fish production has not been conducted, data on angler hours and catch rates indicate that walleye harvests have increased substantially over the last two decades (Case Table 5.1).

Two research efforts began in 1992 to evaluate the success of the artificial reefs. The aim of

Case Table 5.1. Walleye sport boat harvest in Ohio, 1975-1993.*

Year	Walleye (thousands)
1975	86
1976	638
1977	2,171
1978	1,596
1979	3,288
1980	2,165
1981	2,932
1982	3,013
1983	1,846
1984	4,038
1985	3,730
1986	4,400
1987	4,438
1988	4,890
1989	4,192
1990	2,283
1991	1,578
1992	2,082
1993	2,669

*Fish Ohio. Division of Wildlife. 1993. Ohio's Lake Erie — 1993 Sport and Commercial Harvests.

one was to determine the fish concentration ability of the reefs; towards this end, an underwater video assessment was conducted at the Lorain artificial reef site. This effort involved monthly dives at both the reef site and a non-reef control site to identify and enumerate fish as well as to determine habitat differences. Analysis reveals that the 1992 and 1993 total seasonal numbers of fish were significantly higher at the reef site than at the control site. Thus, the reefs appear to be effective as a fish concentration device.[3]

The second research effort to evaluate the effectiveness of the reefs sites was designed to identify changes in social and economic values resulting from the artificial reef project. In 1992, survey data were collected from a random sample of individuals at various launch sites and marinas regarding their recreational use and expenses on Lorain County waters. Initial analysis reveals that 87 percent of the 466 respondents (55 percent response rate) knew about the reef and 64 percent of these individuals used the reef during 1992.

The typical respondent made 20 trips to Lorain County waters during 1992 and 7.1 of those trips involved fishing out at the artificial reef for at least part of the trip. Of those respondents who traveled less than 40 miles to Lorain County, more than two-thirds used the artificial reef. Of those who traveled 40 or more miles to Lorain County, less than one-half used the artificial site. These figures indicate that the artificial reef use is dominated by local sport anglers, as intended.[4]

Exercise

This case study suggests that there are significant potential economic benefits beyond positive economic impacts from the construction of artificial reefs. Fishery managers of the Lake Erie region have expressed satisfaction with the artificial program thus far. It has been highly visible and generated much enthusiasm within the local sport-fishing community. Many believe that the reef has also helped improve the integrity of Lake Erie's central basin. Given the information pro-

[3] The Cleveland site is currently being investigated utilizing the video technique.

[4] Glenn, S.J., D.O.Kelch, and L.J. Hushak. 1994. Economic Evaluation of the Lorain County Artificial Reef in 1992: An Overview. Ohio Sea GrantProgram. Technical Summary OHSU-TS-022.

vided above, outline the economic analysis that you would recommend be included in an environmental impact statement of other similar reef programs. Use the following questions as a guide:

1. What type of economic analysis would be appropriate in determining whether to proceed with an artificial reef project?

2. Some believe environmental valuation, which would assess the benefits of artificial reef projects to society, should be standard protocol in all planned artificial reef projects within the Great Lakes. Do you agree?

3. Assuming adequate cost information exists, what sorts of value information would you need to assess in order to conduct a benefit-cost analysis of an artificial reef project?

4. What methodologies or techniques would you recommend for each of the value categories identified above?

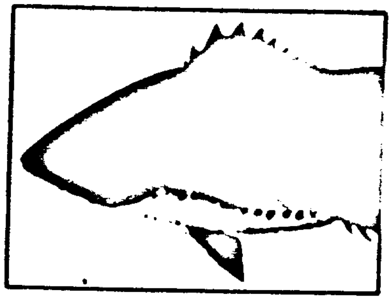
5. Fish and fishers move. How would you account for this movement in your analysis of changes in commercial or recreational fishing values?

6. Which of the various economic approaches described in this handbook would be used by different stakeholders in the policy decision process?

    - Developers
    - Local agencies making decisions regarding public investments
    - Interest groups
    - Public at large
    - Federal regulators/decision makers

7. How would economic information be developed and presented by each group?

Red Snapper Fishery Management in the Gulf of Mexico



Situation

Declines in red snapper stocks in the Gulf of Mexico have impacted commercial and recreational fishers. Among the potential management plan options is the use of Individual Transferrable Quotas (ITQ). While ITQs have been employed within the commercial fishery sector, questions arise as to their applicability within the recreational sector.

Background

In 1984 the Gulf of Mexico Fishery Management Council implemented the Reef Fish Fishery Management Plan — its goal was to manage the reef fish fishery with the Gulf for attaining the greatest overall benefit to the nation. In 1988, a National Marine Fishery Service (NMFS) stock assessment indicated that red snapper was significantly overfished and that reductions in fishing mortality rates of as much as 60 to 70 percent were necessary to rebuild red snapper stocks to a recommended 20 percent spawning stock potential ratio. The 1988 assessment also identified shrimp trawl bycatch as a significant source of juvenile red snapper mortality.

In response, the Fishery Management Council amended the 1984 Fishery Management Plan. The 1990 Amendment 1 provided for a commercial quota of 3.1 million pounds of red snapper. In 1991, the Total Allowable Catch (TAC) was set at 4.0 million pounds with a commercial quota allocation of 2.04 million pounds and a recreational daily bag limit of seven fish (1.96 million pounds). The 1991 Regulatory Amendment also contained an intent by the Council to establish a 50 percent reduction of the offshore shrimp trawler fleet snapper bycatch in 1994.

Despite the intent of the 1991 Regulatory Amendments, the effort capacity for the commercial red-snapper fishery continues to be excessively high, given current quota levels, as evidenced by the 2.04 million pound quota (1992) being filled in just 53 days. Under Amendment 6 of the Reef Fish Fishery Management Plan, a quota increase to 3.06 million pounds provided some benefits but did not prevent a derby fishery from developing. Under the same quota, the 1994 season lasted for 77 days.

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In reaction to the current conditions in the red snapper fishery the Gulf of Mexico Fishery Management Council is now considering a proposed Amendment to the existing Reef Fish Fishery Management Plan[1]. Alternatives in this amendment include a proposal to establish a comprehensive effort management program for the red snapper fishery. The alternatives under consideration include:

1. No action (a system with additional effort controls beyond those currently allowed in the Fishery Management Plan's framework procedure for setting total allowable catch)

2. License limitation

3. Individual Transferable Quotas

Individual Transferable Quota Management System

The Council has identified an Individual Transferable Quotas scheme as the preferred alternative. An ITQ program would involve issuing either a certain poundage or percentage of the total annual commercial allocation of red snapper to each qualifying owner or operator, based on his or her historical landings in the fishery. This poundage or percentage would be that person's initial share. Shares would be the property of the shareholder, probably subject to annual administrative fees for issuing coupons and for transfers of shares. Shares or quota coupons would be transferrable. Under an ITQ system, a "bycatch" allowance for red snapper would not be needed—anyone who wanted to sell *any* red snapper would be required to have quota coupons in the amount of red snapper landed for sale.

The expectations are that an ITQ program will result in increased revenues to the fishing industry as well as decreased total costs of harvesting. In addition, ITQs will afford fishermen greater flexibility by adjusting their share holdings and determining when they will go fishing. Fishermen who choose to exit the fishery may receive economic benefit if they sell their share of harvest privilege.

Under limited access alternatives, fishers would receive specific privileges to participate in the red snapper fishery based on an initial allocation scheme. Fishers who desire to subsequently enter or increase their participation in the fishery could do so only in conjunction with another fisher who decreases his or her participation or leaves the fishery. Thus, allocation of the commercial quota among users would be self-adjusting and ideally would be independent of measures to achieve or maintain the biological goals of the Fishery Management Plan. Unlike limited access, open access systems have no limits on the number of fishers in the fishery or the amount of fish

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[1] GMFMC. 1994. Draft Amendment 8 and Environmental Assessment (Effort Management Amendment) to the Reef Fishery Management Plan of the Reef Fish Resources of the Gulf of Mexico

any fisher can harvest in a season. Allocation among commercial fishers and total annual harvest are treated as a single combined issue and are controlled by limits on short-term effort or vessel trip limits to spread out the harvest.

Costs of an ITQ System

Costs under ITQ management will be higher than under the other proposed alternative systems largely due to the need for increased enforcement and the extensive records and tracking system for coupons (or similar accounting devices) and ITQ shares. If law enforcement can be increased only to the level necessary to enforce current regulations or license limitation systems, then the additional cost is estimated at $450,000 (Case Table 6.1). However, for "full" compliance, defined to be a compliance level of about 90 to 95 percent, the cost will be $1,540,000. Therefore, depending on the level of compliance desired or necessary to realize a substantial portion of the benefits which are possible under an ITQ program, the enforcement costs will be covered by the range just described.

The public burden costs will be $67,000 initially and $64,000 annually thereafter. The National Marine Fisheries Service's (NMFS) costs to design and maintain the ITQ system are estimated to be $230,000 for the first year and then $145,000 annually. The estimate of total costs for the ITQ program, which includes the Council and NMFS administrative costs will range from $1.17 to $2.26 (Case Table 6.2) million the first year and from $659,000 to $1.75 million annually, depending on the level of law enforcement. Case Tables 6.1 and 6.2 summarize the differences in cost between maintaining the status quo or imposing license limitations on the fishery.

Benefits

Changes in revenue to the commercial red snapper fishery are predicted based on historical prices and expectations of how different management systems will affect overall prices. In brief, the status quo is expected to result in an overall price decline of $.15 to $.40 per pound. The license limitation program is not expected to have much effect on current prices. The ITQ system can be expected to generate a price increase ranging from $.85 to $1.35 per pound based on the level of law enforcement. No information is available on the changes in benefits to recreational fishermen.

Exercise

The Gulf reef fishery is a multispecies fishery with two major user groups, namely, the recreational and commercial sectors. In 1991, the recreational sector caught about 52 million pounds of fish in the Gulf, of which no less than 13 million pounds may be considered reef fish species under the management unit of the fishery plan. For this same year, about 1.6 million individuals (coastal and non-coastal) participated in marine recreational fishing in the Gulf region, and about

Case Table 6.1. Costs associated with different management regimes for red snapper.

	Status Quo	License Limitation	ITQ
Council/NMFS administrative costs	$339,884	$339,884	$339,884
Initial public burden cost to apply for permits	2,000	3,000	3,000
Annual public burden costs to maintain management system	28,000	32,000	64,000
Initial NMFS costs to design and implement management system	0	20,000	85,000
Annual NMFS costs to maintain management system	30,000	42,000	145,000
NMFS law enforcement costs to achieve acceptable compliance[1]	450,000	450,000	450,000 to 1,540,000
Coast guard enforcement	N.A.[2]	N.A.	N.A.
Start-up plus first year	849,884	906,884	1,171,884 to 2,261,884
Continuing annual cost	508,000	524,000	659,000 to 1,749,000

[1] Current level of expenditure is estimated at $400,000. Additional $450,000 is required for any of the major alternatives.
[2] To be estimated.

SOURCE: Gulf of Mexico Fishery Management Council, Draft Amendment 8 and Environmental Assessment to the Reef Fish Fishery Management Plan for the Reef Fish Resources of the Gulf of Mexico, 1994.

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15.5 million fishing trips were made by the recreational fishers. There are no current estimates on the economic value of the recreational reef fishery in the Gulf.

In 1991, the commercial sector landed approximately 21.1 million pounds of reef fish with an ex-vessel value of $34.6 million[2]. In 1992, the commercial reef fish sector was composed of about 2,214 reef fish permitted vessels. Because of the moratorium on issuance of additional commercial permits implemented in May 1992, the number of permitted vessels could not significantly be more than the 1992 number. This moratorium is intended to remain in effect through 1995 unless earlier supplanted with a comprehensive limited access management system or extended by the Secretary of Commerce upon recommendation of the Gulf Council.

A major question facing the Gulf of Mexico Fishery Management Council is this: If an ITQ program for red snapper is developed, how will the initial quota be allocated between commercial and recreational fishers? All of the existing ITQ systems are designed to manage fisheries that are dominated by commercial fishing. There is no reason, however, why ITQs could not be used in recreational or combined commercial/recreational (or mixed) fisheries such as the red snapper fishery. As in commercial fisheries, problems of unlimited entry and inefficient allocation to low valued users can be overcome through the transfer of catch rights in the recreational fishery.

Theoretically, recreational fishers who have a high value for the resource could buy catch rights from other recreational fishers or from commercial fishers. Similarly commercial fishers could increase their individual share of total allowable catch by buying catch rights from recreational fishers. These sales of catch rights could be for part or all of a year or for the duration of the ITQ system. Although each group has a different motive for participating in the fishery, transfers of shares between different user groups would direct the share of rights to the most valued use. As a result, all harvest shares could be owned by either commercial or recreational fishers if they are willing to buy the harvest rights. If fishery managers decide that they want to preserve some portion of the total catch for a particular group of users then some of the catch shares can be exempt from trading.

The Council has three options. It can create ITQs for: (1) the commercial fishery only with recreational harvest regulated through bag limits and season closures; (2) a single class of ITQ shares for both commercial and recreational sectors with no restrictions on transfers between commercial and recreational fishers; or (3) two separate classes of ITQ shares — one for the commercial sector and one for the recreational sector. Separate subgroups within a recreational share class for certain groups of recreational fishers such as headboats, party boats, or other identified recreational groups could be established.

The rationale for these subgroups would be to protect certain recreational groups such as headboats or to protect stocks in specific areas. Alternatively, the initial allocation of ITQ shares could be used to address specific distributional concerns about recreational share ownership and allow full transferability to determine the most desirable pattern of share ownership.

Suppose that you are on the Gulf of Mexico Fishery Management Council. You are tasked with establishing a preferred option regarding initial allocation of ITQ shares within the current red snapper fishery. Consider the role of environmental valuation in your analysis of options. Us-

[2]Waters, J. 1992. Economic Assessment of the Commercial Reef Fishery in the U.S. Gulf of Mexico. NMFS Beaufort Laboratory, Southeast Fisheries Science Center, Beaufort, NC.

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Case Table 6.2. Costs and benefits from alternative forms of management for red snapper.

Cost or Benefit	Status Quo	License Limitation	ITQ
Change in expected annual revenue based on quota of three million pounds	Decrease of $450,000 to $1,200,000	Not much change	Increase of $2,550,000 to $4,050,000
Change in cost of harvesting	Significantly higher	Not much change	Significantly lower
Effect on stock recovery affecting long-term revenues:			
	Low enforcement effort	Negative	None None
	High enforcement effort	Negative	None Positive
Public and private costs to implement	$849,884	$906,884	$1,171,884 to $2,261,884
Continuing public private annual costs	$508,000	$524,000	$659,000 to $1,749,000
Relative overall change in net benefits	Significantly negative	Not much change	Significantly higher but similar for each level of law enforcement.

SOURCE: Gulf of Mexico Fishery Management Council, Draft Amendment 8 and Environmental Assessment to the Reef Fish Resources of the Gulf of Mexico, 1994.

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ing the following questions as a guide, outline the study you would request of the Council staff economist or outside contractor.

1. What information would be needed regarding the economic benefits of each allocation strategy in order to make a well-informed decision?

2. What natural resources services should be analyzed?

3. What techniques would you recommend in order to determine the values of these resources and services?

4. What are the limitations to the existing methodologies in this case?

5. What discount rate would you recommend in a benefit-cost analysis of each allocation alternative?

6. Based on your hypothetical stakeholder perspective, the information given, and your hypothetical "back-of-the-envelope" benefit-cost calculations, what option would you recommend as the preferred allocation option?

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Wetland Restoration in Louisiana

Situation

Coastal wetlands in Louisiana play an essential role in the vitality of commercial and sport fishing and recreational hunting. But these wetlands are being devastated by a host of continuing human activities that range from population growth to artificial levees for flood control to the mining of offshore oil fields. Wetland restoration is critical and poses difficult choices that must take into account short and long-term costs.

Background

The Louisiana coastal zone is one of the Nation's foremost geological, biological, and cultural resources. Containing 40 percent of the country's coastal wetlands, it includes 2.5 million acres of marshes (fresh, brackish, and saline) and 637,400 acres of forested wetlands. The Louisiana coastal zone, created by the Mississippi River, is the most active deltaic land mass in North America, draining 40 percent of the 48 contiguous states and substantial areas in the Canadian provinces.[1]

Between 50 to 75 percent of Louisiana's residents live within 50 miles of the coast. These inhabitants benefit from the numerous resources and resource services that wetlands provide. They are the source of livelihood to a substantial number of people including fishers and foresters. Even those who do not depend economically on marshes benefit from the hurricane and flood protection they provide through absorption of storm surges and mitigation of flood damage. The coastal zone also serves valuable water quality treatment functions.

[1] Coastal wetland formation: The land forms within the coastal zones (with the exception of salt domes) were formed as a result of the dynamic interactions between river deposition, waves and currents, and subsidence. Over the past several thousand years, the Mississippi River has periodically changed course. This "delta switching" causes some areas of land to build while others deteriorate. When the river shifts into a new channel, land is built rapidly. The river builds a delta out into shallow shelf areas until its course becomes long, sinuous and inefficient, at which time it changes course to follow a shorter, more efficient route to the Gulf. It is this change which switches the location of the delta. The periodic switching has resulted in a series of delta lobes in various stages of abandonment and deterioration. These lobes, deprived of riverine sediment, slowly break up and erode. However, because a new delta was always building, a natural balance between sinking and accretion existed. At any one location there could be land gain or land loss. In fact, for the past 5,000 years, there has been a net coastal land gain in the Mississippi deltaic plain of between one and two square miles a year. However, the natural cycle of deltaic development — the continuous building and eroding of river basins — is no longer operative today due to human intervention (Coastal Resources Program-Louisiana Department of Transportation and Development. 1978. The Value of Wetlands in the Barataria Basin).

While the natural beauty and abundant wildlife of the wetlands attract tourists from all over the country, the region possesses a unique cultural diversity that includes Native Americans, European immigrants, and Cajun ancestry.

Commercial importance of the Louisiana coastal wetlands includes major economic activities related to commercial fishing, recreational hunting, and sport fishing. Fishing is Louisiana's oldest industry and its prominence is directly attributable to the area's extensive marsh and estuarine system.[2] The region supports the largest coastal finfish and shellfish fisheries in the country, producing two billion pounds of fish and shellfish annually. The Louisiana Wildlife and Fisheries Commission issued over 63,000 commercial fishing licenses in 1985, including almost 16,000 commercial shrimp licenses. The recreational hunting and fishing activity of the region are also substantial. The Louisiana coastal zone leads the Nation in trapping of fur-bearing animals and operates a highly regulated harvest of alligator skins.[3]

Coastal Wetland Decline — Causes and Conflict

For decades artificial levees, managed by the U.S. Army Corps of Engineers with Congressional, State, and public support, have confined the Mississippi River to its present channel, preventing a change of course and the associated development of new delta regions. The purpose of the levees is to contain overflows for navigation and flood control. However, the ecological balance and productive capacity of the adjacent wetlands are adversely affected by the lack of additional fresh water and nutrient-rich material. The river control structures confine the sediments to the river channel and transport it to deep Gulf of Mexico waters so that most of these sediments are discharged over the edge of the continental shelf, forever lost to the sediment-starved coastal zone. In addition, the Mississippi's tributary dams and other activities have significantly reduced the sediment load carried by the river.

In addition to flood control activities, another major cause of coastal erosion is construction of navigation, oil recovery, and access canals. Canals adversely impact the wetlands by interfering with sheetwater flow, allowing destruction by wave action, reducing nutrient exchange, decreasing interface, and increasing salinities. Spoil banks, created by the deposition of material dredged from the canals also result in wetland deterioration. Approximately 8 percent of the marshes in coastal Louisiana have been converted to canals and associated spoil banks.[4] Other activities, such as land reclamation projects for agricultural, urban, and industrial purposes, have also destroyed many acres of viable wetland. The pollution from toxic chemicals and oilfield brines contributes to wetland degradation as well.

Wetland loss due to flooding as a result of subsidence-related sea level rise is another problem. Sea level rise occurs as land forms shrink, resulting in a relative rise in water level. Scientific evidence exists which suggests that sea level rise may accelerate significantly due to atmos-

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[2] *Ibid.*, p. 36.

[3] U.S. Department of the Interior. 1994. The Impact of Federal Programs on Wetlands, Vol. II. A Report to Congress by the Secretary of the Interior. Washington, D.C., p. 143.

[4] Coalition to Restore Coastal Louisiana. 1987. Coastal Louisiana: Here Today and Gone Tomorrow? A Citizens' Program for Saving the Mississippi River Delta Region to Protect Its Heritage, Economy, and Environment. Draft for public review, p. 10.

pheric warming resulting from the greenhouse effect.[5] These rises would led to increased flooding and additional loss of coastal wetlands.[6]

The cumulative impact of human activities and natural processes on the coastal zone has been devastating. At the turn of the century, coastal Louisiana contained 4.07 million acres of wetlands. By 1978, 22 percent of the wetlands had been lost. Conservative estimates indicate that another 3 million acres have been lost since then. Current loss rates are estimated to be about 0.75 percent per year. It is projected that if losses are not reduced, another 167 million acres of Louisiana coastal wetlands will disappear or be converted by the year 2000. These predictions indicate that the Gulf shoreline will advance inland as much as 33 miles in some areas. About 1,200 businesses, residences, camps, schools, storage tanks, electric power substations, water control structures, and pumping stations would require protection or relocation. Furthermore, the U.S. Army Corps of Engineers estimates that without action to reverse projected wetland losses commercial fish and shellfish harvests will decline by 30 percent by the year 2040.[7]

The threatened disappearance of Louisiana coastal wetlands have potentially staggering economic, cultural, and environmental consequences. The loss of habitat for coastal fish, shellfish, and wildlife species would be colossal. The loss for social and cultural functions which depend on proper ecological functioning of the coastal zone would also be devastating. Furthermore, the present Louisiana coast would become uninhabitable as flooding moves further inland.

Coastal Wetland Restoration Management Plan

The prospective losses of wetland functions and services have motivated implementation of a wetland restoration policy. That policy is based on the belief that technological ingenuity and management can separate wetland destruction from some of the causes of that destruction, navigation, flood control, oil and gas production, and urban development. The short-term costs of employing advanced techniques and restoration strategies will undeniably be substantial; the long-term costs, however, of not employing environmental engineering technologies and not implementing management and restoration strategies may be far greater. A restoration program might concentrate on three tasks:

1. Enhancement of sediment and fresh water input into the coastal zone and capture of resuspended sediments

2. Repair or restoration of disturbed wetlands and barrier island transacted by exiting canals

3. Phase-out and halt to construction or expansion of canals.

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[5] Some scientists predict that sea level rise by 2075 may range from 38 to over 200 centimeters depending on the global level of combustion of fossil fuels and emissions of other greenhouse gases.

[6] Coalition to Restore Coastal Louisiana, op. cit., p. 10.

[7] U.S. Department of the Interior, op. cit., p. 154.

Benefits and Costs of Wetland Restoration Strategies

A wetland restoration policy for the Louisiana wetlands coastal zone must manage all of its uses, both short term and long term. One key factor in developing a plan — recognition of the conflicts over multiple uses and societal tradeoffs — is determining the economic value of the wetlands. Economic values provide a basis for realistic appraisal of the wide-ranging social impacts generated by various proposed restoration developments. Thus, the overall benefits and costs of maintaining and restoring Louisiana's coastal wetland resources must be assessed.

A benefit-cost analysis can be conducted by assigning a dollar value to a unit-acre of wetland. However, the economic value of the services provided by wetlands is difficult to appraise due to the lack of a market mechanism for directly pricing those functions. For example, the benefits derived from the wetland's provision of food for commercial fish species and fur-bearing animals have often been ignored. Other values typically disregarded because of the difficulty in assigning economic value are recreational opportunities provided by the wetlands, such as hunting, crabbing, bird watching, swimming, and camping.[8]

Furthermore, the economic value of the protective services provided by wetlands, for instance, storm and flooding protection and the absorption of urban and agricultural waste products, are also difficult to assess, as are the option value and existence value. The option value is the amount which non-users place on a unique resource to know that it is there and could be used, while the existence value is the amount which non-users place on the knowledge that the wetlands exist, even if they never intend to use them directly.

Despite the data and methodological limitations, analysts have developed several different methods by which to value wetlands, including (1) economic impact analysis (EIA); (2) willingness-to-pay (WTP); and (3) energy analysis (EA). These methodologies attempt to place economic value on wetland-related activities and services. In general, some of the major services provided by wetlands can be classified into the following categories: commercial fishing, recreational fishing, commercial trapping, and recreation (subdivided into economic impact expenditures for recreation and the estimated value of user benefits related to recreational activity), and storm protection.

Gross Economic Contribution Analysis. The gross economic contribution analysis for wetland valuation focuses on the question of gross impact on the economy. In other words, values for major activities associated with wetlands are estimated on the basis of gross benefits to the economy. A per-acre value for each of the wetlands-dependent activities is determined, and the respective values are summed to derive the total estimated monetary worth of a wetland acre in its natural state. Case Table 7.1 presents the estimated gross economic contribution of a wetland acre in Louisiana's Terrebonne Parish.[9]

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[8] Coastal Resources Program-Louisiana Department of Transportation and Development, op. cit., p. 85.

[9] For consistency within the case study, the name of this coastal area has been changed. See the source, Coastal Resources Program-Louisiana Department of Transportation and Development, op. cit., for additional information.

Case Table 7.1. Estimated Gross Economic Contribution of a Wetland Acre in the Terrebonne Wetlands.

Activity Director	Annual Return Per Acre	Present Value Per Acre
	Fishing and Hunting	
Commercial fishing	$286.36	$5,540.42
Non-commercial fishing	3.19	46.40
Commercial trapping (Pelts and meats)	11.69	170.05
	Recreation	
Economic impact of recreation expenditures	60.08	873.89
Economic value of user benefits from recreation	104.33	2,428.17
Total	$465.65	$9,058.93

WILLINGNESS-TO-PAY (WTP). The willingness-to-pay approach to wetlands valuation is based on the concept of consumer surplus — this is a measure of the amount a consumer would be willing to pay to continue receiving the good or service, over and above what the consumer is already paying. Thus, in the case of the Louisiana wetlands, WTP estimates the value of the wetlands based on an evaluation of society's willingness-to-pay to avoid the loss of an acre of wetlands or wetland area. Theoretically, this estimate represents the maximum society would pay rather than do without. WTP assumes that the resources employed to produce the good are not part of the value of the resource but are transferable to other uses. The difficulty with the technique is in obtaining true estimates from all the potential beneficiaries for all the direct and indirect goods and services provided by the wetlands. Costanza and Farber used WTP to assess the value of the Terrebonne Parish wetlands in Louisiana.[10] Case Table 7.2 summarizes their estimates of the WTP valuation wetland service categories. Column 2 shows the annual values on a per-acre basis. The authors note that it may not be appropriate to place the storm protection values on a per-acre basis.

[10] Costanza, R. and S. Farber. 1985. The Economic Value of Wetlands in Terrebonne Parish, Louisiana. Final Report to the Terrebonne Parish Policy Jury.

Case Table 7.2. Summary of WTP valuation of Terrebonne Wetlands, using 1983 dollars*.

Valuation Category	Annual per Acre Value of Wetlands	Per Acre Present Value at Various Discount Rates	Per Acre Present Value at Various Discount Rates
(1)	(2)	(3)	(4)
		8%	3%
Commercial Fishery	$25.37	$317.00	$846.00
Trapping	12.04	151.00	401.00
Recreation	3.07	46.00	181.00
Storm Protection	128.30	1,915.00	7,549.00
Total	$168.30	$2,429.00	$8,977.00
Option and Existence	NA	NA	NA

*The present values for recreation and storm protection assume population growth rates of 1.3%

Source: R. Costanza and S. Farber. 1995. *The Economic Value of Wetlands in Terrebonne Parish Louisiana*. A Final Report to the Terrebonne Policy Jury.

ENERGY ANALYSIS (EA). In contrast to WTP, energy analysis looks at the supply side of wetland values, as opposed to the demand side. The method uses the total amount of energy captured by natural ecosystems in primary production as an estimate of their potential to produce economically useful products such as fish and wildlife. The energy captured in photosynthesis is the basis for the food chain that ultimately supports all the production in wetlands, or in any natural system. Therefore, a suitable analysis of the inputs to these systems might provide a convenient index of their ultimate value to society. However, there is no guarantee that all of the products of wetlands are useful to society, and some values to society (e.g., aesthetics and recreational value) are omitted in EA estimates. Case Table 7.3 presents a summary of EA based value estimates for Louisiana wetlands as assessed by Costanza and Farber. These values range from $6,400 to $10,602/acre using an 8 percent discount rate to $17,000 to $28,600/acre using a 3 percent discount rate. Their "best estimate" for the value of an acre of wetlands is a range: $2,429 to $6,400 per acre using an 8 percent discount rate, and $8,977 to $17,000 per acre using a 3 percent discount rate.

Exercise

The activities that have had the most damaging effects on the coastal region are primarily related to the major economic uses of the Mississippi River and coastal zone for navigation, flood

Case Table 7.3. Gross primary production and energy analysis-based economic value estimates for relevant Louisiana wetland and marine habitats.

Habitat type	Total Energy Captured Measured by GPP[a] kcal/m²/yr)	Annual Equivalent Dollar Value[b] ($/ac/yr)	Net Marsh-Aquatic Change in Annual Value ($/ac/yr)	Present Value ($/ac) assuming rate[d] 8%	Present Value ($/ac) assuming rate[d] 3%
Salt marsh	48,000	624			
Salt aquatic	6,600	86	538	6,700	18,000
Brackish marsh	70,300	914			
Brackish aquatic	5,130	67	847	10,602	28,200
Fresh marsh	40,500	630			
Fresh aquatic	9,300	121	509	6,400	17,000
Coastal plankton	3,600	47 (Average)	631	7,900	21,000
Spoil banks[c]	13,000	169			

[a] GPP is gross primary production. Values are from Hopkinson 1979.

[b] Based on conversion factors of 0.05 coal equivalent (CE) kcal/GPP kcal 15,000 CE kcal/1983 dollar and 4,047 m^2/ac. The overall conversion factor from GPP (in kcal/m^2, to estimated economic value (in $/ac/yr) is therefore: (05 x 4047) 15000x.013. See the ONR report for details.

[c] Estimated from values for upland systems.

[d] Rounded to nearest $100.

Source: R. Costanza and S. Farber. 1995. *The Economic Value of Wetlands in Terrebonne Parish Louisiana.* Final Report to the Terrebonne Parish Policy Jury.

control, oil and gas production, and urban development. For years the manner in which these enterprises were carried out have resulted in wetland sediment starvation and delta destruction. In essence, the Louisiana coastal zone is engaged in an economic-ecologic conflict. The region's abundant variety of resources have allowed a wide diversity of economic activity. The utilization of these resources has led to both economic development as well as ecological degradation. Coastal wetland degradation will continue unless a coastal wetlands policy which restores deltaic functions is adopted.

Suppose that you have been asked to be a member of a task force to develop a wetland restoration policy for Terrebonne Parish. Given the information provided in this case study, consider the following questions:

1. What are some of the advantages and limitations of the "valuation" approaches outlined above?

2. What role can environmental valuation play in regional wetland restoration policy?

3. How would environmental valuation at the regional level differ from the use of economics at the site level?

4. The capitalized value of an annual stream of wetland benefits is highly dependent on the discount rate, which reflects the value which people today put on retention or production of a resource for future use, and the predicted value of coastal wetlands for fish and wildlife, recreation, water quality management, storm buffer protection and other functions in future years. One can expect that the value of the coastal Louisiana wetlands would increase if their resources were to become scarce through lack of proper management. What discount would you suggest be used in this analysis?

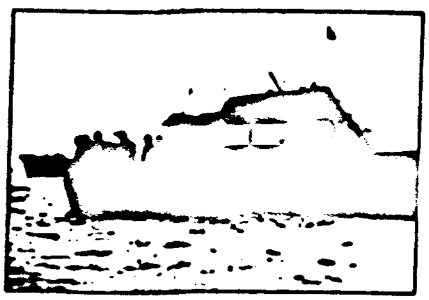
5. It has been suggested that, to date, existing legal mechanisms for regulating activities in the Louisiana coastal zone have not been sufficiently restrictive of access and navigation construction projects. A wetland restoration policy must develop more stringent regulatory programs in this regard by imposing mitigation requirements which will fully compensate for direct and indirect land loss where dredging of canals is permitted. Construction of access and navigation canals should be drastically restricted by mandating use of alternative means of access for oil and gas equipment. With regard to urban development, it has been suggested federal subsidies should be suspended (e.g., funds for low-income housing, mortgage insurance, and National Flood Insurance for urban development projects) in environmentally significant wetlands. These expenditures currently offer significant incentives for development that impacts important wetlands. They also set the stage for future federal outlays for damages caused by storms to developments located in naturally flood-prone areas. Strictly on economic grounds, would it make sense (in terms of sound public policy) to withhold incentives for developing areas subject to high flooding risks?

6. Which of the various economic approaches would be used by different stakeholders in the policy decision process? How would economic information be developed and presented by each group?

- Developers
- Local agencies making decisions regarding public investments
- Interest groups
- Public at large
- Federal regulators/decision makers

7. How can the various economic approaches aid in developing consensus among stakeholders?

NONPOINT SOURCE POLLUTION CONTROL IN CALIFORNIA



Situation

Recreational facilities such as marinas and activities such as boating can be sources of dangerous contamination in nearshore waters. Toxic compounds from antifouling paints, batteries, detergents, and sewage are a threat to water quality, living resources, and human health. Management safeguards and other control measures to prevent pollutant runoff could, in the long run, cost less than environmental clean-up costs.

Background

In the Coastal Zone Management Act (CZMA) of 1972, as amended, Congress declared it to be national policy that state coastal management programs must provide for public access to the coasts for recreational purposes. Clearly, boating and adjunct activities and facilities are an important means of public access. The availability of public access facilities and services such as marinas has helped boating to become a major industry in California. More than 650,000 pleasure boats are registered with the state and during 1986, recreational boaters engaged in an estimated 56 million boating-days.

Boater spending supports a wide range of businesses, among them, boat and equipment manufacturing, retailing, and various types of boating services. A 1986 inventory of 5,035 boating businesses throughout California revealed that these businesses had total gross receipts of $2.6 billion, employed 40,000 people, and paid $476 million in payroll. Businesses that support recreational boaters paid over $191 million in state and local taxes during that year. The direct spending by boaters on goods and services stimulates the entire California economy. Including all the other businesses that support the boating industries in California, the total economic activity traceable to boating in 1986 was more than $6.7 billion.[1] Clearly, marinas and other public access facilities and services are integral to California's economy.

However, when these facilities are poorly planned or managed, they can pose a threat to the health of aquatic systems; they can also introduce other environmental hazards. Because marinas are located at the water's edge, there is often no buffering of the release of pollutants to waterways. Adverse environmental impacts may result from the following sources of pollution associated with marinas and recreational boating:

- Pollutants illegally discharged from boats and fueling stations
- Pollutants transported in stormwater runoff from marina parking lots, roofs, and other surrounding impervious surfaces
- Physical alteration or destruction of wetlands and of shellfish and other bottom communities during the construction of marinas, ramps, and related facilities
- Pollutants generated from boat maintenance activities on land and in the water[2]

Recreational boating and marinas are increasingly popular uses of the California coastal zone. In areas such as San Diego Bay, the growth of recreational boating, along with the growth of coastal development in general, has led to a growing awareness of the need to protect waterways. Normal marina operations such as waste disposal, boat fueling, and boat maintenance and cleaning generate contaminant runoff. Moreover, storage areas for the materials required for these activities are also a source of pollutants. Of special concern are substances such as paint sandings and chippings, waste oil and grease, batteries, fuel, detergents, and sewage that can be toxic to aquatic biota, or degrade water quality and pose a threat to human health.

Historically, point source wastes from shipyards, boatyards and other repair facilities, and marinas were dumped or washed directly into the San Diego Bay. Environmental legislation over the past 20 years has put an end to these practices. However, large sinks of sand blast material and other paint-containing waste are still present in the Bay's sediments. The effects of these sinks on water quality is not known.[3]

Non-point source pollution continues to be a paramount concern as current boat maintenance activities, such as the use of antifouling paints on boat hulls, generate contaminants that can harm the marine environment. These paints that contain chemical pesticides are applied to the hulls of boats to deter the attachment and growth of aquatic organisms — the buildup of such

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[1] D.M. Dornbusch and Company, Inc. 1988. Economic Impact of the Boating Industry in California. Prepared for the California Department of Boating and Waterways.

[2] U.S. Environmental Protection Agency. 1993. Guidance Specifying Management Measures for Sources of Nonpoint Pollution in Coastal Waters. EPA Document 840-B-92-002, pp.5.2-5.3.

[3] Conway, J.B. and L.P. Locke. 1994. A Final Report on Marine Fouling and Underwater Hull Cleaning in San Diego Bay. Prepared for the California Regional Water Quality Control Board, San Diego Region.

organisms can promote hull corrosion and increase drag.

Biocides from antifouling paints generally enter the marine environment in different ways: (1) through the normal leaching process of paints as they age, and (2) through paint chips abraded from vessels' hulls in the water during underwater hull cleaning. The concern is that the copper-based biocide chemicals released from antifouling paint applied to boat hulls may be deleterious to the marinas' aquatic environment. Because of the poor tidal flushing characteristics of San Diego Bay, copper concentrations can become elevated to levels harmful to aquatic organisms.

Numerous studies have shown that the concentrations of antifouling biocides are highest near marinas and small yacht basins. A recent study assessing the average concentrations of total and dissolved copper in San Diego and Mission Bays found that while ambient copper concentrations appeared to be non-toxic, several marinas did have average dissolved copper concentrations that were above the U.S. EPA's Ambient Water Quality Criteria for saltwater aquatic life.[4]

Another study attempted to measure the deleterious effects (within the water column) of in-water maintenance of boats at recreational marinas. The study revealed that although copper releases can be significant in the immediate vicinity of a boat hull during cleaning, the water rapidly returns to pre-cleaning concentrations. However, the findings were inconclusive as to the extent and degree of dispersal of the contaminant plume and the total load to the Bay from a hull cleaning operation. Other studies have found evidence of elevated levels of copper in the tissues of organisms living in the San Diego Bay. These studies suggest that boat owners should be educated about biofouling processes and antifouling paints so that they can make sound, informed, and environmentally sensitive decisions.

Nonpoint Source Control Solutions

It is important that marina operators such as those in San Diego Bay recognize that there are alternatives to obtaining permits to pollute. They can take steps to control or minimise the entry of polluting substances into marina waters. For the most part, this control can be accomplished with simple preventive measures such as locating service equipment where the risk of spillage is reduced, providing adequate and well-marked disposal facilities, and educating the boating public about the importance of pollution prevention. Benefits of effective pollution prevention to the marina operator may be realized in terms of lower direct pollution control costs. The costs of pollution prevention could well be lower than environmental clean-up costs.

Section 6217 of the Coastal Zone Act Reauthorization Amendments of 1990 (CZARA) requires coastal states (including Great Lakes states) with approved coastal zone management programs to address nonpoint pollution impacting or threatening coastal waters. States must submit Coastal Nonpoint Pollution Control Programs for approval to both the U.S. Environmental Protection Agency (EPA) and the National Oceanic and Atmospheric Administration (NOAA). Requirements for state programs are described in *Coastal Nonpoint Pollution Control Program: Program Development and Approval Guidance* and are summarized in a separate fact sheet. Some of the

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[4] McPherson, T.N. and G.B. Peters. 1995. The Effects of Copper-Based Antifouling Paints on Water Quality in Recreational Boat Marinas in San Diego and Mission Bays. Prepared for the California Regional Water Quality Control Board, San Diego Region.

management measures outlined in the guidance include practices related to the best possible siting for marinas, best available design and construction, and appropriate operation and maintenance (e.g., solid waste management, liquid waste management, and petroleum control management). Other management efforts might include staff and boater education programs on all areas of non-point source control and best management practices; petroleum station management; improved sewage pumpout systems; and installation of fuel spill controls.

California is currently revising its Nonpoint Source (NPS) Pollution Management Plan pursuant to the 1990 CZARA. For each management measure, a Technical Advisory Committee accepted or modified EPA's management measure as it should be applied to California; for each management measure, the report also addresses applicability, methods of implementation, specific implementors, enforcement mechanisms, triggers of enforcement actions, and the actions that are necessary to begin implementation.

Costs of Compliance

The California Regional Water Quality Control Board, San Diego Region, could choose to implement some of the operations and maintenance management measures outlined in the 1994 *Marina and Recreational Boating Technical Committee Report* in an attempt to improve the quality of San Diego Bay. Implementation of these measures, unlike compliance with cleanup and abatement orders by boatyards, is not expected to impose significant costs on marina operators in the area. The cost of providing recreational boating services will likely increase with implementation of management measures affecting the San Diego Bay marinas.

Nonpoint source control requirements have the potential to delay new facility construction and/or business failures of existing marinas. Some of these costs are expected to be passed along to recreational boaters. In addition to costs passed on to boaters by marinas, boaters may incur costs associated with more expensive non-toxic paints (silicone) and hull cleaners who are licensed, insured, approved under best management practices; higher cost boat maintenance (experienced labor, more frequent cleanings, required draping); and higher cost oil-change services which recycle.

Case Table 8.1[5], though not directly related to the implementation of boat-cleaning management practices, presents some high estimates of the potential costs to San Diego Bay marinas of selected operation and maintenance practices. While operations and maintenance management measures include waste disposal, education and boat-operation practices, this analysis is restricted to solid-waste disposal practices and liquid-waste disposal practices. The specific costs are associated with purchasing a commercial vacuum to collect debris at hull-maintenance sites, providing covered dumpsters for solid-waste collection, and purchasing liquid waste containers for storing and recycling oil, antifreeze, gasoline, diesel fuel, and kerosene.[6]

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[5] U.S. Environmental Protection Agency. 1992. Economic Analysis of Coastal Nonpoint Source Pollution Controls: Marinas. Original estimates have been adjusted for the purposes of this hypothetical case study.

[6] These cost estimates are based on large-scale repair facilities. Boat maintenance at San Diego area marinas is actually small-scale, general upkeep done on individual boats

Case Table 8.1. Costs of Selected Operation and Maintenance Management Practices: High Estimates.

	Liquid Waste Management		Commercial Vacuum		Covered Dumpster	
Marina Number	Capital ($)	Operating ($/yr)	Capital ($)	Operating ($/yr)	Capital ($)	Operating ($/yr)
1	90	112	1,063	19	0	1,620
2	360	174	1,063	93	0	1,620
3	4,080	407	1,063	372	0	7,056
4	4,170	485	1,063	465	0	7,056
5	15,980	1,652	4,252	1,860	0	21,168
6	15,980	1,652	4,252	1,860	0	21,168

Key Assumptions:
1. Assume one vacuum is needed for every 250 slips of capacity.
2. Assume one filter must be replaced annually for every 50 slips of capacity. Each filter costs $93.
3. Assume model marina owners pay for dumpster rental and collection.

Sources: Dickerson, George. Sales Representative for Capital Vacuum, Raleigh, NC. May 13,1992. Personal communication with Julie Duffin, Research Triangle Institute.

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Benefits of Marina Operations and Management Measures

Numerous benefits are associated with the implementation of nonpoint source marina operations and maintenance management measures. For example, increases in water quality will provide improvements in the integrity of the San Diego Bay environment leading to increased recreational boating and fishing values, aesthetics and nonuse values, and reduced costs for dredging when sediments are less contaminated. The steps in determining the benefits of such control measures include:

1. Determination of the benefit categories which match potential management measures

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2. Estimation of the benefits of each management measure in terms of how each measure will affect natural resource parameters. For example, if non-toxic hull cleansing is required, an attempt must be made to determine the linkage between reduction of pollutants such as copper and the improvement of water quality.

3. Determination of how changes in ecological parameters affect human health, recreational enjoyment, and aesthetic appreciation through impacts on market and nonmarket services provided by the Bay. For example, how does an increase in water quality affect the quantity or quality of recreational boating and other uses of San Diego Bay surface water?

4. Translation of these public health, recreational, aesthetic and ecological effects into estimates of monetary values.

In addition, there may be benefits from some best management practices such as the use of underwater hull cleaning. These benefits include increased vessel maneuverability and fuel efficiency as well as the potential for increased paint life with a corresponding decrease in total antifouling chemical discharge.

Exercise

Given the information provided above, develop an economic argument in favor of or against the implementation of boat-cleaning management measures in San Diego Bay marinas.

1. Do you see a role for environmental valuation in the development of your argument? Would it be most appropriately used in a case-by-case (marina-by-marina) implementation decision basis or as an overall policy decision?

2. What natural resources and resource services do you think should be analyzed?

3. What techniques would you recommend in order to determine the values of these resources and services?

4. What are the limitations to the existing methodologies in this case?

5. Boat-cleaning management measures are only one set of management measures and practices recommended in the EPA nonpoint source pollution control guidance. Using the economic techniques described in the seminar, how would you decide whether focusing on operations and maintenance management actions is appropriate?

6. Would other economic approaches outlined in the seminar be of use to others in the decision process?

- Developers
- Local agencies making decisions regarding supporting public investment decisions
- Interest groups
- Public at large
- Federal regulators/decision-makers

How would this information be developed and presented by each group?

How can these tools aid in the developing consensus among the various stakeholders?

7. There are numerous benefits that can be attached to the implementation of nonpoint-source management measures for marina operations and maintenance. These benefits may not be directly incurred by individual marina operators (though some cost savings may be expected), but are more likely to be felt by the public at large. Should those benefits be weighted similarly in your decision process or should one group or another be weighted more heavily? Should the marina operators be compensated for the capital costs that they will incur to implement the management measures?

8. To describe and measure the benefits of these measures, it is necessary to identify linkages between the measures, the resources of the Bay, and the activities and user groups that derive economic value from the Bay. These relationships are complex and a single measure may affect several different resource services at once. Conceptually, what would those linkages look like? What kind of data would you need to collect to analyze those linkages?

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GLOSSARY

benefit-cost analysis — a technique to compare the relative economic efficiency of different states of the world usually brought about by undertaking projects or policies. A comparison is made between gross benefits of a project or policy and the opportunity costs of the action. Benefits and costs are measured as changes in consumer and producer surpluses accruing to individuals in society.

consumer surplus — a money measure of an individual or group's welfare from consumption of a good or service or the existence of a particular state of the world. This surplus is the difference between the maximum the individual is willing to pay for consumption of the good and the amount that has to be paid.

contingent valuation — a methodology to determine money measures of change in welfare by describing a hypothetical situation to respondents and eliciting how much they would be willing to pay either to obtain or to avoid a situation.

demand — in economics, the usual inverse relationship between quantity consumed (or otherwise used or even preserved) and a person's maximum willingness-to-pay for incremental increases in quantity. Market prices often (but not always) reveal the increments of willingness-to-pay. Other factors influencing willingness-to-pay include income, prices of substitutes, and, in recreational fishing, catch rate. Unlike planning where demand refers to the size of the quantity variable, economic demand is a behavioral relationship.

discounting — is a procedure to use when comparing value streams (benefits or costs) occurring in different magnitudes at different dates in the future. The procedure "discounts" future values in order to obtain the present value of the stream.

environmental valuation — procedures for valuing changes in environmental goods and services, whether or not they are traded in markets, by measuring the changes in the producer and consumer surpluses associated with these environmental goods.

existence value — see nonuse value

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gross domestic product (GDP) — aggregate annual output of the economy before deducting the value of the assets of the economy that have been used up or depreciated in the production process during the year. Gross domestic product provides a summary measure of the Nation's overall economic performance.

hedonic method — a methodology for estimating the relationship between the price of a good (e.g. housing) and the characteristics of the good (e.g. number of bedrooms, air quality, proximity to amenities, etc.). Can sometimes be used to value changes in environmental characteristics.

input-output model — a methodology that models the linkages between input supplies, outputs, and households in a regional economy that can be used to predict the impact of changes on economic activity (e.g., industry revenues and household incomes) within the region.

market benefits — benefits from goods or services bought and sold in normal commerce so that there is a revealed price that reflects consumers willingness-to-pay for the quantity offered and suppliers marginal production costs.

non-market benefits — benefits that accrue to individuals for goods, services, experiences or states of nature that are not normally traded in commerce.

nonuse value (see also use value) — value of knowing that something exists in a particular state even though there is no sensory contact with the resource.

opportunity cost — the highest value a productive resource such as labor, capital, land or a natural resource could return if placed in its best alternative use.

producer surplus — total revenue minus the opportunity cost of production, including the opportunity costs of the entrepreneurs skills, labor, capital, and ownership of natural resources.

random utility model (RUM) — an extension of the travel cost method which explicitly considers individuals participation decisions and the selection among alternative recreation sites.

supply — schedule of the quantities of goods and services that a business is willing to sell at various prices. Other factors that affect supply include input prices.

travel cost method — a methodology which relies on travel-related costs as a surrogate for price in a non-market situation in order to estimate demand and money measures of willingness-to-pay.

use value — value derived from either the consumption of a good, the utilization of a service, or that otherwise involves some sensory contact with the resource. For example, whale-watching is not consumptive but involves visual contact with the whales.

value — what one is willing to give up in order to obtain a good, service, experience, or state of nature. Economists try to measure this in dollars.

welfare economics — a field of inquiry within the broad scope of economics that is concerned with money measures of individual and social well-being, particularly in changes in well-being due to implementation of public policies.

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LIST OF ACRONYMS

CERCLA — Comprehensive Environmental Response, Compensation and Liability Act

COP — NOAA Coastal Ocean Program

CVM — contingent valuation method or methodology

EPA — Environmental Protection Agency

GDP — gross domestic product

ITQ — individual transferable quotas

NEPA — National Environmental Policy Act

NMFS — NOAA National Marine Fisheries Service

NOAA — National Oceanic and Atmospheric Administration

OPA — Oil Pollution Act

WTP — willingness-to-pay

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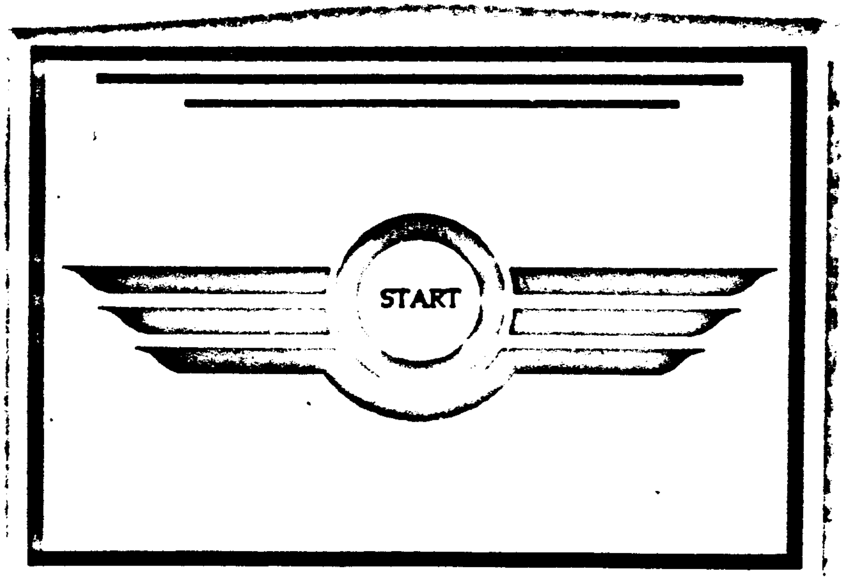

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HAZARDOUS AND TOXIC WASTES ASSOCIATED WITH URBAN STORMWATER RUNOFF

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ABSTRACT

This paper summarizes some of the information obtained during a research project sponsored and directed by the EPA's Storm and Combined Sewer Research Program and conducted under a subcontract from Foster-Wheeler/Enviresponse. The research project examined a variety of organic and metallic toxicants in stormwater and combined sewer overflow (SCSO) source flows (Pitt and Barron 1990). The study was designed to use rain events and sample locations to illustrate the variables associated with toxicant concentrations in urban runoff. An attempt was made to specifically address the following questions:

1. What are the typical toxicant contaminant levels in stormwater?
2. What are the origins of these toxicants in stormwater?
3. What rain or land use factors affect toxicant concentrations in stormwater?

INTRODUCTION

Stormwater runoff has been identified as a major contributor to the degradation of many urban streams and rivers (Field and Turkeltaub 1981; Pitt and Bozeman 1982; Pitt and Bissonnette 1984). Organic and metallic toxicants are expected to be responsible for much of these detrimental effects, and have been found in urban runoff discharges during many previous studies (EPA 1983; Hoffman, et al. 1984; Fam, et al. 1987; Pereira, et al. 1988).

Table 1 summarizes the estimated discharges of commonly detected organic and metallic toxicants from all U.S. cities having populations greater than 100,000 population (which total about 15,000 square miles, Dept. of Commerce 1980). These cities will be required to participate in the EPA's stormwater permit program (Federal Register, December 7, 1988). These values are for discharges that are directly entering the nation's surface receiving waters. This information is based on the Nationwide Urban Runoff Program (NURP) results of about 100 stormwater outfall samples (EPA 1983). This NURP data is mostly for residential areas, with some commercial area influences. More recent information indicates that industrial stormwater discharges can have many times the concentrations of the toxicants as the areas represented in the NURP data (Pitt and McLean 1986). In addition, base flows occurring in storm drains during dry weather that may be contaminated by non-stormwater discharges (such as industrial waste cross-connections), can also significantly increase these estimated loadings (Pitt, et al. 1990). Therefore, the large discharges noted in Table 1 can be expected to be even much larger, when all urban areas, land uses, and flow regimes are considered. Most importantly, these are actual discharges as monitored at outfalls, and not estimated discharges associated with chemical storage or disposal operations.

METHODOLOGY

This research included the collection and analysis of several hundred urban runoff samples from a variety of source areas and under different rain conditions. A number of combined sewer overflow and detention pond samples were also included in the evaluation portion of these first phase activities. This effort was significantly greater than has been attempted previously for toxic pollutants in stormwater and will enable several critical questions to be addressed, as stated previously in the objectives.

Samples were analyzed for many organic pollutants using gas chromatographs with a mass selective detector (GC/MSD) and with an electron capture detector (GC/ECD) and metals using a graphite furnace equipped atomic adsorption spectrophotometer (GFAA). All samples were also analyzed for particle distributions from about 1 to 100 microns. All samples were also analyzed using a toxicity screening technique. All SCSO samples were also filtered to determine the liquid/solid partition coefficients of the pollutants and the relative toxicities of the filterable and nonfilterable portions of the samples. The following paragraphs briefly summarize the sampling and analyses features of this first phase research effort.

Sampling Effort

About 300 subsamples were analyzed for organic and metallic toxicants, toxicity screening, and particle size distributions. All of these samples were partitioned into filterable and non-filterable components for complete analyses.

The relative importance of different source areas (such as roofs, streets, parking areas, etc.) in contributing toxicants were examined from field studies conducted as part of this research. Samples were collected from the most significant potential source areas in residential, commercial, and industrial land uses. The areas that received the most sampling attention were parking and storage areas in industrial and commercial areas. These areas have been noted in previous studies to have the largest potential of discharging toxicants (Pitt and McLean 1986).

Sheetflow samples were collected during five Birmingham Alabama rains. Replicate samples from many of the same source areas, but during different rains, enabled differences due to rain conditions versus site locations to be statistically evaluated.

Source Area Runoff Grab Samples

The sheetflow samples were collected using manual grab procedures. Hand operated pumps created a vacuum in the sample bottle which then drew the sample directly into the container through Teflon tubes. About one liter of sample was collected, split into two containers: one 500-mL glass with Teflon lined lid was used for the organic and toxicity analyses, and another 500-mL polyethylene bottle was used for the metal and other analyses.

Most of the source area sheetflow samples were obtained from the Birmingham, Alabama area during the first phase of this project. However, cooperative researchers in Seattle, Washington also submitted a limited number of additional stormwater samples for comparison.

CSO Grab Samples

Twenty combined sewer overflow (CSO) outfall grab samples were collected in the New York City area for complete analyses. These outfall samples were used to make a preliminary evaluation of the relative toxicities of CSOs and urban stormwater runoff. These samples were collected during four different rains in New York.

Organic Pollutant Analyses

The samples were analyzed using a Hewlett Packard 5890 gas chromatograph with a 5970B mass selective detector (GC/MSD), and a Perkin-Elmer Sigma 300 gas chromatograph with an electron capture detector (GC/ECD). The following lists the organic toxicants that were analyzed in these samples:

Pesticides (detection limit: 0.3 ug/L):

BHC, heptachlor, aldrin, heptachlor epoxide, endosulfan, DDE, DDD, DDT, endrin, and chlordane.

Phthalate Esters (detection limit: 0.5 ug/L):

Bis(2-ethyhexyl) phthalate, butyl benzyl phthalate, di-n-butyl phthalate, diethyl phthalate, dimethyl phthalate, and di-n-octyl phthalate.

Polynuclear Aromatic Hydrocarbons (detection limit: 0.5 ug/L):

Acenaphthene, acenaphthylene, anthracene, benzo (a) anthracene, benzo (a) pyrene, benzo (b) fluoranthene, benzo (ghi) perylene, benzo (k) fluoranthene, chrysene, dibenzo (a,h) anthracene, fluoranthene, fluorene, indeno (1,2,3-cd) pyrene, naphthalene, phenanthrene, and pyrene.

In addition, selected nitroaromatics, haloethers, and other chlorinated hydrocarbons were also analyzed.

Metallic Pollutant Analyses

The samples were analyzed using a Perkin-Elmer graphite furnace atomic absorption spectrophotometer (GFAA). Standard EPA approved methods were used in these analyses. Aluminum, cadmium, chromium, copper, lead, nickel, and zinc were analyzed in all samples. The detection limits were about 1 ug/L, except for cadmium which had a detection limit of about 0.1 ug/L.

Low detection limits were necessary for these metal analyses. In prior studies, the total forms of most of the metals were well within the detection limits of standard flame atomic absorption spectrophotometer (AAS) procedures, but the filterable portions were commonly not detected (Pitt and McLean 1986; EPA 1983). The partitioning of the heavy metals between the solid and liquid phases is an important factor in determining the treatability of these pollutants and was therefore an important goal of this research. This information is needed to assess the fates of the metals in receiving waters and in treatment processes.

Toxicity Screening Tests

A number of previous studies have found high concentrations of toxic pollutants in SCSOs. Some urban stormwater runoff studies attempted to use conventional 96-hr fish bioassay toxicity tests (such as Pitt 1979), but very few fish died during the tests. However, in situ taxonomic studies of urban runoff receiving waters found significant evidence of toxic effects from the long-term exposure to these pollutants (such as

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reported by Pitt and Bozeman 1982, for the same stream as the negative fish bioassay tests). More recent bioassay tests have used more sensitive organisms and have detected significant SCSO toxicities (Spiegal et al. 1984 in Syracuse, NY; Mount et al. 1985 in Birmingham, AL; Mount et al. 1986 in Waterbury, CN, and Norberg-King et al. 1988 in San Francisco Bay).

The objective of this task was to obtain toxicity measurements from a large number of SCSO and source area samples, along with toxicity measurements corresponding to different SCSO sample partitions. It was necessary to use a rapid screening method to examine the relative toxicities for the different samples because of the time and financial limitations of this first phase of the research program. A series of special tests were made to compare toxicities of selected sheetflow and CSO samples to both the screening method and conventional bioassay methods.

The toxicity testing procedure that was used (Microtox from Microbics, Inc.) uses luminescent bacteria to indicate relative toxicities of samples. This procedure was used to screen all of the samples collected during this project. The partitioned samples (filterable and non-filtrable for each sample) were all tested for relative toxicity. These data enabled toxicity comparisons between different source areas, in addition to toxicity reduction potential for different treatment processes, to be made. These tests were not used to determine the absolute toxicities of the samples, but only to examine the toxicity differences between the different source areas and sample partitions. In addition, about twenty samples were also analyzed concurrently using a variety of conventional bioassay techniques, for comparison with the Microtox procedure.

<u>Particle Size Analyses</u>

Many SCSO treatment processes are very sensitive to the particle size distributions and settling velocities of the solids (Dalrymple et al. 1975). Wet detention ponds, catchbasins, grass filters, street cleaning, microscreening, filtration, swirl concentrators are some of the treatment methods that require a knowledge of particle size and/or settling characteristics. Additionally, the fate of many toxic pollutants in receiving waters is also very sensitive to these particle physical characteristics. Without knowing the specific particle size distributions and settling velocities, the necessary design information for these controls therefore remains unknown.

Unfortunately, there are wide variations in the particle distributions for different source areas (Pitt and McLean 1986), which makes the design of runoff controls having consistent performance difficult. The objective of this subtask was to obtain a statistically significant number of individual particle size distributions from many SCSO source areas.

A laser particle counter (SPC-510 from Spectrex Corp.) was used to analyze particle size distributions for all of the SCSO and receiving water samples. This instrument produces particle size distribution plots for particle sizes ranging from 0.5 microns to more than 100 microns. Settling column tests are currently being conducted to determine the specific gravities of SCSO samples which will enable settling velocities to be calculated.

<u>Treatability Tests</u>

This project also included tests to examine the treatability of source area and outfall samples. Filtration tests, in conjunction with literature information, enabled an examination to be made of the benefits of typical treatment processes to reduce toxicity and potential toxic pollutant components of SCSOs. This subtask stressed the fate mechanisms (partitioning) that can be later related to specific control processes. As an example, knowing the filterable fraction of the aggregate toxicity of a sample will allow estimates to be made concerning the maximum treatability of the waste by particle separation processes (such as catchbasins, grass filter strips, and wet detention ponds). The detailed particle size distributions obtained in this research will enable the relative benefits of various sediment barrier practices (such as filtration and screening) to be estimated. Many detailed bench-scale unit processes will be performed during the current phase of this study, and future work will include pilot- and full-scale tests of various treatment practices.

DATA OBSERVATIONS

Toxicity Observations

The Microtox procedure allowed toxicity screening tests to be conducted on each sample's total and filtered components. This screening procedure enabled about 300 samples to be evaluated. The Microtox procedure was not used to determine the absolute toxicity of the samples, or to show that urban stormwater runoff components were in fact toxic. The objectives of these analyses were to identify the most toxic source areas and to identify the approximate toxic reductions possible by complete separation of the unfiltered pollutants from the mixtures.

Actual urban stormwater runoff problems that have been monitored are quite varied, but are probably mostly associated with long-term pollutant exposures, especially through heavily polluted sediments. Receiving water concentrations during runoff events and typical laboratory bioassay tests have not shown many significant short-term receiving water problems (Field and Pitt 1990).

Each sample was tested as unfiltered and filtered. A Millipore 0.45-micron filter was used, under a gentle vacuum, to prepare the filtered samples. The toxicity, as determined by the Microtox procedure, was expressed as three values, I_{10} (the percentage light decrease after about 10 minutes of exposure), I_{35} (the percentage light decrease after about 35 minutes of exposure), and the EC_{50}. The EC_{50} is the sample dilution corresponding to a 50 percent light decrease after a 35 minute exposure. Therefore, only samples that have I_{35} values greater than 50 were further tested to determine the EC_{50} values. Higher values of I_{10} and I_{35}, and lower fractions of EC_{50}, correspond to greater toxicities.

Microbics suggests that light decrease values greater than 60 percent correspond to "highly" toxic samples, light decrease values between 20 and 60 percent correspond to "moderately" toxic samples, and light decrease values less than 20 percent correspond to "not" toxic samples. Table 2 shows the percentages of samples in each category that corresponded to each of these groupings. Also shown on Table 2 are the numbers of samples analyzed in each source area category.

The category having the largest percentage of highly toxic samples was the combined sewer overflows. The urban creeks and detention pond effluents had the largest percentage of samples that can be considered least toxic. The source areas that had the greatest toxic responses were the parking and storage areas.

Tests were conducted on unfiltered and filtered portions of each sample to indicate the toxic reduction potential associated with complete separation of the particulate pollutant components. When the toxic responses of all of the samples were compared, it was found that no significant differences in the toxic responses occurred for the unfiltered versus filtered samples. In many cases, the filtered samples actually indicated greater toxicities than their unfiltered counterparts. This was probably because of normal experimental errors (found to be about 15 percent through controlled testing).

The chemical analyses found that significant portions of the monitored toxicants were associated with the suspended solids (nonfilterable residue). Upon sample filtering, the concentrations of the toxicants were generally greatly reduced. However, as noted above, the Microtox toxicities of the samples were apparently little affected by filtration. Either other nonmonitored toxicants were responsible for the indicated toxicities and were mostly associated with filterable forms, or the toxicants associated with the suspended solids had little effect on the test organisms. The chemical analyses did find significant portions of the toxicants associated with suspended solids that may form highly toxic sediments in receiving waters. These sediments may adversely affect receiving water beneficial uses long after a runoff event.

In summary, the Microtox analyses indicated short-term toxicities associated with filtered pollutants that would not be removed through sedimentation processes. In contrast, the chemical analyses found significant toxicant concentrations associated with sediment forming materials that would affect long-term toxic responses and these could be partially removed through sedimentation and other particle separation processes.

<u>Suspended Solids Analyses</u>

Suspended solids (particulate residue), turbidity, pH, and particle size distributions were obtained for the unfiltered portions of the samples. The runoff from the paved areas all had relatively low suspended solids concentrations (generally less than 100 mg/L), while some of the sheetflows from unpaved areas had concentrations as high as 750 mg/L. The turbidity values varied in a similar manner; they were all quite low, except for the unpaved areas. Except for roof runoff and storage area runoff, the pH values were within a typical range of about 7 to 8.5. They were as low as 4.4 for roof runoff and as high as 11.6 for storage area runoff. The samples representing complex mixtures of source areas (urban creeks, detention ponds, and CSOs), all had pH values closest to 7.

For any one sample, the particle size distributions were generally narrow; the 10 to 90 percent ranges were represented by particle sizes as close as 20 microns apart. The smallest particle sizes were found for roof runoff. In contrast, landscaped areas and loading docks had some of the largest particle sizes found.

<u>Organic Toxicant Concentration Observations</u>

A major portion of the effort of this research project was spent in conducting the organic toxicant analyses. Table 3 summarizes the organics that were observed in at least ten percent of the unfiltered samples analyzed. Most of the organic compounds detected were PAHs. Two ethers were also frequently detected. This list is similar to the frequency of detection list prepared by the EPA (1983) as part of the Nationwide Urban Runoff Program.

Table 4 contains all of the observed base neutral data, while Table 5 contains all of the observed pesticide data. Roof runoff, urban creeks, and the CSOs had the greatest number of observed maximum organic toxicant values. As noted previously, the CSO category had the largest percentage of highly toxic samples. The roofs contained high concentrations of several pesticides, fluroanthenes and a pyrene. A CSO sample had an extremely high bis (2-ethly hexyl) phthalate concentration of 56 mg/L. Vehicle service areas and parking areas also had several of the observed maximums.

<u>Heavy Metal Concentration Observations</u>

Table 6 summarizes the heavy metal observations. In contrast to the organic analyses, the detection frequencies for all of the metals were very high. Roof runoff had the highest concentrations of zinc, probably associated with galvanized metal. Parking areas had the highest nickel concentrations, vehicle service areas had the highest cadmium and lead concentrations, while streets had high aluminum concentrations. Surprisingly, landscaped areas had the highest chromium and urban creeks had the highest copper concentrations.

Many observations of filterable metals were also made and are also summarized on Table 6. Except for storage areas, most of the zinc was associated with the filterable sample partitions. In contrast, very little of the nickel was found in the filterable sample partitions. Most of other metals were also found associated with the suspended solids fraction. Therefore, suspended solids separation processes would be very effective in removing heavy metals from these source areas, with the exception of zinc. Similarly, if the metals were not removed before discharge, they would likely contribute to polluted sediments in the receiving waters.

CONCLUSIONS

The following paragraphs summarize the major project conclusions, as they related to the project objectives.

Objective 1: Characterization of Toxic Components in SCSOs

Overall, about 300 sample components were analyzed to determine toxicant concentrations in sheetflows and other SCSOs as part of the first phase of this project.

Most pH values were in a narrow range of 7 to 8.5 and the suspended solids concentrations were generally less than 100 mg/L. The particle size ranges were usually narrow for any one sample, but the distribution ranges developed using all samples from a single source area were substantially greater.

Only a small fraction of the toxic organic pollutants analyzed were frequently detected. Thirteen organics were detected in more than ten percent of all samples analyzed. The greatest detection frequencies were for 1,3-dichlorobenzene and fluoranthene, which had detection frequencies of 23 percent. The organics most frequently found in these samples were similar to organics most frequently detected in prior studies conducted elsewhere and were mostly the PAHs, especially fluoranthenes and pyrenes.

Roof runoff, urban creeks, and CSO samples had the greatest frequencies of detection for the organic compounds analyzed. Vehicle service areas and parking areas had several of the observed maximum organic compound concentrations observed. Very little evidence was obtained to differentiate the solid/liquid partitioning of organics for different source areas.

The detection limits of the analyses were greater than anticipated and the frequency of detection was therefore less than if the detection limits were improved. The use of larger sample volumes would have reduced the detection limits, which would result in substantially greater detection frequencies. Most of the organics were associated with unfilterable sample portions. In contrast to the organics, the heavy metals were detected in almost all samples analyzed, including the filtered samples.

Roof runoff had the highest concentrations of zinc observed, probably due to galvanized roof drainage components. Parking areas had the highest nickel concentrations, while vehicle service areas had the highest concentrations of cadmium and lead. Urban creek samples had the highest copper concentrations, probably due to illicit discharges.

Objective 2: Relative Toxicities of Sheetflows and SCSOs

The toxicity and chemical tests were not conducted to demonstrate the toxicity of urban runoff. Many actual receiving water studies (summarized in the project report

Pitt and Barron 1990; and by Field and Pitt 1990) identified the various problems that have been associated with urban stormwater discharges. These long-term receiving water studies have demonstrated that actual urban stormwater problems are quite varied, and are probably mostly associated with long-term exposures to toxicants, especially in the sediments, and to habitat destruction associated with high flows and debris. Receiving water concentrations during runoff events and typical laboratory bioassay tests have not indicated many significant short-term problems associated with urban stormwater runoff.

The Microtox screening tests found that CSOs had the greatest percentage of samples considered the most toxic, followed by samples obtained from parking and storage areas. Runoff from paved areas all had relatively low suspended solids concentrations and turbidities, especially compared to samples obtained from unpaved areas.

About 15 percent of all of the unfiltered samples analyzed were considered highly toxic using the Microtox screening procedure. The remaining samples were approximately evenly split between being moderately toxic and not being toxic.

Preliminary data evaluations indicated that variations in observed Microtox toxicities and organic toxicant concentrations may be greater for different rains than for the different source areas sampled. As an example, high concentrations of PAHs were mostly associated with long-antecedent dry-periods.

Objective 3: Partitioning of Toxic Components and Treatability of Toxicants in SCSOs

There were no significant differences in the measured Microtox toxicities associated with the unfiltered samples and the filtered portions of the samples. However, most of the organics and metals were associated with the suspended solids of the runoff samples. An exception was for zinc, which was found mostly in the filtered sample portions. This implies that most of the Microtox measured toxicity was associated with filterable forms of the pollutants.

This preliminary result suggests that simple sedimentation, even though removing much of the mass of toxic pollutants from the water, may have minimal benefits in reducing immediate toxicant effects. Uncontrolled sedimentation, such as in lakes or reservoirs, or large rivers, may result in long-term contaminated sediment problems. However, controlled sedimentation in SCSO control devices allow effective residue management, including appropriate disposal of the potentially heavily contaminated sediments, which would minimize downstream receiving water sediment problems.

The literature review of the potential transport and fate mechanisms of these pollutants found that many processes will affect these pollutants. Sedimentation in the receiving water is the most common fate mechanism because many of the pollutants investigated are mostly associated with particulate matter. Exceptions included zinc and 1,3-dichlorobenzene which were mostly associated with the filterable sample portions. Particulate removal can occur in many SCSO control processes, including catchbasins, swirl concentrators, screens, drainage systems, and detention ponds. These control processes allow removal of the accumulated polluted sediment for final disposal in an appropriate manner. Uncontrolled sedimentation will occur in receiving waters, such as lakes, reservoirs, or large rivers. In these cases, the wide dispersal of the contaminated sediment is difficult to remove and can cause significant detrimental effects. Biological or chemical degradation of the toxicants in the sediments may occur, but is quite slow for many of the pollutants in the expected anaerobic environments. Degradation of the soluble pollutants in the water column may occur, especially when near the surface in aerated waters. Volatilization (evaporation) is also a mechanism that may affect many of the detected organic toxicants. Increased turbulence and oxygen supplies would encourage these processes that may significantly reduce pollutant concentrations.

Sorption of pollutants onto solids and metal precipitation increases the sedimentation potential of the pollutants and also encourages more efficient bonding of the pollutants in soils, preventing their leaching to surrounding waters.

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Table 1. Estimated Toxicant Discharges from Large U.S. Municipalities (15,000 square miles total)

	Median Conc. (ug/L)	Detection Frequency (%)	Discharges (tons/year)
Arsenic	7	50	80
Chromium	30	60	350
Copper	35	90	700
Cyanide	40	25	200
Lead	150	95	3000
Zinc	150	95	3000
Bis(2-ethylhexyl) phthalate	6	20	30
Chlordane	1.5	20	5
Chrysene	1.5	10	3
Fluoranthene	3	15	10
Pentachlorophenol	15	20	70
Phenanthrene	1.5	10	4
Pyrene	2	15	8

Source: from EPA 1983

Table 2. General Toxicity Groupings of Analyzed Samples

	most toxic	moderatly toxic	least toxic	number analyzed
roofs	8%	58%	33%	12
parking areas	19	38	44	16
storage areas	25	50	25	8
streets	0	67	33	6
loading docks	0	67	33	3
vehicle service areas	0	40	60	5
landscaped areas	17	33	50	6
urban creeks	0	12	88	19
detention ponds	10	10	80	12
CSOs	65	30	5	20

Table 3. Detection Frequencies of the Most Frequently Occurring Organic Compounds

	Frequency of detection:
1,3-Dichlorobenzene	23%
Fluoranthene	23
Pyrene	19
Benzo (b) fluoranthene	17
Benzo (k) fluoranthene	17
Benzo (a) pyrene	17
Bis (2-chloroethyl) ether	14
Bis (chloroisopropyl) ether	14
Naphthalene	13
Chlordane	13
Benzo (a) anthracene	12
Benzyl butyl phthalate	12
Phenanthrene	10

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Table 4. Observed Base Neutral Compounds (µg/L)

number of nonfiltered analyses:	road runoff 12	parking 13	storage 7	streets 6	loading dock 3
Base Neutrals					
Bis (2-chloroethyl) ether	30.3;20.5;86.6	15.3; 23.8		15.1	
1,3-Dichlorobenzene	13.6;54.7;88.4	9.6;33.2;60.2	16.2	5.4	
Bis (chloroisopropyl) ether	67.0;81.5;147	81.4;102;217			
Hexachloroethane	55.8	40.9;47.2			
Bis (2-chloroethoxyl) methane					
Naphthalene	47.7;187	71.8			
Acenaphthylene					
Fluorene					
Di-n-butyl phthalate	31.2				
Phenanthrene	22.1	12.8;41			
Anthracene	23.7				
Benzyl butyl phthalate	106	a3.3;21.4			
Fluoranthene	7.6;15.3;64.8	1.0;15.6;93.8	4.5	0.6	
Bis (2-ethyl hexyl) phthalate			31.2	306	
Pyrene	27.6	1.0;40.2;79.6	8	8.7	
Benzo (a) anthracene	16.3	1.8;16.2;54.8			
Chrysene	73.1	29.3			
Benzo (b) fluoranthene	6.4;14.2;27.5;266	10;17.8;132		13.9	
Benzo (k) fluoranthene	3.4;11.5;12.2;221	8;11.3;41.6		15.4	
Benzo (a) pyrene	20.9;34;51.6;300	31.4;19.8;78.3		18.8	
Benzo (g,h,i) perylene		29.7			
Di-n-octyl phthalate					
Nitrobenzene					
Isophorone					
Diethyl phthalate					

Table 4. Observed Base Neutral Compounds (µg/L) (cont'd.)

nonfiltered analyses:	vehicle service areas 4	landscaped areas 5	urban creeks 4	detention ponds 4	New York CSOs 19	overall detection freq.	overall maximum
Base Neutrals							
Bis (2-chloroethyl) ether	45.2	54.3	204	15.3	15.5	14%	204
1,3-Dichlorobenzene	6;64.6;72.2	4.5;27.5;54.4	65;120	27	22	23	120
Bis (chloroisopropyl) ether	74;161	86.2	40;76			14	217
Hexachloroethane	57		25;38	53		9	57.3
Bis (2-chloroethoxyl) methane		≥6;11.5	20.9			4	20.9
Naphthalene	36.7;104	49.4	296	18;68	7.7	12	296
Acenaphthylene	≥1.9					1	≥1.9
Fluorene	0.8				9.3	3	9.3
Di-n-butyl phthalate					17.1;17.4;30;61	6	60.6
Phenanthrene	11.2	27.9	68.9	10.4	33.2	10	68.9
Anthracene	44.3	20.3	40	5.8		6	44.3
Benzyl butyl phthalate	≥3.8;47.3	128	58.9	12.9	83.3	12	128
Fluoranthene	≥0.4;25.4;52.8	0.7;1.3;30.1	128	5.6;13.9	6.6	23	128
Bis (2-ethyl hexyl) phthalate					115;142;541 836;56,000	9	56,000
Pyrene	≥0.7;37.7;51	2.2;8.2	102	6;57	15.3	19	102
Benzo (a) anthracene	31.1;39	54.1	60.6		10.9	12	60.6
Chrysene	25		237		8.2	6	237
Benzo (b) fluoranthene	89.6;107	29.7	8;64			17	266
Benzo (k) fluoranthene	14.7;103	61.4	31;70			17	221
Benzo (a) pyrene	59.7;130	54	19;136			17	300
Benzo (g,h,i) perylene						1	19.7
Di-n-octyl phthalate					42.6	1	42.6
Nitrobenzene					26.5	1	26.5
Isophorone					10.4	1	10.4
Diethyl phthalate					103	1	103

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Table 5. Observed Pesticides (μg/L)

	roof runoff	parking	storage	streets	loading dock	vehicle service areas	New York CSOs	overall detection frequency	overall maximum
Number of analyses:	12	13	7	6	3	4	19		
Pesticides							all BHCs:	all BHCs:	
alpha BHC	0.7						0.3	4	0.7
delta BHC	1.1								1.1
aldrin	0.7							1	0.7
DDT	0.3;46.3	0.3						4	46.3
endrin		1.4						1	1.4
chlordane	0.5;0.9;2.2	0.8;1.2	1.1	0.8	1.0	0.8	0.5	13	2.2
DDD							1.2	1	1.2

Table 6. Observed Source Area Metal Concentrations (µg/L)

Source Area Runoff	Aluminum non filt.	Aluminum filt.	Cadmium non filt.	Cadmium filt.	Chromium non filt.	Chromium filt.	Copper non filt.	Copper filt.	Lead non filt.	Lead filt.	Nickel non filt.	Nickel filt.	Zinc non filt.	Zinc filt.
roofs														
detection frequency	11/12	9/12	11/12	8/12	7/12	2/12	11/12	7/12	12/12	1/12	10/12	0/12	12/12	12/12
median	270	13	0.82	0.23	7	<1	17	1.2	13	<1	5.1	<1	100	80
maximum	8370	1550	30	0.95	510	2.3	900	8.7	170	1.1	70	<1	1580	1550
% filt. (range,median)	2→100	(15%)	1→69	(50%)	6→14	(10%)	4→87	(20%)	7	(<10%)		(<20%)	57→100	(90%)
parking areas														
detection frequency	12/12	10/10	11/12	4/10	11/12	4/12	12/13	9/12	13/13	5/13	11/13	1/13	13/13	13/13
median	1550	360	0.72	<0.1	18	<1	20	1.8	30	<1	40	<1	30	23
maximum	22,500	2890	70	1.0	310	2.4	770	9.2	130	2.5	130	1.6	150	88
% filterable	1→100	(20%)	<1→63	(20%)	2→82	(35%)	<1→88	(15%)	1→45	(10%)		(<5%)	15→100	(75%)
storage areas														
detection frequency	6/6	1/7	7/7	4/7	7/7	4/7	7/7	5/7	7/7	6/7	7/7	0/7	6/6	6/6
median	975	<1	2.4	0.27	60	1.1	30	1.8	30	1.6	30	<1	66	9
maximum	6990	37	10	1.3	340	32	300	1.7	330	5.7	90	<1	290	103
% filterable		(1%)	3→13	(10%)	3→46	(10%)	1→15	(3%)	2→50	(10%)		(<3%)	3→100	(15%)
streets														
detection frequency	4/4	4/4	6/6	5/6	5/6	4/6	6/6	5/6	6/6	4/6	5/6	0/6	5/5	5/5
median	4,000	200	0.76	0.18	3.3	1.3	15	1.9	30	1.3	3.0	<1	50	23
maximum	10,040	4,380	220	0.57	30	2.7	1250	11.4	150	3.9	70	<1	130	76
% filterable	1→44	(20%)	12→91	(50%)	9→60	(30%)	<1→67	(10%)	6→100	(20%)		(<30%)	8→100	(40%)
loading docks														
detection frequency	3/3	1/3	3/3	3/3	3/3	0/3	3/3	2/3	3/3	1/3	3/3	1/3	2/2	2/2
median	810	<1	1.2	0.5	8.9	<1	20	2.6	60	<1	7.8	<1	55	33
maximum	930	<1	2.4	0.6	40	<1	30	15	80	2.3	8.1	1.3	79	62
% filterable		(<5%)	23→61	(40%)		(<10%)	9→100	(10%)		(<5%)		(<10%)	13→78	(50%)
vehicle service areas														
detection frequency	4/4	3/3	4/4	2/4	4/4	0/4	4/4	3/3	4/4	1/4	4/4	0/4	4/4	4/4
median	920	200	8	<0.2	19	<1	8.3	2.1	75	<1	35	<1	67	18
maximum	1370	410	30	0.34	330	<1	580	6.3	110	1.4	70	<1	130	83
% filterable	<1→87	(30%)	1→16	(<5%)		(<5%)	<1→95	(30%)		(<5%)		(<5%)	10→100	(40%)

Table 6. Observed Source Area Metal Concentrations (μ/L) (cont'd.)

Source Area Runoff	Aluminum non filt.	Aluminum filt.	Cadmium non filt.	Cadmium filt.	Chromium non filt.	Chromium filt.	Copper non filt.	Copper filt.	Lead non filt.	Lead filt.	Nickel non filt.	Nickel filt.	Zinc non filt.	Zinc filt.
landscaped areas														
detection frequency	4/4	4/4	3/5	1/5	5/15	4/5	4/4	4/4	5/5	1/5	3/5	0/5	5/5	5/5
medium	2500	1600	0.04	<0.1	100	1.5	80	2.0	9.4	<1	30	<1	32	32
maximum	4610	1860	1.0	1.0	250	4.1	300	8.3	70	1.7	130	<1	1160	670
% filterable	34→93	(50%)	(<25%)		2→68	(10%)	3→20	(3%)	(<10%)		(<5%)		58→100	(100%)
New York CSOs														
detection frequency	19/19	-	20/20	20/20	20/20	1/20	20/20	16/20	20/20	14/20	20/20	19/20	20/20	20/20
median	720		1.6	0.25	17.6	<1	70	9.1	40	1.8	11.3	5.5	96	34
maximum	23,030		10	5.1	130	18	340	30	120	7.5	48.2	48.2	390	80
% filt. (range,median)	?		2→100	(35%)	(<5%)		2→100	(20%)	2→100	(15%)	12→100	(50%)	3→100	(35%)
urban creeks														
detection frequency	4/4	4/4	4/4	0/4	4/4	0/4	4/4	3/4	4/4	0/4	3/4	0/4	4/4	4/4
median	1600	240	5	<0.1	6.0	<1	160	1.2	38	<1	20	<1	24	19
maximum	3250	500	30	<0.1	30	<1	440	1.4	100	<1	70	<1	32	23
% filterable	13→42	(15%)	(<1%)		(<15%)		<1→23	(20%)	(<3%)		(<5%)		53→100	(80%)
detention ponds														
detection frequency	4/4	4/4	4/4	1/4	3/4	0/4	4/4	0/4	4/4	0/4	3/4	0/4	4/4	4/4
median	550	200	0.24	<0.1	5.5	<1	47	<1	1.9	<1	20	<1	22	22
maximum	1350	330	1.0	<0.1	230	<1	210	<1	8.0	<1	70	<1	25	25
% filterable	6→100	(60%)	(<5%)		(<20%)		(<2%)		(<25%)		(<5%)		(all 100%)	

U.S. Department of Commerce
Economics and Statistics Administration
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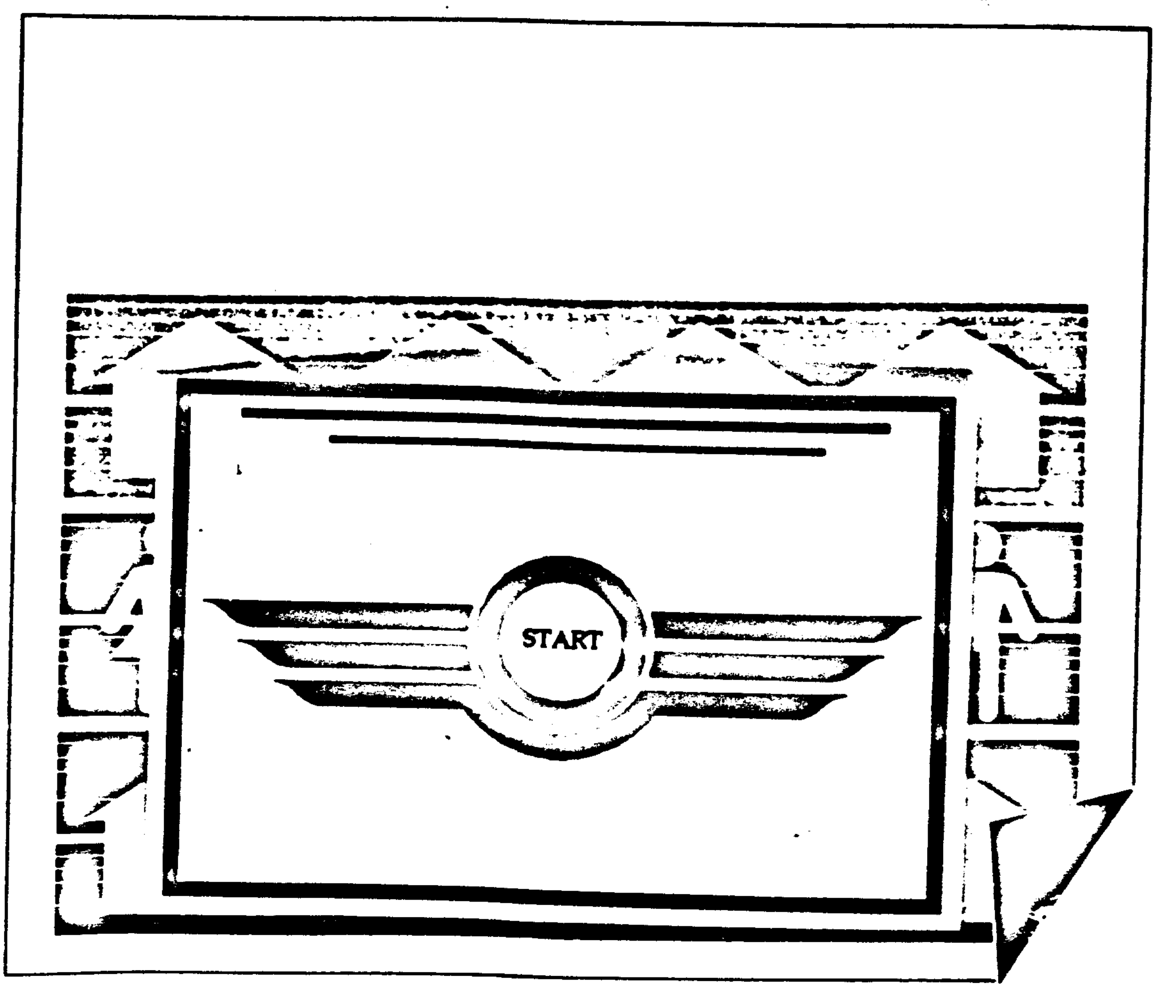
1990 CPH-1-6

1990 Census of Population and Housing

Summary Population and Housing Characteristics

California



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California

Issued August 1991

U.S. Department of Commerce
Robert A. Mosbacher, Secretary
Rockwell A. Schnabel, Deputy Secretary

Economics and Statistics Administration
Michael R. Darby, Under Secretary
for Economic Affairs and Administrator

BUREAU OF THE CENSUS
Barbara Everitt Bryant, Director

Table 15. **Land Area and Population Density: 1990—Con.**

[For definitions of terms and meanings of symbols, see text]

State County County Subdivision Place	All persons	Land area: Square kilometers	Land area: Square miles	Persons per—: Square kilometer	Persons per—: Square mile
Fresno County—Con.					
Reedley division	20 639	172.2	66.5	119.9	310.4
Reedley city (pt.)	15 506	9.6	3.7	1 615.2	4 190.8
Riverdale division	4 169	186.6	72.0	22.2	57.6
Riverdale CDP	1 980	10.3	4.0	192.2	495.2
Sanger division	25 274	196.7	75.9	128.5	333.0
Sanger city	16 839	11.9	4.6	1 415.0	3 660.7
San Joaquin-Tranquillity division	5 889	817.4	315.6	7.2	18.7
San Joaquin city	2 311	2.6	1.0	888.8	2 311.0
Selma division	22 587	207.0	79.9	109.1	282.7
Fowler city (pt.)	-	.2	.1	-	-
Kingsburg city (pt.)	-	.1	-	-	-
Selma city	14 757	9.8	3.8	1 505.8	3 883.4
Sierra division	14 475	6 955.8	2 685.7	2.1	5.4
Auberry CDP	1 866	49.2	19.0	37.9	98.2
Squaw Valley CDP	2 161	146.8	56.7	14.7	38.1
Glenn County	24 798	3 405.6	1 314.9	7.3	18.9
Orland division	14 236	1 574.3	607.9	9.0	23.4
Hamilton City CDP	1 811	.8	.3	2 263.8	6 036.7
Orland city	5 052	5.7	2.2	886.3	2 296.4
Willows division	10 564	1 831.2	707.0	5.8	14.9
Willows city	5 988	6.7	2.6	893.7	2 303.1
Humboldt County	119 118	9 253.5	3 572.8	12.9	33.3
Arcata division	20 687	766.3	295.9	27.0	69.9
Arcata city (pt.)	15 197	20.9	8.1	727.1	1 876.2
Eureka city (pt.)	-	.3	.1	-	-
Eureka division	45 834	377.4	145.7	121.4	314.6
Bayview CDP	1 318	1.9	.7	693.7	1 882.9
Cutten CDP	1 516	3.4	1.2	445.9	1 263.2
Eureka city (pt.)	27 025	24.2	9.3	1 116.7	2 905.9
Humboldt Hill CDP	2 865	10.6	4.1	270.3	698.8
Myrtletown CDP	4 413	5.0	1.9	882.6	2 322.6
Pine Hills CDP	2 947	26.4	10.2	111.6	288.9
Ferndale division	2 299	1 008.4	389.3	3.3	8.5
Ferndale city	1 331	2.7	1.0	493.0	1 331.0
Fortuna division	14 316	1 167.0	450.6	12.3	31.8
Fortuna city	8 788	12.3	4.8	714.5	1 830.8
Hydesville CDP	1 131	15.0	5.8	75.4	195.0
Garberville division	12 168	2 191.9	846.3	5.6	14.4
Redway CDP	1 212	3.2	1.2	378.8	1 010.0
Rio Dell city	3 012	4.8	1.8	627.5	1 673.3
North Coastal division	17 929	1 368.1	530.5	13.2	34.4
Arcata city (pt.)	-	-	-	-	-
Blue Lake city	1 235	1.6	.6	771.9	2 058.3
McKinleyville CDP	10 749	43.5	16.8	247.1	639.8
Trinidad city	362	1.2	.5	301.7	724.0
Westhaven-Moonstone CDP	1 109	21.0	8.1	52.8	136.9
Trinity Klamath division	4 885	2 396.6	925.3	2.0	5.3
Willow Creek CDP	1 576	534.8	206.5	2.9	7.6
Imperial County	109 303	10 813.4	4 175.1	10.1	26.2
Brawley division	20 152	491.8	189.9	41.0	106.1
Brawley city	18 923	12.9	5.0	1 466.9	3 784.6
Calexico division	20 152	237.6	91.7	84.8	219.8
Calexico city	18 633	10.7	4.1	1 741.4	4 544.6
Heber CDP (pt.)	-	-	-	-	-
Calipatria-Westmorland division	6 803	796.8	307.6	8.5	22.1
Calipatria city	2 690	4.8	1.8	560.4	1 494.4
Niland CDP	1 183	1.1	.4	1 075.5	2 957.5
Westmorland city	1 380	1.0	.4	1 380.0	3 450.0
East Imperial division	1 543	5 778.8	2 231.2	.3	.7
El Centro division	42 303	372.5	144.2	113.3	293.6
El Centro city	31 384	16.2	6.2	1 937.3	5 061.9
Heber CDP (pt.)	2 566	3.8	1.5	675.3	1 710.7
Imperial city (pt.)	14	.3	.1	46.7	140.0
Seeley CDP	1 228	[illegible]	[illegible]	[illegible]	[illegible]
Holtville division	6 952	305.8	118.1	22.7	58.9
Holtville city	4 820	2.8	1.1	1 721.4	4 381.8
Imperial division	5 571	180.5	69.7	30.9	79.9
Imperial city (pt.)	4 099	5.9	2.3	694.7	1 782.2
West Imperial division	2 672	2 537.4	979.7	1.1	2.7
Westmorland-Bard division	3 155	111.2	43.0	28.3	73.4
Inyo County	18 281	26 397.5	10 192.1	.7	1.8
Bishop division	12 355	1 897.3	732.6	6.5	16.9
Bishop city	3 475	4.5	1.8	772.2	1 930.6
Dixon Lane-Meadow Creek CDP	2 561	8.8	3.4	291.0	753.2
West Bishop CDP	2 908	22.6	8.7	128.7	334.3
Death Valley division	841	12 208.4	4 713.7	.1	.2
Independence division	2 531	6 790.9	2 622.0	.4	1.0
Big Pine CDP	1 158	6.3	2.4	183.8	482.5
Lone Pine division	2 554	5 500.9	2 123.9	.5	1.2
Lone Pine CDP	1 818	48.2	18.6	37.7	97.7
Kern County	543 477	21 086.8	8 141.6	25.8	66.8
Arvin-Lamont division	26 704	510.8	197.2	52.3	135.4
Arvin city (pt.)	9 286	7.6	2.9	1 221.8	3 202.1
Bakersfield city (pt.)	38	12.0	4.6	3.2	8.3
Lamont CDP	11 517	12.0	4.6	959.8	2 503.7
Weedpatch CDP	1 892	7.6	2.9	248.9	652.4
Bakersfield division	291 782	639.8	247.0	456.1	1 181.3
Bakersfield city (pt.)	171 105	191.7	74.0	892.6	2 312.2
Oildale CDP	26 553	15.5	6.0	1 713.1	4 425.5
Buttonwillow division	2 808	482.2	186.2	5.8	15.1
Bakersfield city (pt.)	-	.3	-	-	-
Buttonwillow CDP	1 301	3.0	1.2	433.7	1 084.2
East Kern division	88 969	4 685.9	1 809.2	14.7	38.1
Boron CDP	2 101	7.6	2.9	276.4	724.5
California City city	5 955	478.1	184.6	12.5	32.3
Edwards AFB CDP	7 423	38.7	14.9	191.8	498.2
Inyokern CDP	3 763	35.1	13.5	107.2	278.7
North Edwards CDP	1 259	11.1	4.3	113.4	292.8
Ridgecrest city	27 725	53.8	20.8	515.3	1 332.9
Kern County—Con.					
East Kern division—Con.					
Rosamond CDP	7 430	52.2	20.2	142.3	367.8
Greenfield-Panama division	8 717	458.2	176.9	21.2	54.9
Bakersfield city (pt.)	3 232	18.8	7.3	171.9	442.7
Rexland Acres CDP (pt.)	-	.6	.2	-	-
Lake Isabella division	15 633	4 330.3	1 671.9	3.6	9.4
Bodfish CDP	1 283	14.1	5.4	91.0	237.6
Kernville CDP	1 656	26.3	10.2	63.0	162.4
Lake Isabella CDP	3 323	20.3	7.9	163.7	420.6
Mountain Mesa CDP	1 153	2.5	1.0	461.2	1 153.0
South Lake CDP	1 059	12.4	4.8	85.4	220.6
Wofford Heights CDP	2 270	15.0	5.8	151.3	391.4
McFarland-Delano division	33 525	581.5	224.5	57.7	149.3
Delano city	22 762	22.1	8.5	1 030.0	2 677.9
McFarland city	7 005	5.3	2.1	1 321.7	3 335.7
Rosedale division	12 693	131.7	50.8	96.4	249.9
Bakersfield city (pt.)	445	15.0	5.8	29.7	76.7
Greenacres CDP	7 379	10.2	4.0	723.4	1 844.8
Rosedale CDP (pt.)	4 673	92.4	35.7	50.6	130.9
Shafter division	15 080	418.8	161.7	36.0	93.3
Shafter city	8 409	4.9	1.9	1 716.1	4 425.8
Taft-Maricopa division	25 902	2 427.1	937.2	[illegible]	[illegible]
Arvin city (pt.)	-	.3	.1	-	-
Bear Valley Springs CDP	1 593	13.3	5.1	119.8	312.4
Golden Hills CDP	5 423	10.9	4.2	497.5	1 291.2
Maricopa city	1 212	15.2	5.9	[illegible]	[illegible]
Taft city	5 791	[illegible]	[illegible]	[illegible]	[illegible]
Wasco division	15 868	2 463.6	951.2	6.5	16.7
Lost Hills CDP	1 212	1.7	.6	712.9	2 020.0
Wasco city	12 412	8.3	3.2	1 495.4	3 878.8
Weedpatch division	24 796	2 977.2	1 149.5	8.3	21.6
Ford City CDP	3 781	2.9	1.1	1 303.8	3 437.3
Frazier Park CDP	2 201	2.9	1.1	759.0	2 000.9
Maricopa city	1 193	1.8	.7	662.8	1 704.3
South Taft CDP	2 170	2.6	1.0	834.6	2 170.0
Taft city	5 902	9.2	3.6	641.5	1 639.4
Taft Heights CDP	2 050	1.5	.6	1 366.7	3 416.7
Kings County	101 469	3 598.8	1 389.5	28.2	73.0
Avenal division	9 882	790.7	305.3	12.5	32.4
Avenal city (pt.)	9 734	43.3	16.7	224.8	582.9
Corcoran division	10 787	52.0	20.1	207.4	536.7
Corcoran city (pt.)	8 312	10.8	4.2	769.6	1 979.0
Hanford division	42 735	483.0	186.5	88.5	229.1
Armona CDP	3 122	5.0	1.9	624.4	1 643.2
Hanford city	30 897	29.9	11.5	1 033.3	2 686.7
Home Garden CDP	1 549	1.5	.6	1 032.7	2 581.7
Hanford Northeast division	3 544	255.1	98.5	13.9	36.0
Lemoore division	25 648	313.7	121.1	81.8	211.8
Lemoore city	13 622	14.7	5.7	926.7	2 389.8
Lemoore Station CDP	-	[illegible]	[illegible]	[illegible]	[illegible]
Stratford division	8 873	1 704.2	658.0	5.2	13.5
Avenal city (pt.)	36	6.2	2.4	5.8	15.0
Corcoran city (pt.)	5 051	3.8	1.5	1 329.2	3 367.3
Kettleman City CDP	1 411	.4	.2	3 527.5	7 055.0
Lake County	50 631	3 290.4	1 258.5	15.5	40.2
Lakeport division	21 079	699.6	270.0	30.1	78.1
Kelseyville CDP	1 212	11.3	4.4	116.1	298.2
Lakeport city (pt.)	2 861	12.4	4.8	230.7	596.0
Lakeport city	4 390	6.3	2.4	696.8	1 829.2
Lower Lake-Middletown division	19 781	856.4	330.7	22.5	58.3
Clearlake city	11 804	26.8	10.3	440.4	1 146.0
Clearlake Oaks CDP (pt.)	154	.3	.1	513.3	1 540.0
Cobb CDP (pt.)	165	1.4	.6	117.9	275.0
Hidden Valley Lake CDP	1 961	28.1	10.9	69.8	179.9
Lower Lake CDP	1 217	10.0	3.9	121.7	312.1
Upper Lake-Clearlake Oaks division	10 271	1 703.7	657.8	6.0	15.6
Clearlake Oaks CDP (pt.)	2 265	7.2	2.8	314.6	808.9
Lucerne CDP	2 011	9.8	3.8	205.2	529.2
Nice CDP	2 126	5.5	2.1	386.5	1 012.4
Lassen County	27 598	11 803.9	4 557.5	2.3	6.1
Big Valley division	1 596	2 446.3	944.5	.7	1.7
Honey Lake division	2 900	1 321.6	510.3	2.2	5.7
Madeline Plains division	369	5 081.7	1 962.0	.1	.2
Susanville division	19 834	1 091.2	421.3	18.2	47.1
Susanville city	7 279	7.2	2.8	1 011.0	2 599.6
Westwood division	2 911	1 863.2	719.4	1.6	4.0
Westwood CDP	2 017	14.8	5.7	136.3	353.9
Los Angeles County	8 863 164	10 515.3	4 060.0	842.9	2 183.0
Burbank division	93 645	44.9	17.3	2 085.6	5 413.0
Burbank city (pt.)	93 643	44.9	17.3	2 085.6	5 412.9
Los Angeles city (pt.)	2	-	-	-	-
Calabasas division	72 739	419.3	161.9	173.5	449.3
Agoura Hills city	20 390	21.2	8.2	961.8	2 486.6
Hidden Hills city	1 729	4.2	1.6	411.7	1 080.6
Los Angeles city (pt.)	-	-	-	-	-
Point Dume CDP	2 809	4.4	1.7	638.4	1 652.4
Westlake Village city	7 455	13.5	5.2	552.2	1 433.7
Compton division	311 718	118.3	45.7	2 635.0	6 821.0
Carson city (pt.)	83 958	48.8	18.8	1 720.5	4 465.9
Compton city (pt.)	90 446	26.3	10.2	3 439.0	8 867.3
East Compton CDP	7 967	1.3	.5	6 128.5	15 934.0
Long Beach city (pt.)	27	.9	.4	30.0	67.5
Los Angeles city (pt.)	-	-	-	-	-
Lynwood city (pt.)	61 883	12.5	4.8	4 950.6	12 892.3
Paramount city (pt.)	-	.1	-	-	-
West Carson CDP	20 143	5.9	2.3	3 414.1	8 757.8
West Compton CDP	5 451	4.2	1.6	1 297.9	3 406.9
Willowbrook CDP (pt.)	32 760	9.7	3.7	3 377.3	8 854.1

SUMMARY POPULATION AND HOUSING CHARACTERISTICS

VOL 12

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Table 15. **Land Area and Population Density: 1990—Con.**

[For definitions of terms and meanings of symbols, see text]

State / County / County Subdivision / Place	All persons	Land area: Square kilometers	Land area: Square miles	Persons per—: Square kilometer	Persons per—: Square mile
Los Angeles County—Con.					
Downey-Norwalk division	364 508	111.7	43.1	3 263.3	8 457.3
Artesia city	15 464	4.2	1.6	3 681.9	9 665.0
Bellflower city	61 815	15.7	6.1	3 937.3	10 133.6
Bell Gardens city (pt.)	-	-	-	-	-
Cerritos city (pt.)	53 223	22.3	8.6	2 386.7	6 180.7
Downey city (pt.)	91 444	32.2	12.4	2 839.9	7 374.5
Norwalk city (pt.)	94 275	25.1	9.7	3 756.0	9 719.1
Paramount city (pt.)	47 666	12.1	4.7	3 939.3	10 141.7
Santa Fe Springs city (pt.)	199	-	-	-	-
East San Gabriel Valley division	860 847	556.6	214.9	1 546.6	4 005.8
Avocado Heights CDP	14 232	6.9	2.7	2 062.6	5 271.1
Azusa city	41 333	23.3	9.0	1 773.9	4 592.6
Baldwin Park city (pt.)	69 330	17.1	6.6	4 054.4	10 504.5
Charter Oak CDP	8 858	2.3	.9	3 851.3	9 842.2
Citrus CDP	9 481	2.3	.9	4 122.2	10 534.4
Claremont city	32 503	28.5	11.0	1 140.5	2 954.8
Covina city	43 207	17.0	6.9	2 613.8	6 261.9
Diamond Bar city	53 672	39.1	15.1	1 372.7	3 554.4
Duarte city (pt.)	-	-	-	-	-
Glendora city (pt.)	47 785	37.0	14.3	1 291.5	3 341.6
Hacienda Heights CDP	52 354	28.6	11.1	1 830.6	4 716.6
Industry city (pt.)	622	29.0	11.2	21.4	55.5
Irwindale city (pt.)	1 050	24.1	9.3	43.6	112.9
La Habra Heights city (pt.)	526	1.4	.5	375.7	1 052.0
La Puente city	36 955	9.0	3.5	4 106.1	10 558.6
La Verne city (pt.)	30 897	19.6	7.6	1 576.4	4 065.4
Pomona city	131 723	59.1	22.8	2 228.8	5 777.3
Rowland Heights CDP	42 647	21.1	8.2	2 021.2	5 200.9
San Dimas city	32 397	40.2	15.5	805.9	2 090.1
South San Jose Hills CDP	17 814	3.7	1.4	4 814.6	12 724.3
Valinda CDP	18 735	5.2	2.0	3 602.9	9 367.5
Vincent CDP	13 713	3.8	1.5	3 608.7	9 142.0
Walnut city	29 105	22.0	8.9	1 323.0	3 270.2
West Covina city	96 086	42.0	16.2	2 287.8	5 931.2
West Puente Valley CDP	20 254	4.6	1.8	4 403.0	11 252.2
Glendale division	197 944	88.6	34.2	2 234.1	5 787.8
Burbank city (pt.)	-	-	-	-	-
Glendale city (pt.)	180 038	79.2	30.6	2 273.0	5 883.9
La Canada Flintridge city (pt.)	858	.6	.2	1 430.0	4 290.0
La Crescenta-Montrose CDP	16 968	8.7	3.4	1 950.3	4 990.6
Los Angeles city (pt.)	-	-	-	-	-
Inglewood division	342 790	76.7	29.6	4 469.3	11 581.0
Alondra Park CDP	12 215	4.1	1.6	2 979.3	7 634.4
Del Aire CDP	8 040	2.6	1.0	3 092.3	8 040.0
Gardena city	49 847	13.7	5.3	3 638.5	9 405.1
Hawthorne city	71 349	15.4	5.9	4 633.1	12 093.1
Inglewood city (pt.)	109 229	23.6	9.1	4 628.3	12 003.2
Lawndale city	27 331	5.1	2.0	5 359.0	13 665.5
Lennox CDP	22 757	3.0	1.2	7 585.7	18 964.2
Los Angeles city (pt.)	2	.2	.1	10.0	20.0
West Athens CDP	8 859	3.5	1.3	2 531.1	6 814.6
Westmont CDP	31 044	4.8	1.9	6 467.5	16 338.9
Long Beach-Lakewood division	526 383	162.9	62.9	3 231.3	8 368.6
Carson city (pt.)	27	-	-	-	-
Cerritos city (pt.)	17	-	-	-	-
Compton city (pt.)	8	-	-	-	-
Hawaiian Gardens city	13 639	2.5	.9	5 455.6	15 154.4
Lakewood city	73 557	24.3	9.4	3 027.0	7 825.2
Long Beach city (pt.)	429 406	120.6	49.7	3 239.1	8 640.0
Signal Hill city	8 371	5.8	2.2	1 443.3	3 805.0
Los Angeles division	3 647 256	1 282.1	495.0	2 844.8	7 368.2
Alhambra city (pt.)	730	-	-	-	-
Beverly Hills city	31 971	14.7	5.7	2 174.9	5 608.9
Burbank city (pt.)	-	-	-	-	-
Carson city (pt.)	-	-	-	-	-
Culver City city	38 793	13.2	5.1	2 938.9	7 606.5
East Los Angeles CDP (pt.)	-	-	-	-	-
Glendale city (pt.)	-	-	-	-	-
Inglewood city (pt.)	373	.1	-	3 730.0	-
Ladera Heights CDP	6 316	5.8	2.2	1 089.0	2 870.9
Lomita city (pt.)	-	-	-	-	-
Los Angeles city (pt.)	3 484 793	1 212.4	468.1	2 874.3	7 444.5
Marina del Rey CDP	7 431	2.3	.9	3 230.9	8 256.7
Rancho Palos Verdes city (pt.)	-	-	-	-	-
San Fernando city	22 580	6.2	2.4	3 641.9	9 408.3
Santa Monica city (pt.)	-	-	-	-	-
Vernon city (pt.)	-	-	-	-	-
View Park-Windsor Hills CDP	11 769	4.7	1.8	2 504.0	6 538.3
West Hollywood city	36 118	4.9	1.9	7 371.0	19 009.5
Willowbrook CDP (pt.)	12	-	-	-	-
Newhall division	141 551	980.4	378.5	144.4	374.0
Los Angeles city (pt.)	-	.4	.1	-	-
Santa Clarita city (pt.)	100 470	90.8	37.8	1 106.8	2 869.6
Val Verde CDP	1 689	.9	.3	1 876.7	5 630.0
North Antelope Valley division	129 893	2 424.0	935.9	53.6	138.8
Lake Los Angeles CDP	7 977	12.6	4.9	633.1	1 628.0
Lancaster city (pt.)	97 275	225.9	87.2	430.6	1 115.5
Palmdale city (pt.)	281	39.5	15.2	7.1	18.5
Quartz Hill CDP (pt.)	6 931	6.8	2.6	1 019.3	2 665.8
Palos Verdes division	89 890	413.0	159.5	217.7	563.6
Avalon city	2 918	3.1	1.2	941.3	2 431.7
Lomita city (pt.)	19 382	4.8	1.9	4 037.9	10 201.1
Los Angeles city (pt.)	64	-	-	-	-
Palos Verdes Estates city	13 512	12.4	4.8	1 089.7	2 815.0
Rancho Palos Verdes city (pt.)	41 659	35.4	13.7	1 176.8	3 040.8
Rolling Hills city	1 871	7.9	3.1	236.8	603.5
Rolling Hills Estates city	7 789	9.2	3.5	846.6	2 225.4
Torrance city (pt.)	-	-	-	-	-

State / County / County Subdivision / Place	All persons	Land area: Square kilometers	Land area: Square miles	Persons per—: Square kilometer	Persons per—: Square mile
Los Angeles County—Con.					
Pasadena division	239 099	130.8	50.5	1 828.0	[illegible]
Altadena CDP	42 658	22.5	8.7	1 895.9	[illegible]
Arcadia city (pt.)	13	-	-	-	-
East Pasadena CDP	5 910	3.4	1.3	1 738.2	[illegible]
Glendale city (pt.)	20	.1	-	208.6	[illegible]
La Canada Flintridge city (pt.)	18 520	21.8	8.4	849.5	[illegible]
Los Angeles city (pt.)	-	-	-	-	-
Pasadena city (pt.)	131 591	59.5	23.0	2 211.6	[illegible]
San Marino city	12 959	9.8	3.8	1 322.3	[illegible]
South Pasadena city	23 936	8.9	3.4	2 689.4	[illegible]
Santa Monica division	86 955	21.4	8.3	4 063.3	[illegible]
Los Angeles city (pt.)	50	-	-	-	-
Santa Monica city (pt.)	86 905	21.4	8.3	4 061.0	[illegible]
South Antelope Valley division	173 178	2 084.4	1 190.9	83.1	[illegible]
Acton CDP	1 471	12.0	4.6	39.0	[illegible]
Desert View Highlands CDP	2 154	1.2	.5	1 795.0	[illegible]
Glendora city (pt.)	43	13.5	5.2	3.2	[illegible]
Lancaster city (pt.)	16	4.1	1.6	3.9	[illegible]
La Verne city (pt.)	-	.6	.2	-	-
Littlerock CDP	1 320	3.8	1.5	347.4	[illegible]
Los Angeles city (pt.)	409	2.0	.8	204.5	[illegible]
Palmdale city (pt.)	68 561	161.6	62.4	424.3	[illegible]
Palmdale East CDP	3 052	1.2	.5	2 543.3	[illegible]
Pasadena city (pt.)	-	-	-	-	-
Quartz Hill CDP (pt.)	2 695	3.2	1.2	842.2	[illegible]
Santa Clarita city (pt.)	2 172	6.8	2.6	319.4	[illegible]
South Bay Cities division	125 672	44.5	17.2	2 824.1	[illegible]
El Segundo city	15 223	14.4	5.5	1 057.2	[illegible]
Hermosa Beach city	18 219	3.7	1.4	4 924.1	[illegible]
Los Angeles city (pt.)	-	-	-	-	-
Manhattan Beach city	32 063	10.2	3.9	3 143.4	[illegible]
Redondo Beach city (pt.)	60 167	16.3	6.3	3 691.2	[illegible]
Torrance city (pt.)	-	-	-	-	-
Southeast division	481 569	107.2	41.4	4 492.2	[illegible]
Bell city	34 365	6.6	2.6	5 206.8	[illegible]
Bell Gardens city (pt.)	42 355	6.5	2.5	6 516.2	[illegible]
Commerce city (pt.)	12 114	16.9	6.5	716.8	[illegible]
Cudahy city	22 817	2.9	1.1	7 867.9	[illegible]
Downey city (pt.)	-	-	-	-	-
East Los Angeles CDP (pt.)	125 837	19.3	7.5	6 520.1	[illegible]
Florence-Graham CDP	57 147	9.2	3.6	6 211.6	[illegible]
Huntington Park city	56 065	7.9	3.1	7 096.8	[illegible]
Los Angeles city (pt.)	70	.1	-	700.0	-
Lynwood city (pt.)	62	.1	-	620.0	-
Maywood city	27 850	3.0	1.2	9 283.3	23 208.3
Montebello city (pt.)	56	.1	-	560.0	-
Monterey Park city (pt.)	1 642	.8	.3	2 052.5	5 473.3
Paramount city (pt.)	3	-	-	-	-
South Gate city	86 284	19.0	7.4	4 541.3	11 660.0
Vernon city (pt.)	152	12.8	4.9	11.9	31.0
Walnut Park CDP	14 722	1.9	.7	7 748.4	21 031.4
Southwest San Gabriel Valley division	308 267	91.4	35.3	3 372.7	8 732.8
Alhambra city (pt.)	81 376	19.7	7.6	4 130.8	10 707.4
Commerce city (pt.)	21	-	-	-	-
East Los Angeles CDP (pt.)	542	.1	-	5 420.0	-
East San Gabriel CDP (pt.)	5 236	2.0	.8	2 618.0	6 545.0
El Monte city (pt.)	92	.2	.1	460.0	920.0
Los Angeles city (pt.)	-	-	-	-	-
Montebello city (pt.)	59 508	21.2	8.2	2 793.8	7 257.1
Monterey Park city (pt.)	59 096	19.0	7.3	3 110.3	8 095.2
Pico Rivera city (pt.)	-	-	-	-	-
Rosemead city (pt.)	51 617	13.2	5.1	3 910.4	10 121.0
San Gabriel city	37 120	10.7	4.1	3 469.2	9 053.7
South El Monte city (pt.)	-	-	-	-	-
South San Gabriel CDP	7 700	2.2	.8	3 500.0	9 625.0
Temple City city (pt.)	551	.1	.1	5 510.0	5 510.0
Torrance division	133 107	53.1	20.5	2 506.7	6 493.0
Redondo Beach city (pt.)	-	-	-	-	-
Torrance city (pt.)	133 107	53.1	20.5	2 506.7	6 493.0
Upper San Gabriel Valley division	299 775	149.7	57.8	2 002.5	5 186.4
Arcadia city (pt.)	48 277	28.2	10.9	1 712.0	4 429.1
Baldwin Park city (pt.)	-	-	-	-	-
Bradbury city	829	4.3	1.7	192.8	487.6
Duarte city (pt.)	20 688	18.7	7.2	1 106.3	2 873.3
East San Gabriel CDP (pt.)	7 500	2.0	.8	3 750.0	9 375.0
El Monte city (pt.)	106 117	24.4	9.4	4 349.1	11 289.0
Industry city (pt.)	9	.2	.1	45.0	90.0
Irwindale city (pt.)	-	-	-	-	-
Mayflower Village CDP	4 978	1.7	.7	2 928.2	7 111.4
Monrovia city	35 761	34.6	13.4	1 033.6	2 668.7
North El Monte CDP	3 384	1.1	.4	3 076.4	8 460.0
Pico Rivera city (pt.)	-	-	-	-	-
Rosemead city (pt.)	21	-	-	-	-
Sierra Madre city	10 762	7.8	3.0	1 379.7	3 587.3
South El Monte city (pt.)	20 850	7.5	2.9	2 780.0	7 189.7
Temple City city (pt.)	30 549	10.2	4.0	2 995.0	7 637.3
Whittier division	286 420	154.4	59.6	1 855.1	4 805.7
East La Mirada CDP	9 367	2.9	1.1	3 230.0	8 515.5
Industry city (pt.)	-	.7	.3	-	-
La Habra Heights city (pt.)	5 700	15.1	5.8	377.5	982.8
La Mirada city	40 452	20.3	7.9	1 992.7	5 120.5
Norwalk city (pt.)	4	.2	.1	20.0	40.0
Pico Rivera city (pt.)	59 177	20.6	8.0	2 872.7	7 397.1
Santa Fe Springs city (pt.)	15 321	22.4	8.7	684.0	1 761.0
South Whittier CDP	49 514	13.9	5.4	3 562.2	9 169.3
West Whittier-Los Nietos CDP	24 164	6.8	2.6	3 553.5	9 293.8
Whittier city	77 671	32.5	12.5	2 389.9	6 213.7
Madera County	88 090	5 538.5	2 138.4	15.9	41.2
Chowchilla division	10 160	404.9	156.3	25.1	65.0
Chowchilla city	5 930	7.6	2.9	780.3	2 044.8

United States
Environmental Protection
Agency

Office of Water
Washington, DC 20460

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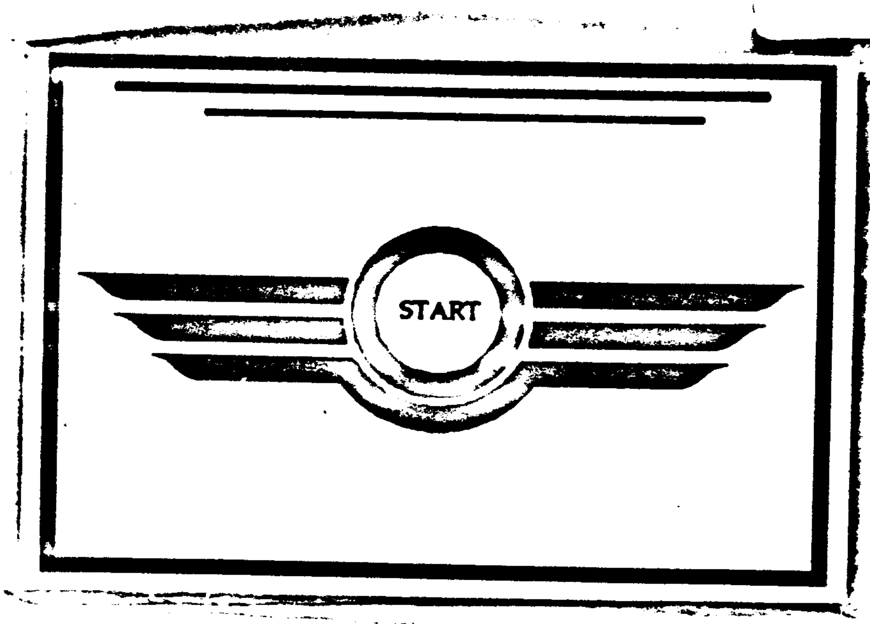
Guidance Specifying Management Measures For Sources Of Nonpoint Pollution In Coastal Waters



Issued Under the Authority of
Section 6217(g) of the Coastal Zone Act
Reauthorization Amendments of 1990

Guidance Specifying Management Measures For Sources Of Nonpoint Pollution In Coastal Waters

Issued Under the Authority of Section 6217(g)
of the Coastal Zone Act Reauthorization
Amendments of 1990

United States Environmental Protection Agency
Office of Water
Washington, DC

FOREWORD

This document contains guidance specifying management measures for sources of nonpoint pollution in coastal waters. Nonpoint pollution is the pollution of our nation's waters caused by rainfall or snowmelt moving over and through the ground. As the runoff moves, it picks up and carries away natural pollutants and pollutants resulting from human activity, finally depositing them into lakes, rivers, wetlands, coastal waters, and ground waters. In addition, hydrologic modification is a form of nonpoint source pollution that often adversely affects the biological and physical integrity of surface waters.

In the Coastal Zone Act Reauthorization Amendments of 1990 (CZARA), Congress recognized that nonpoint pollution is a key factor in the continuing degradation of many coastal waters and established a new program to address this pollution. Congress further recognized that the solution to nonpoint pollution lies in State and local action. Thus, in enacting the CZARA, Congress called upon States to develop and implement State Coastal Nonpoint Pollution Control Programs.

Congress assigned to the U.S. Environmental Protection Agency (EPA) the responsibility to develop this technical guidance to guide the States' development of Coastal Nonpoint Pollution Control Programs, which must be in conformity with the technical guidance. EPA developed this guidance by carefully surveying the technical literature, working with Federal and State agencies, and engaging in extensive dialogue with the public to identify the best economically achievable measures that are available to protect coastal waters from nonpoint pollution.

This "management measures" guidance addresses five source categories of nonpoint pollution: agriculture, silviculture, urban, marinas, and hydromodification. A suite of management measures is provided for each source category. In addition, we have included a chapter that provides management measures that provide other tools available to address many source categories of nonpoint pollution; these tools include the protection, restoration, and construction of wetlands, riparian areas, and vegetated treatment systems.

In addition to this "management measures" guidance, EPA and the National Oceanic and Atmospheric Administration (NOAA) have jointly published final guidance for the approval of State programs that implement management measures. That guidance explains more fully how the management measures guidance will be implemented in State programs.

We at EPA strongly believe that, working together, the States, EPA, NOAA, other Federal agencies, and local communities can achieve the goal of the Clean Water Act to make our waters fishable and swimmable. We hope that the enclosed guidance will help us all achieve our common goal.

Robert H. Wayland III, Director
Office of Wetlands, Oceans, and
Watersheds

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CHAPTER 1: Introduction

I. BACKGROUND

This guidance specifying management measures for sources of nonpoint pollution in coastal waters is required under section 6217 of the Coastal Zone Act Reauthorization Amendments of 1990 (CZARA). It provides guidance to States and Territories on the types of management measures that should be included in State and Territorial Coastal Nonpoint Pollution Control Programs. This chapter explains in detail the requirements of section 6217 and the approach used by the U.S. Environmental Protection Agency (EPA) to develop the management measures.

A. Nonpoint Source Pollution

1. What Is Nonpoint Source Pollution?

Nonpoint source pollution generally results from land runoff, precipitation, atmospheric deposition, drainage, seepage, or hydrologic modification. Technically, the term "nonpoint source" is defined to mean any source of water pollution that does not meet the legal definition of "point source" in section 502(14) of the Clean Water Act. That definition states:

> The term "point source" means any discernible, confined and discrete conveyance, including but not limited to any pipe, ditch, channel, tunnel, conduit, well, discrete fissure, container, rolling stock, concentrated animal feeding operation, or vessel or other floating craft, from which pollutants are or may be discharged. This term does not include agricultural storm water discharges and return flows from irrigated agriculture.

Although diffuse runoff is generally treated as nonpoint source pollution, runoff that enters and is discharged from conveyances such as those described above is treated as a point source discharge and hence is subject to the permit requirements of the Clean Water Act. In contrast, nonpoint sources are not subject to Federal permit requirements. The distinction between nonpoint sources and diffuse point sources is sometimes unclear. Therefore, at several points in this document, EPA provides detailed discussions to help the reader discern whether a particular source is a point source or a nonpoint source. Refer to Chapter 2, Section II.B.1 (discussing applicability of management measures to confined animal facility management); Chapter 4, Section I.E (discussing overlaps between this program and the storm water permit program for point sources); and Chapter 5, Section I.G (discussing overlaps between this program and several other programs, including the point source permit program).

Nonpoint pollution is the pollution of our nation's waters caused by rainfall or snowmelt moving over and through the ground. As the runoff moves, it picks up and carries away natural pollutants and pollutants resulting from human activity, finally depositing them into lakes, rivers, wetlands, coastal waters, and ground waters. In addition, hydrologic modification is a form of nonpoint source pollution that often adversely affects the biological and physical integrity of surface waters. A more detailed discussion of the range of nonpoint sources and their effects on water quality and riparian habitats is provided in subsequent chapters of this guidance.

2. National Efforts to Control Nonpoint Pollution

a. *Nonpoint Source Program*

During the first 15 years of the national program to abate and control water pollution, EPA and the States have focused most of their water pollution control activities on traditional "point sources," such as discharges through pipes from sewage treatment plants and industrial facilities. These point sources have been regulated by EPA and the States through the National Pollutant Discharge Elimination System (NPDES) permit program established by section 402 of the Clean Water Act. Discharges of dredged and fill materials into wetlands have also been regulated by the U.S. Army Corps of Engineers and EPA under section 404 of the Clean Water Act.

As a result of the above activities, the Nation has greatly reduced pollutant loads from point source discharges and has made considerable progress in restoring and maintaining water quality. However, the gains in controlling point sources have not solved all of the Nation's water quality problems. Recent studies and surveys by EPA and by State water quality agencies indicate that the majority of the remaining water quality impairments in our nation's rivers, streams, lakes, estuaries, coastal waters, and wetlands result from nonpoint source pollution and other nontraditional sources, such as urban storm water discharges and combined sewer overflows.

In 1987, in view of the progress achieved in controlling point sources and the growing national awareness of the increasingly dominant influence of nonpoint source pollution on water quality, Congress amended the Clean Water Act to focus greater national efforts on nonpoint sources. In the Water Quality Act of 1987, Congress amended section 101, "Declaration of Goals and Policy," to add the following fundamental principle:

> It is the national policy that programs for the control of nonpoint sources of pollution be developed and implemented in an expeditious manner so as to enable the goals of this Act to be met through the control of both point and nonpoint sources of pollution.

More importantly, Congress enacted section 319 of the Clean Water Act, which established a national program to control nonpoint sources of water pollution. Under section 319, States address nonpoint pollution by assessing nonpoint source pollution problems and causes within the State, adopting management programs to control the nonpoint source pollution, and implementing the management programs. Section 319 authorizes EPA to issue grants to States to assist them in implementing those management programs or portions of management programs which have been approved by EPA.

b. National Estuary Program

EPA also administers the National Estuary Program under section 320 of the Clean Water Act. This program focuses on point and nonpoint pollution in geographically targeted, high-priority estuarine waters. In this program, EPA assists State, regional, and local governments in developing comprehensive conservation and management plans that recommend priority corrective actions to restore estuarine water quality, fish populations, and other designated uses of the waters.

c. Pesticides Program

Another program administered by EPA that controls some forms of nonpoint pollution is the pesticides program under the Federal Insecticide, Fungicide, and Rodenticide Act (FIFRA). Among other provisions, this program authorizes EPA to control pesticides that may threaten ground water and surface water. FIFRA provides for the registration of pesticides and enforceable label requirements, which may include maximum rates of application, restrictions on use practices, and classification of pesticides as "restricted use" pesticides (which restricts use to certified applicators trained to handle toxic chemicals). The requirements of FIFRA, and their relationship to this guidance, are discussed more fully in Chapter 2, Section II.D, of this guidance.

B. Coastal Zone Management

The Coastal Zone Management Act of 1972 (CZMA) established a program for States and Territories to voluntarily develop comprehensive programs to protect and manage coastal resources (including the Great Lakes). To receive Federal approval and implementation funding, States and Territories had to demonstrate that they had programs, including enforceable policies, that were sufficiently comprehensive and specific both to regulate land uses, water uses, and coastal development and to resolve conflicts between competing uses. In addition, they had to have the authorities to implement the enforceable policies.

There are 29 federally approved State and Territorial programs. Despite institutional differences, each program must protect and manage important coastal resources, including wetlands, estuaries, beaches, dunes, barrier islands, coral reefs, and fish and wildlife and their habitats. Resource management and protection are accomplished in a number of ways through State laws, regulations, permits, and local plans and zoning ordinances.

While water quality protection is integral to the management of many of these coastal resources, it was not specifically cited as a purpose or policy of the original statute. The Coastal Zone Act Reauthorization Amendments of 1990, described below, specifically charged State coastal programs, as well as State nonpoint source programs, with addressing nonpoint source pollution affecting coastal water quality.

C. Coastal Zone Act Reauthorization Amendments of 1990

1. Background and Purpose of the Amendments

On November 5, 1990, Congress enacted the Coastal Zone Act Reauthorization Amendments of 1990. These Amendments were intended to address several concerns, a major one of which is the impact of nonpoint source pollution on coastal waters. In section 6202(a) of the Amendments, Congress made a set of findings, which are quoted below in pertinent part.

"1. Our oceans, coastal waters, and estuaries constitute a unique resource. The condition of the water quality in and around the coastal areas is significantly declining. Growing human pressures on the coastal ecosystem will continue to degrade this resource until adequate actions and policies are implemented.

"2. Almost one-half of our total population now lives in coastal areas. By 2010, the coastal population will have grown from 80,000,000 in 1960 to 127,000,000 people, an increase of approximately 60 percent, and population density in coastal counties will be among the highest in the Nation.

"3. Marine resources contribute to the Nation's economic stability. Commercial and recreational fishery activities support an industry with an estimated value of $12,000,000,000 a year.

"4. Wetlands play a vital role in sustaining the coastal economy and environment. Wetlands support and nourish fishery and marine resources. They also protect the Nation's shores from storm and wave damage. Coastal wetlands contribute an estimated $5,000,000,000 to the production of fish and shellfish in the United States coastal waters. Yet, 50 percent of the Nation's coastal wetlands have been destroyed, and more are likely to decline in the near future.

"5. Nonpoint source pollution is increasingly recognized as a significant factor in coastal water degradation. In urban areas, storm water and combined sewer overflow are linked to major coastal problems, and in rural areas, runoff from agricultural activities may add to coastal pollution.

"6. Coastal planning and development control measures are essential to protect coastal water quality, which is subject to continued ongoing stresses. Currently, not enough is being done to manage and protect coastal resources.

. . . .

"8. There is a clear link between coastal water quality and land use activities along the shore. State management programs under the Coastal Zone Management Act of 1972 (16 U.S.C. 1451 et seq.) are among the best tools for protecting coastal resources and must play a larger role, particularly in improving coastal zone water quality."

Based upon these findings, Congress declared that:

> "It is the purpose of Congress in this subtitle [the Coastal Zone Act Reauthorization Amendments of 1990] to enhance the effectiveness of the Coastal Zone Management Act of 1972 by increasing our understanding of the coastal environment and expanding the ability of State coastal zone management programs to address coastal environmental problems." (Section 6202(b))

2. State Coastal Nonpoint Pollution Control Programs

To address more specifically the impacts of nonpoint source pollution on coastal water quality, Congress enacted section 6217, "Protecting Coastal Waters," which was codified as 16 U.S.C. §1455b. This section provides that each State with an approved coastal zone management program must develop and submit to EPA and the National Oceanic and Atmospheric Administration (NOAA) for approval a Coastal Nonpoint Pollution Control Program. The purpose of the program "shall be to develop and implement management measures for nonpoint source pollution to restore and protect coastal waters, working in close conjunction with other State and local authorities."

Coastal Nonpoint Pollution Control Programs are not intended to supplant existing coastal zone management programs and nonpoint source management programs. Rather, they are to serve as an update and expansion of existing nonpoint source management programs and are to be coordinated closely with the existing coastal zone management programs. The legislative history indicates that the central purpose of section 6217 is to strengthen the links between Federal and State coastal zone management and water quality programs and to enhance State and local efforts to manage land use activities that degrade coastal waters and coastal habitats. The legislative history further indicates that State coastal zone and water quality agencies are to have coequal roles, analogous to the sharing of responsibility between NOAA and EPA at the Federal level.

Section 6217(b) states that each State program must "provide for the implementation, at a minimum, of management measures in conformity with the guidance published under subsection (g) to protect coastal waters generally," and also to:

(1) Identify land uses which, individually or cumulatively, may cause or contribute significantly to a degradation of (a) coastal waters where there is a failure to attain or maintain applicable water quality standards or protect designated uses, or (b) coastal waters that are threatened by reasonably foreseeable increases in pollution loadings from new or expanding sources;

(2) Identify critical coastal areas adjacent to coastal waters identified under the preceding paragraph;

(3) Implement additional management measures applicable to land uses and areas identified under paragraphs (1) and (2) above that are necessary to achieve and maintain applicable water quality standards and protect designated uses;

(4) Provide technical assistance to local governments and the public to implement the additional management measures;

(5) Provide opportunities for public participation in all aspects of the program;

(6) Establish mechanisms to improve coordination among State and local agencies and officials responsible for land use programs and permitting, water quality permitting and enforcement, habitat protection, and public health and safety; and

(7) Propose to modify State coastal zone boundaries as necessary to implement NOAA's recommendations under section 6217(e), which are based on NOAA's findings that inland boundaries must be modified to more effectively manage land and water uses to protect coastal waters.

Congress required that, within 30 months of EPA's publication of final guidance, States must develop and obtain EPA and NOAA approval of their Coastal Nonpoint Pollution Control Programs. Failure to submit an approvable program (i.e., one that meets the requirements of section 6217(b)) will result in a reduction of Federal grant dollars under the nonpoint source and coastal zone management programs. The reductions will begin in Fiscal Year 1996 (FY 1996) as a 10 percent cut, increasing to 15 percent in FY 1997, 20 percent in FY 1998, and 30 percent in FY 1999 and thereafter.

3. Management Measures Guidance

Section 6217(g) of the Coastal Zone Act Reauthorization Amendments of 1990 requires EPA to publish (and periodically revise thereafter), in consultation with NOAA, the U.S. Fish and Wildlife Service, and other Federal agencies, "guidance for specifying management measures for sources of nonpoint pollution in coastal waters." "Management measures" are defined in section 6217(g)(5) as:

> economically achievable measures for the control of the addition of pollutants from existing and new categories and classes of nonpoint sources of pollution, which reflect the greatest degree of pollutant reduction achievable through the application of the best available nonpoint pollution control practices, technologies, processes, siting criteria, operating methods, or other alternatives.

The management measures guidance is to include at a minimum six elements set forth in section 6217(g)(2):

> "(A) a description of a range of methods, measures, or practices, including structural and nonstructural controls and operation and maintenance procedures, that constitute each measure;
>
> "(B) a description of the categories and subcategories of activities and locations for which each measure may be suitable;
>
> "(C) an identification of the individual pollutants or categories or classes of pollutants that may be controlled by the measures and the water quality effects of the measures;
>
> "(D) quantitative estimates of the pollution reduction effects and costs of the measures;
>
> "(E) a description of the factors which should be taken into account in adapting the measures to specific sites or locations; and
>
> "(F) any necessary monitoring techniques to accompany the measures to assess over time the success of the measures in reducing pollution loads and improving water quality."

State Coastal Nonpoint Pollution Control programs must provide for the implementation of management measures that are in conformity with this management measures guidance.

The legislative history (floor statement of Rep. Gerry Studds, House sponsor of section 6217, as part of debate on Omnibus Reconciliation Bill, October 26, 1990) confirms that, as indicated by the statutory language, the "management measures" approach is technology-based rather than water-quality-based. That is, the management measures are to be based on technical and economic achievability, rather than on cause-and-effect linkages between particular land use activities and particular water quality problems. As the legislative history makes clear, implementation of these technology-based management measures will allow States to concentrate their resources initially on developing and implementing measures that experts agree will reduce pollution significantly. As explained more fully in a separate document, *Coastal Nonpoint Pollution Control Program: Program Development and Approval Guidance*, States will follow up the implementation of management measures with additional management measures to address any remaining coastal water quality problems.

The legislative history indicates that the range of management measures anticipated by Congress is broad and may include, among other measures, use of buffer strips, setbacks, techniques for identifying and protecting critical coastal areas and habitats, soil erosion and sedimentation controls, and siting and design criteria for water-related uses such as marinas. However, Congress has cautioned that the management measures should not unduly intrude upon the more intimate land use authorities properly exercised at the local level.

The legislative history also indicates that the management measures guidance, while patterned to a degree after the point source effluent guidelines' technology-based approach (see 40 CFR Parts 400-471 for examples of this approach), is not expected to have the same level of specificity as effluent guidelines. Congress has recognized that the effectiveness of a particular management measure at a particular site is subject to a variety of factors too complex to address in a single set of simple, mechanical prescriptions developed at the Federal level. Thus, the legislative history indicates that EPA's guidance should offer State officials a number of options and permit them considerable flexibility in selecting management measures that are appropriate for their State. Thus, the management measures in this document are written to allow such flexibility in implementation.

An additional major distinction drawn in the legislative history between effluent guidelines for point sources and this management measures guidance is that the management measures will not be directly or automatically applied to categories of nonpoint sources as a matter of Federal law. Instead, it is the State coastal nonpoint program, backed by the authority of State law, that must provide for the implementation of management measures in conformity with the management measures guidance. Under section 306(d)(16) of the CZMA, coastal zone programs must provide for enforceable policies and mechanisms to implement the applicable requirements of the State Coastal Nonpoint Pollution Control Program, including the management measures developed by the State "in conformity" with this guidance.

D. Program Implementation Guidance

In addition to this "management measures" guidance, EPA and NOAA have also jointly published *Coastal Nonpoint Pollution Control Program: Program Development and Approval Guidance*. That document provides guidance to States in interpreting and applying the various provisions of section 6217 of CZARA. It addresses issues such as the following: the basis and process for EPA/NOAA approval of State Coastal Nonpoint Pollution Control Programs; how EPA and NOAA expect State programs to implement management measures "in conformity" with this management measures guidance; how States may target sources in implementing their programs; changes in State coastal boundaries to implement their programs; and other aspects of State implementation of their programs.

II. DEVELOPMENT OF THE MANAGEMENT MEASURES GUIDANCE

A. Process Used to Develop This Guidance

Congress established a 6-month deadline (May 5, 1991) for publication of the proposed management measures guidance and an 18-month deadline (May 5, 1992) for publication of the final guidance.

EPA published the proposed guidance on June 14, 1991, and, in the interest of promoting the broadest possible consideration of the proposal by a wide variety of interested Federal and State agencies, affected industries, and citizens groups, provided a 6-month comment period. EPA received 477 public comments on the proposed guidance. In addition, EPA maintained an open process of consultation and discussion with many of the commenters and other experts. EPA's response to those comments, both written and oral, is reflected in the final guidance and is summarized in a separate document available from EPA entitled *Guidance Specifying Management Measures for Sources of Nonpoint Pollution in Coastal Waters: Response to Public Comments.*

In developing the final guidance, EPA continued to draw upon a diversity of knowledgeable sources of technical nonpoint source expertise by using a work group approach. Since the guidance addresses all nationally significant categories of nonpoint sources that impact or could impact coastal waters, EPA drew upon expertise covering the very wide range of subject areas addressed in this guidance.
Because experts in the field of nonpoint source pollution tend to specialize in particular source categories, EPA decided to form work groups on a category basis. Thus, in consultation with NOAA, the U.S. Fish and Wildlife Service, and other Federal and State agencies, EPA established five work groups to develop this guidance:

(1) Urban, Construction, Highways, Airports/Bridges, and Septic Systems;
(2) Agriculture;
(3) Forestry;
(4) Marinas and Recreational Boating; and
(5) Hydromodification and Wetlands.

Each of these work groups held many 1- or 2-day meetings to discuss the technical issues related to the guidance. These meetings, which included State and Federal non-EPA participation, were very helpful to EPA in formulating the final guidance. EPA, however, made all decisions on the final contents of the guidance.

B. Scope and Contents of This Guidance

1. Categories of Nonpoint Sources Addressed

Many categories and subcategories of nonpoint sources could affect coastal waters and thus could potentially be addressed in this management measures guidance. Including all such sources in this guidance would have required more time than the tight statutory deadline allowed. For this reason, Congressman Studds stated in his floor statement, "The Conferees expect that EPA, in developing its guidance, will concentrate on the large nonpoint sources that are widely recognized as major contributors of water pollution."

This guidance thus focuses on five major categories of nonpoint sources that impair or threaten coastal waters nationally: (1) agricultural runoff; (2) urban runoff (including developing and developed areas); (3) silvicultural (forestry) runoff; (4) marinas and recreational boating; and (5) channelization and channel modification, dams, and streambank and shoreline erosion. EPA has also included management measures for wetlands, riparian areas, and vegetated treatment systems that apply generally to various categories of sources of nonpoint pollution.

2. Relationship Between This Management Measures Guidance for Coastal Nonpoint Sources and NPDES Permit Requirements for Point Sources

a. Urban Runoff

Historically, there have always been ambiguities in and overlaps between programs designed to control urban runoff nonpoint sources and those designed to control urban storm water point sources. For example, runoff may often originate from a nonpoint source but ultimately may be channelized and discharged through a point source. Potential confusion between these two programs has been heightened by Congressional enactment of two important pieces of legislation: section 402(p) of the Clean Water Act, which establishes permit requirements for certain municipal and industrial storm water discharges, and section 6217 of CZARA, which requires EPA to promulgate and States to provide for the implementation of management measures to control nonpoint pollution in coastal waters. The discussion below is intended to clarify the relationship between these two programs and describe the scope of the coastal nonpoint program and its applicability to urban runoff in coastal areas.

b. The Storm Water Permit Program

The storm water permit program is a two-phase program enacted by Congress in 1987 under section 402(p) of the Clean Water Act. Under Phase I, National Pollutant Discharge Elimination System (NPDES) permits are required to be issued for municipal separate storm sewers serving large or medium-sized populations (greater than 250,000 or 100,000 people, respectively) and for storm water discharges associated with industrial activity. Permits are also to be issued, on a case-by-case basis, if EPA or a State determines that a storm water discharge contributes to a violation of a water quality standard or is a significant contributor of pollutants to waters of the United States. EPA published a rule implementing Phase I on November 16, 1990.

Under Phase II, EPA is to prepare two reports to Congress that assess the remaining storm water discharges; determine, to the maximum extent practicable, the nature and extent of pollutants in such discharges; and establish procedures and methods to control storm water discharges to the extent necessary to mitigate impacts on water quality. Then, EPA is to issue regulations that designate storm water discharges, in addition to those addressed in Phase I, to be regulated to protect water quality, and EPA is to establish a comprehensive program to regulate those designated sources. The program is required to establish (1) priorities, (2) requirements for State storm water management programs, and (3) expeditious deadlines.

These regulations were to have been issued by EPA not later than October 1, 1992. Because of EPA's emphasis on Phase I, however, the Agency has not yet been able to complete the studies and issue appropriate regulations as required under section 402(p).

c. Coastal Nonpoint Pollution Control Programs

As discussed above, Congress enacted section 6217 of CZARA in late 1990 to require that States develop Coastal Nonpoint Pollution Control Programs that are in conformity with this management measures guidance published by EPA.

d. Scope and Coverage of This Guidance with Respect to Storm Water

EPA is excluding from coverage under this section 6217(g) guidance all storm water discharges that are covered by Phase I of the NPDES storm water permit program. Thus EPA is excluding any discharge from a municipal separate storm sewer system serving a population of 100,000 or more; any discharge of storm water associated with industrial activity; any discharge that has already been permitted; and any discharge for which EPA or the State makes a determination that the storm water discharge contributes to a violation of a water quality standard or is a significant contributor of pollutants to waters of the United States. All of these activities are clearly addressed by the storm water permit program and therefore are excluded from the coastal nonpoint pollution control program.

EPA is adopting a different approach with respect to other (non-Phase I) storm water discharges. At present, EPA has not yet promulgated regulations that would designate additional storm water discharges, beyond those regulated in Phase I, that will be required to be regulated in Phase II. It is thus not possible to determine at this point which additional storm water discharges will be regulated by the NPDES program and which will not. Furthermore, because of the great number of such discharges, it is likely that it would take many years to permit all of these discharges, even if EPA allows for relatively expeditious State permitting approaches such as the use of general permits.

Therefore, to give effect to the Congressional intent that coastal waters receive special and expeditious attention from EPA, NOAA, and the States, storm water runoff that potentially may be ultimately covered by Phase II of the storm water permit program is subject to this management measures guidance and will be addressed by the States' Coastal Nonpoint Pollution Control Programs. Any storm water runoff that ultimately is regulated under an NPDES permit will no longer be subject to this guidance once the permit is issued.

In addition, it should be noted that some other activities are not presently covered by NPDES permit application requirements and thus would be subject to a State's Coastal Nonpoint Pollution Control Program. Most importantly, construction activities on sites that result in the disturbance of less than 5 acres, which are not currently covered by Phase I storm water application requirements[1], are covered by the Coastal Nonpoint Pollution Control Program. Similarly, runoff from wholesale, retail, service, or commercial activities, including gas stations, which are not covered by Phase I of the NPDES storm water program, would be subject instead to a State's Coastal Nonpoint Pollution Control Program. Further, onsite disposal systems, which are generally not covered by the storm water permit program, would be subject to a State's Coastal Nonpoint Pollution Control Program.

Finally, EPA emphasizes that while different legal authorities may apply to different situations, the goals of the NPDES and CZARA programs are complementary. Many of the techniques and practices used to control urban runoff are equally applicable to both programs. Yet, the programs do not work identically. In the interest of consistency and comprehensiveness, States have the option to implement management measures in conformity with this guidance throughout the State's 6217 management area, as long as NPDES storm water requirements continue to be met by Phase I sources in that area. States are encouraged to develop consistent approaches to addressing urban runoff throughout their 6217 management areas.

e. Marinas

Another specific overlap between the storm water program and the coastal nonpoint source programs under CZARA occurs in the case of marinas (addressed in Chapter 5 of this guidance). In this guidance, EPA has attempted to avoid addressing marina activities that are clearly regulated point source discharges. Any storm water runoff at a marina that is ultimately regulated under an NPDES permit will no longer be subject to this guidance once the permit is issued. The introduction to Chapter 5 contains a detailed discussion of the scope of the NPDES program with respect to marinas and of the corresponding coverage of marinas by the CZARA program.

f. Other Point Sources

Overlapping areas between the point source and nonpoint source programs also occur with respect to concentrated animal feeding operations. Operations that meet particular size or other criteria are defined and regulated as point sources under the section 402 permit program, while other confined animal feeding operations are not currently regulated as point sources. Other overlaps may occur with respect to aspects of mining operations, oil and gas extraction, land disposal, and other activities.

[1] On May 27, 1992, the United States Court of Appeals for the Ninth Circuit invalidated EPA's exemption of construction sites smaller than 5 acres from the storm water permit program in *Natural Resources Defense Council v. EPA*, 965 F.2d 759 (9th Cir. 1992). EPA is conducting further rulemaking proceedings on this issue and will not require permit applications for construction activities under 5 acres until further rulemaking has been completed.

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EPA intends that the Coastal Nonpoint Pollution Control Programs to be developed by the States, and the management measures they contain, apply only to sources that are not required under EPA's current regulations to obtain an NPDES permit. For any discharge ultimately covered by Phase II of the storm water permitting program, the management measures will continue to apply until an NPDES permit is issued for that discharge. In this guidance, EPA has attempted to avoid addressing activities that are regulated point source discharges.

3. Contents of This Guidance

a. General

Each category of sources (agriculture, forestry, etc.) is addressed in a separate chapter of this guidance. Each chapter is divided into sections, each of which contains (1) the management measure; (2) an applicability statement that describes, when appropriate, specific activities and locations for which the measure is suitable; (3) a description of the management measure's purpose; (4) the basis for the management measure's selection; (5) information on management practices that are suitable, either alone or in combination with other practices, to achieve the management measure; (6) information on the effectiveness of the management measure and/or of practices to achieve the measure; and (7) information on costs of the measure and/or practices to achieve the measure.

b. What "Management Measures" Are

Each section of this guidance begins with a succinct statement, set off in bold typeface in a box, that specifies a "management measure." As explained earlier, "management measures" are defined in CZARA as economically achievable measures to control the addition of pollutants to our coastal waters, which reflect the greatest degree of pollutant reduction achievable through the application of the best available nonpoint pollution control practices, technologies, processes, siting criteria, operating methods, or other alternatives.

These management measures will be incorporated by States into their coastal nonpoint programs, which under CZARA are to provide for the implementation of management measures that are "in conformity" with this guidance. Under CZARA, States are subject to a number of requirements as they develop and implement their Coastal Nonpoint Pollution Control Programs in conformity with this guidance and will have some flexibility in doing so. The application of these management measures by States to activities causing nonpoint pollution is described more fully in *Coastal Nonpoint Pollution Control Program: Program Development and Approval Guidance*, published jointly by EPA and NOAA.

c. What "Management Practices" Are

In addition to specifying management measures, this guidance also lists and describes management practices for illustrative purposes only. While State programs are required to specify management measures in conformity with this guidance, State programs need not specify or require the implementation of the particular management practices described in this document. As a practical matter, however, EPA anticipates that the management measures typically will be implemented by applying one or more management practices appropriate to the source, location, and climate. The practices listed in this document have been found by EPA to be representative of the types of practices that can be applied successfully to achieve the management measures. EPA has also used some of these practices, or appropriate combinations of these practices, as a basis for estimating the effectiveness, costs, and economic impacts of achieving the management measures. (Economic impacts of the management measures are addressed in a separate document entitled *Economic Impacts of EPA Guidance Specifying Management Measures for Sources of Nonpoint Pollution in Coastal Waters*.)

EPA recognizes that there is often site-specific, regional, and national variability in the selection of appropriate practices, as well as in the design constraints and pollution control effectiveness of practices. The list of practices for each management measure is not all-inclusive and does not preclude States or local agencies from using other technically sound practices. In all cases, however, the practice or set of practices chosen by a State needs to achieve the management measure.

EPA recognizes as well that many sources may already achieve the management measures, or that only one or two practices may need to be added to achieve the measures. Existing NPS progress should be recognized and appropriate credit given to those who have already made progress toward accomplishing our common goal to control NPS pollution. There is no need to spend additional resources for a practice that is already in existence and operational. Existing practices, plans, and systems should be viewed as building blocks for these management measures and may need no additional improvement.

III. TECHNICAL APPROACH TAKEN IN DEVELOPING THIS GUIDANCE

A. The Nonpoint Source Pollution Process

Nonpoint source pollutants are transported to surface water by a variety of means, including runoff, snowmelt, and ground-water infiltration. Ground water and surface water are both considered part of the same hydrologic cycle when designing management measures. Ground-water contributions of pollutant loadings to surface waters in coastal areas are often very significant. Hydrologic modification is another form of nonpoint source pollution that often adversely affects the biological and physical integrity of surface waters.

1. Source Control

Source control is the first opportunity in any nonpoint source control effort. Source control methods vary for different types of nonpoint source problems. Examples of source control include:

(1) Reducing or eliminating the introduction of pollutants to a land area. Examples include reduced nutrient and pesticide application.

(2) Preventing pollutants from leaving the site during land-disturbing activities. Examples include using conservation tillage, planning forest road construction to minimize erosion, siting marinas adjacent to deep waters to eliminate or minimize the need for dredging, and managing grazing to protect against overgrazing and the resulting increased soil erosion.

(3) Preventing interaction between precipitation and introduced pollutants. Examples include installing gutters and diversions to keep clean rainfall away from barnyards, diverting rainfall runoff from areas of land disturbance at construction sites, and timing chemical applications or logging activities based on weather forecasts or seasonal weather patterns.

(4) Protecting riparian habitat and other sensitive areas. Examples include protection and preservation of riparian zones, shorelines, wetlands, and highly erosive slopes.

(5) Protecting natural hydrology. Examples include the maintenance of pervious surfaces in developing areas (conditioned based on ground-water considerations), riparian zone protection, and water management.

2. Delivery Reduction

Pollution prevention often involves delivery reduction in addition to appropriate source control measures. Delivery reduction practices intercept pollutants leaving the source prior to their delivery to the receiving water by capturing the runoff or infiltrate, followed either by treating and releasing the effluent or by permanently keeping the effluent from reaching a surface water or ground-water resource. Management measures in this guidance incorporate delivery reduction practices as appropriate to achieve the greatest degree of pollutant reduction economically achievable, as required by the statute.

By their nature, delivery reduction practices often bring with them side effects that must be accounted for. For example, management practices that intercept pollutants leaving the source may reduce runoff, but also may increase infiltration to ground water. For instance, infiltration basins trap runoff and allow for its percolation. These devices, although highly successful at controlling suspended solids, may not, because of their infiltration properties, be suitable for use in areas with high ground-water tables and nitrate or pesticide residue problems. Thus, the reader should select management practices with some care for the total water quality impact of the practices.

The performance of delivery reduction practices is to a large extent dependent on suitable designs, operational conditions, and proper maintenance. For example, filter strips may be effective for controlling particulate and soluble pollutants where sedimentation is not excessive, but may be overwhelmed by high sediment input. Thus, in many cases, filter strips are used as pretreatment or supplemental treatment for other practices within a management system, rather than as an entire solution to a sedimentation problem.

These examples illustrate that the combination of source control and delivery reduction practices, as well as the application of those practices as components of management measures, is dependent on site-specific conditions. Technical factors that may affect the suitability of management measures include, but are not limited to, land use, climate, size of drainage area, soil permeability, slopes, depth to water table, space requirements, type and condition of the water resource to be protected, depth to bedrock, and pollutants to be addressed. In this management measures guidance, many of these factors are discussed as they affect the suitability of particular measures.

B. Management Measures as Systems

Technical experts who design and implement effective nonpoint source control measures do so from a management systems approach as opposed to an approach that focuses on individual practices. That is, the pollutant control achievable from any given management system is viewed as the sum of the parts, taking into account the range of effectiveness associated with each single practice, the costs of each practice, and the resulting overall cost and effectiveness. Some individual practices may not be very effective alone but, in combination with others, may provide a key function in highly effective systems. This management measures guidance attempts to adopt an approach that encourages such system-building by stating the measures in general terms, followed by discussion of specific management practices, which combined encourage the use of appropriate situation-specific sets of practices that will achieve the management measure.

C. Economic Achievability of the Proposed Management Measures

EPA has determined that all of the management measures in this guidance are economically achievable, including, where limited data were available, cost-effective. Congress defined "management measures" to mean "*economically achievable* measures ... which reflect the greatest degree of pollutant reduction achievable through the application of the best available nonpoint pollution control practices, technologies, processes, siting criteria, operating methods, or other alternatives."

CHAPTER 2: Management Measures for Agriculture Sources

I. INTRODUCTION

A. What "Management Measures" Are

This chapter specifies management measures to protect coastal waters from agricultural sources of nonpoint pollution. "Management measures" are defined in section 6217 of the Coastal Zone Act Reauthorization Amendments of 1990 (CZARA) as economically achievable measures to control the addition of pollutants to our coastal waters, which reflect the greatest degree of pollutant reduction achievable through the application of the best available nonpoint pollution control practices, technologies, processes, siting criteria, operating methods, or other alternatives.

These management measures will be incorporated by States into their coastal nonpoint programs, which under CZARA are to provide for the implementation of management measures that are "in conformity" with this guidance. Under CZARA, States are subject to a number of requirements as they develop and implement their Coastal Nonpoint Pollution Control Programs in conformity with this guidance and will have some flexibility in doing so. The application of these management measures by States to activities causing nonpoint pollution is described more fully in *Coastal Nonpoint Pollution Control Program: Program Development and Approval Guidance*, published jointly by the U.S. Environmental Protection Agency (EPA) and the National Oceanic and Atmospheric Administration (NOAA).

B. What "Management Practices" Are

In addition to specifying management *measures*, this chapter also lists and describes management *practices* for illustrative purposes only. While State programs are required to specify management *measures* in conformity with this guidance, State programs need not specify or require the implementation of the particular management *practices* described in this document. However, as a practical matter, EPA anticipates that States the management measures generally will be implemented by applying one or more management practices appropriate to the source, location, and climate. The practices listed in this document have been found by EPA to be representative of the types of practices that can be applied successfully to achieve the management measures. EPA has also used some of these practices, or appropriate combinations of these practices, as a basis for estimating the effectiveness, costs, and economic impacts of achieving the management measures. (Economic impacts of the management measures are addressed in a separate document entitled *Economic Impacts of EPA Guidance Specifying Management Measures for Sources of Nonpoint Pollution in Coastal Waters.*)

EPA recognizes that there is often site-specific, regional and national variability in the selection of appropriate practices, as well as in the design constraints and pollution control effectiveness of practices. The list of practices for each management measure is not all-inclusive and does not preclude States or local agencies from using other technically sound practices. In all cases, however, the practice or set of practices chosen by a State needs to achieve the management measure.

C. Scope of This Chapter

This chapter addresses six categories of sources of agricultural nonpoint pollution that affect coastal waters:

(1) Erosion from cropland;
(2) Confined animal facilities;
(3) The application of nutrients to cropland;
(4) The application of pesticides to cropland;
(5) Grazing management; and
(6) Irrigation of cropland.

Each category of sources (with the exception of confined animal facilities, which has two management measures) is addressed in a separate section of this guidance. Each section contains (1) the management measure; (2) an applicability statement that describes, when appropriate, specific activities and locations for which the measure is suitable; (3) a description of the management measure's purpose; (4) the basis for the management measure's selection; (5) information on the effectiveness of the management measure and/or of practices to achieve the measure; (6) information on management practices that are suitable, either alone or in combination with other practices, to achieve the management measure; and (7) information on costs of the measure and/or practices to achieve the measure.

D. Relationship of This Chapter to Other Chapters and to Other EPA Documents

1. Chapter 1 of this document contains detailed information on the legislative background for this guidance, the process used by EPA to develop this guidance, and the technical approach used by EPA in the guidance.

2. Chapter 7 of this document contains management measures to protect wetlands and riparian areas that serve a nonpoint source abatement function. These measures apply to a broad variety of sources, including agricultural sources.

3. Chapter 8 of this document contains information on recommended monitoring techniques (1) to ensure proper implementation, operation, and maintenance of the management measures and (2) to assess over time the success of the measures in reducing pollution loads and improving water quality.

4. EPA has separately published a document entitled *Economic Impacts of EPA Guidance Specifying Management Measures for Sources of Nonpoint Pollution in Coastal Waters.*

5. NOAA and EPA have jointly published guidance entitled *Coastal Nonpoint Pollution Control Program: Program Development and Approval Guidance.* This guidance contains details on how State Coastal Nonpoint Pollution Control Programs are to be developed by States and approved by NOAA and EPA. It includes guidance on the following:

   - The basis and process for EPA/NOAA approval of state Coastal Nonpoint Pollution Control Programs;
   - How NOAA and EPA expect State programs to provide for the implementation of management measures "in conformity" with this management measures guidance;
   - How States may target sources in implementing their Coastal Nonpoint Pollution Control Programs;

- Changes in State coastal boundaries; and
- Requirements concerning how States are to implement the Coastal Nonpoint Pollution Control Programs.

E. Coordination of Measures

The management measures developed for agriculture are to be used as an overall system of measures to address nonpoint source (NPS) pollution sources on any given site. In most cases, not all of the measures will be needed to address the nonpoint sources at a specific site. For example, many farms or agriculture enterprises do not have animals as part of the enterprise and would not need to be concerned with the management measures that address confined animal facilities or grazing. By the same token, many enterprises do not use irrigation and would not need to use the irrigation water management measure.

Most enterprises will have more than one source to address and may need to employ two or more of the measures to address the multiple sources. Where more than one source exists, the application of the measures is to be coordinated to produce an overall system that adequately addresses all sources for the site in a cost-effective manner.

The agricultural management measures for CZMA are, for the most part, systems of practices that are commonly used and recommended by the U.S. Department of Agriculture (USDA) as components of Resource Management Systems, Water Quality Management Plans, and Agricultural Waste Management Systems. Practices and plans installed under State NPS programs are also included. Many farms and fields, therefore, may already be in compliance with the measures needed to address the nonpoint sources on them. For cases where existing source control is inadequate to achieve conformity with the needed management measures, it may be necessary to add only one or two more practices to achieve conformity. Existing NPS progress must be recognized and appropriate credit given to the accomplishment of our common goal to control NPS pollution. There is no need to spend additional resources for a practice that is already in existence and operational. Existing practices, plans, and systems should be viewed as building blocks for these management measures and may need no additional improvement.

F. Pollutants That Cause Agricultural Nonpoint Source Pollution[1]

The primary agricultural nonpoint source pollutants are nutrients, sediment, animal wastes, salts, and pesticides. Agricultural activities also have the potential to directly impact the habitat of aquatic species through physical disturbances caused by livestock or equipment, or through the management of water. The general pathways for transport of pollutants from agricultural lands to water resources are shown in Figure 2-1 (USDA, 1991). The effects of these pollutants on water quality are discussed below.

1. Nutrients

Nitrogen (N) and phosphorus (P) are the two major nutrients from agricultural land that degrade water quality. Nutrients are applied to agricultural land in several different forms and come from various sources, including:

- Commercial fertilizer in a dry or fluid form, containing nitrogen (N), phosphorus (P), potassium (K), secondary nutrients, and micronutrients;
- Manure from animal production facilities including bedding and other wastes added to the manure, containing N,P,K, secondary nutrients, micronutrients, salts, some metals, and organics;

[1] This section on Pollutants That Cause Agricultural Nonpoint Source Pollution is adapted from USDA-SCS (1983).

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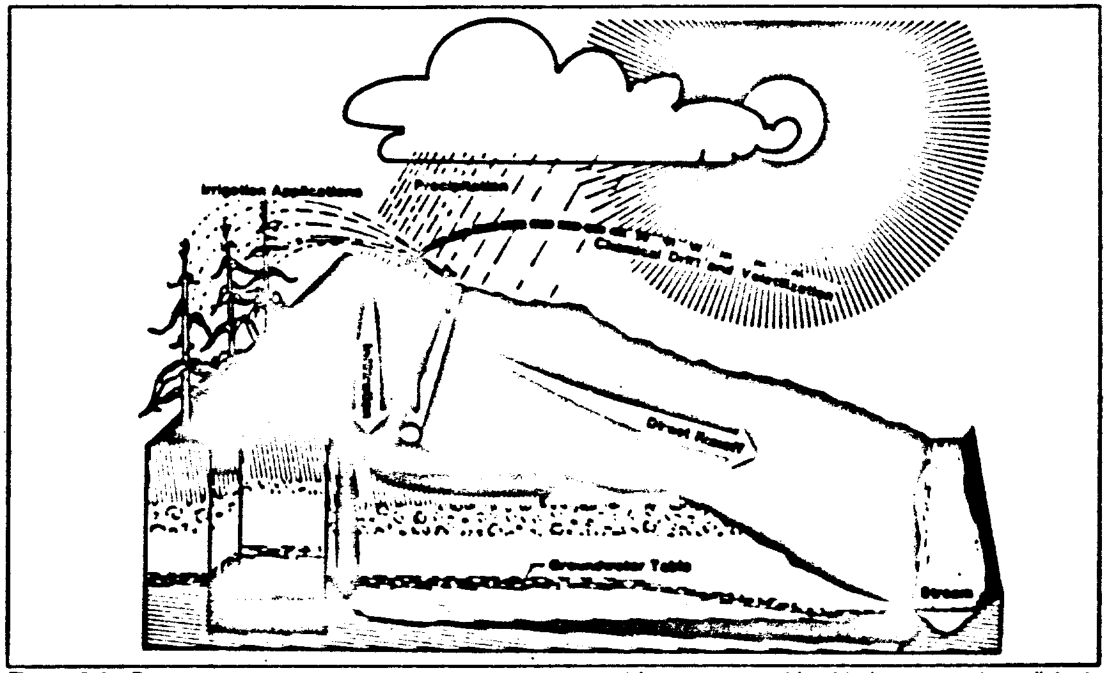

Figure 2-1. Pathways through which substances are transported from agricultural land to become water pollutants (USDA, 1991).

- Municipal and industrial treatment plant sludge, containing N.P.K, secondary nutrients, micronutrients, salts, metals, and organic solids;
- Municipal and industrial treatment plant effluent, containing N.P.K, secondary nutrients, micronutrients, salts, metals, and organics;
- Legumes and crop residues containing N, P, K, secondary nutrients, and micronutrients;
- Irrigation water; and
- Atmospheric deposition of nutrients such as nitrogen and sulphur.

Surface water runoff from agricultural lands to which nutrients have been applied may transport the following pollutants:

- Particulate-bound nutrients, chemicals, and metals, such as phosphorus, organic nitrogen, and metals applied with some organic wastes;
- Soluble nutrients and chemicals, such as nitrogen, phosphorus, metals, and many other major and minor nutrients;
- Sediment, particulate organic solids, and oxygen-demanding material;

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- Salts; and

- Bacteria, viruses, and other microorganisms.

Ground-water infiltration from agricultural lands to which nutrients have been applied may transport the following pollutants: soluble nutrients and chemicals, such as nitrogen, phosphorus, metals, and many other major and minor nutrients, and salts.

Surface water and ground-water pollutants from organic matter and crop residue decomposition and from legumes growing on agricultural land may include nitrogen, phosphorus, and other essential nutrients found in the residue of growing crops.

All plants require nutrients for growth. In aquatic environments, nutrient availability usually limits plant growth. Nitrogen and phosphorus generally are present at background or natural levels below 0.3 and 0.05 mg/L, respectively. When these nutrients are introduced into a stream, lake, or estuary at higher rates, aquatic plant productivity may increase dramatically. This process, referred to as cultural eutrophication, may adversely affect the suitability of the water for other uses.

Increased aquatic plant productivity results in the addition to the system of more organic material, which eventually dies and decays. The decaying organic matter produces unpleasant odors and depletes the oxygen supply required by aquatic organisms. Excess plant growth may also interfere with recreational activities such as swimming and boating. Depleted oxygen levels, especially in colder bottom waters where dead organic matter tends to accumulate, can reduce the quality of fish habitat and encourage the propagation of fish that are adapted to less oxygen or to warmer surface waters. Highly enriched waters will stimulate algae production, with consequent increased turbidity and color. Algae growth is also believed to be harmful to coral reefs (e.g., Florida coast). Furthermore, the increased turbidity results in less sunlight penetration and availability to submerged aquatic vegetation (SAV). Since SAV provides habitat for small or juvenile fish, the loss of SAV has severe consequences for the food chain. Chesapeake Bay is an example in which nutrients are believed to have contributed to SAV loss.

a. Nitrogen

All forms of transported nitrogen are potential contributors to eutrophication in lakes, estuaries, and some coastal waters. In general, though not in all cases, nitrogen availability is the limiting factor for plant growth in marine ecosystems. Thus, the addition of nitrogen can have a significant effect on the natural functioning of marine ecosystems.

In addition to eutrophication, excessive nitrogen causes other water quality problems. Dissolved ammonia at concentrations above 0.2 mg/L may be toxic to fish, especially trout. Nitrates in drinking water are potentially dangerous, especially to newborn infants. Nitrate is converted to nitrite in the digestive tract, which reduces the oxygen-carrying capacity of the blood (methemoglobinemia), resulting in brain damage or even death. The U.S. Environmental Protection Agency has set a limit of 10 mg/L nitrate-nitrogen in water used for human consumption (USEPA, 1989).

Nitrogen is naturally present in soils but must be added to increase crop production. Nitrogen is added to the soil primarily by applying commercial fertilizers and manure, but also by growing legumes (biological nitrogen fixation) and incorporating crop residues. Not all nitrogen that is present in or on the soil is available for plant use at any one time. For example, in the eastern Corn Belt, it is normally assumed that about 50 percent of applied N is assimilated by crops during the year of application (Nelson, 1985). Organic nitrogen normally constitutes the majority of the soil nitrogen. It is slowly converted (2 to 3 percent per year) to the more readily plant-available inorganic ammonium or nitrate.

The chemical form of nitrogen affects its impact on water quality. The most biologically important inorganic forms of nitrogen are ammonium (NH_4-N), nitrate (NO_3-N), and nitrite (NO_2-N). Organic nitrogen occurs as particulate matter, in living organisms, and as detritus. It occurs in dissolved form in compounds such as amino acids, amines, purines, and urea.

Nitrate-nitrogen is highly mobile and can move readily below the crop root zone, especially in sandy soils. It can also be transported with surface runoff, but not usually in large quantities. Ammonium, on the other hand, becomes adsorbed to the soil and is lost primarily with eroding sediment. Even if nitrogen is not in a readily available form as it leaves the field, it can be converted to an available form either during transport or after delivery to waterbodies.

b. Phosphorus

Phosphorus can also contribute to the eutrophication of both freshwater and estuarine systems. While phosphorus typically plays the controlling role in freshwater systems, in some estuarine systems both nitrogen and phosphorus can limit plant growth. Algae consume dissolved inorganic phosphorus and convert it to the organic form. Phosphorus is rarely found in concentrations high enough to be toxic to higher organisms.

Although the phosphorus content of most soils in their natural condition is low, between 0.01 and 0.2 percent by weight, recent soil test results show that the phosphorus content of most cropped soils in the Northeast have climbed to the high or very high range (Sims, 1992). Manure and fertilizers increase the level of available phosphorus in the soil to promote plant growth, but many soils now contain higher phosphorus levels than plants need (Killorn, 1980; Novais and Kamprath, 1978). Phosphorus can be found in the soil in dissolved, colloidal, or particulate forms.

Runoff and erosion can carry some of the applied phosphorus to nearby water bodies. Dissolved inorganic phosphorus (orthophosphate phosphorus) is probably the only form directly available to algae. Particulate and organic phosphorus delivered to waterbodies may later be released and made available to algae when the bottom sediment of a stream becomes anaerobic, causing water quality problems.

2. Sediment

Sediment affects the use of water in many ways. Suspended solids reduce the amount of sunlight available to aquatic plants, cover fish spawning areas and food supplies, smother coral reefs, clog the filtering capacity of filter feeders, and clog and harm the gills of fish. Turbidity interferes with the feeding habits of fish. These effects combine to reduce fish, shellfish, coral, and plant populations and decrease the overall productivity of lakes, streams, estuaries, and coastal waters. In addition, recreation is limited because of the decreased fish population and the water's unappealing, turbid appearance. Turbidity also reduces visibility, making swimming less safe.

Chemicals such as some pesticides, phosphorus, and ammonium are transported with sediment in an adsorbed state. Changes in the aquatic environment, such as a lower concentration in the overlying waters or the development of anaerobic conditions in the bottom sediments, can cause these chemicals to be released from the sediment. Adsorbed phosphorus transported by the sediment may not be immediately available for aquatic plant growth but does serve as a long-term contributor to eutrophication.

Sediment is the result of erosion. It is the solid material, both mineral and organic, that is in suspension, is being transported, or has been moved from its site of origin by air, water, gravity, or ice. The types of erosion associated with agriculture that produce sediment are (1) sheet and rill erosion and (2) gully erosion. Soil erosion can be characterized as the transport of particles that are detached by rainfall, flowing water, or wind (Figure 2-2). Eroded soil is either redeposited on the same field or transported from the field in runoff.

Sediments from different sources vary in the kinds and amounts of pollutants that are adsorbed to the particles. For example, sheet and rill erosion mainly move soil particles from the surface or plow layer of the soil. Sediment that originates from surface soil has a higher pollution potential than that from subsurface soils. The topsoil of a field is usually richer in nutrients and other chemicals because of past fertilizer and pesticide applications, as well as nutrient cycling and biological activity. Topsoil is also more likely to have a greater percentage of organic matter. Sediment from gullies and streambanks usually carries less adsorbed pollutants than sediment from surface soils.

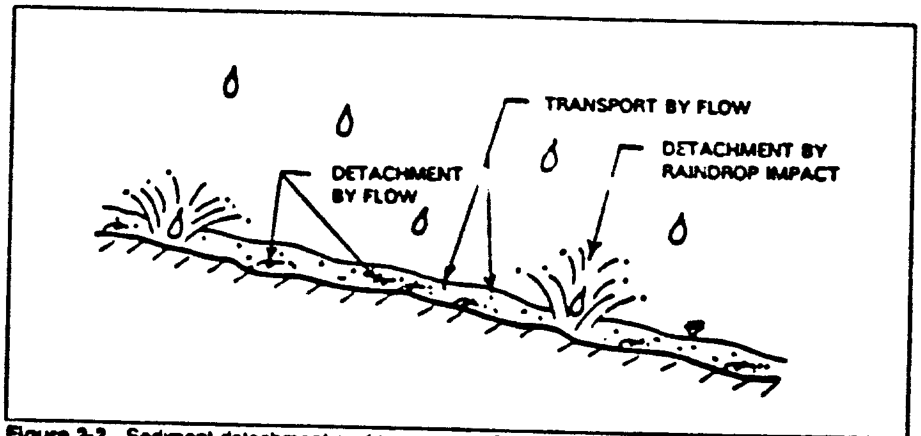

Figure 2-2. Sediment detachment and transport (USEPA, 1981).

Soil eroded and delivered from cropland as sediment usually contains a higher percentage of finer and less dense particles than the parent soil on the cropland. This change in composition of eroded soil is due to the selective nature of the erosion process. For example, larger particles are more readily detached from the soil surface because they are less cohesive, but they also settle out of suspension more quickly because of their size. Organic matter is not easily detached because of its cohesive properties, but once detached it is easily transported because of its low density. Clay particles and organic residues will remain suspended for longer periods and at slower flow velocities than will larger or more dense particles. This selective erosion can increase overall pollutant delivery per ton of sediment delivered because small particles have a much greater adsorption capacity than larger particles. As a result, eroding sediments generally contain higher concentrations of phosphorus, nitrogen, and pesticides than the parent soil (i.e., they are enriched).

3. Animal Wastes

Animal waste (manure) includes the fecal and urinary wastes of livestock and poultry; process water (such as from a milking parlor); and the feed, bedding, litter, and soil with which they become intermixed. The following pollutants may be contained in manure and associated bedding materials and could be transported by runoff water and process wastewater from confined animal facilities:

- Oxygen-demanding substances;
- Nitrogen, phosphorus, and many other major and minor nutrients or other deleterious materials;
- Organic solids;
- Salts;
- Bacteria, viruses, and other microorganisms; and
- Sediments.

Fish kills may result from runoff, wastewater, or manure entering surface waters, due to ammonia or dissolved oxygen depletion. The decomposition of organic materials can deplete dissolved oxygen supplies in water, resulting in anoxic or anaerobic conditions. Methane, amines, and sulfide are produced in anaerobic waters, causing the water to acquire an unpleasant odor, taste, and appearance. Such waters can be unsuitable for drinking, fishing, and other recreational uses.

Solids deposited in waterbodies can accelerate eutrophication through the release of nutrients over extended periods of time. Because of the high nutrient and salt content of manure and runoff from manure-covered areas, contamination of ground water can be a problem if storage structures are not built to minimize seepage.

Animal diseases can be transmitted to humans through contact with animal feces. Runoff from fields receiving manure will contain extremely high numbers of bacteria if the manure has not been incorporated or the bacteria have not been subject to stress. Shellfish closure and beach closure can result from high fecal coliform counts. Although not the only source of pathogens, animal waste has been responsible for shellfish contamination in some coastal waters.

The method, timing, and rate of manure application are significant factors in determining the likelihood that water quality contamination will result. Manure is generally more likely to be transported in runoff when applied to the soil surface than when incorporated into the soil. Spreading manure on frozen ground or snow can result in high concentrations of nutrients being transported from the field during rainfall or snowmelt, especially when the snowmelt or rainfall events occur soon after spreading (Robillard and Walter, 1986). The water quality problems associated with nitrogen and phosphorus are discussed under Section F.1.

When application rates of manure for crop production are based on N, the P and K rates normally exceed plant requirements (Westerman et al., 1985). The soil generally has the capacity to adsorb phosphorus leached from manure applied on land. As previously mentioned, however, nitrates are easily leached through soil into ground water or to return flows, and phosphorus can be transported by eroded soil.

Conditions that cause a rapid die-off of bacteria are low soil moisture, low pH, high temperatures, and direct solar radiation. Manure storage generally promotes die-off, although pathogens can remain dormant at certain temperatures. Composting the wastes can be quite effective in decreasing the number of pathogens.

4. Salts

Salts are a product of the natural weathering process of soil and geologic material. They are present in varying degrees in all soils and in fresh water, coastal waters, estuarine waters, and ground waters.

In soils that have poor subsurface drainage, high salt concentrations are created within the root zone where most water extraction occurs. The accumulation of soluble and exchangeable sodium leads to soil dispersion, structure breakdown, decreased infiltration, and possible toxicity; thus, salts often become a serious problem on irrigated land, both for continued agricultural production and for water quality considerations. High salt concentrations in streams can harm freshwater aquatic plants just as excess soil salinity damages agricultural crops. While salts are generally a more significant pollutant for freshwater ecosystems than for saline ecosystems, they may also adversely affect anadromous fish. Although they live in coastal and estuarine waters most of their lives, anadromous fish depend on freshwater systems near the coast for crucial portions of their life cycles.

The movement and deposition of salts depend on the amount and distribution of rainfall and irrigation, the soil and underlying strata, evapotranspiration rates, and other environmental factors. In humid areas, dissolved mineral salts have been naturally leached from the soil and substrata by rainfall. In arid and semi-arid regions, salts have not been removed by natural leaching and are concentrated in the soil. Soluble salts in saline and sodic soils consist of calcium, magnesium, sodium, potassium, carbonate, bicarbonate, sulfate, and chloride ions. They are fairly easily leached from the soil. Sparingly soluble gypsum and lime also occur in amounts ranging from traces to more than 50 percent of the soil mass.

Irrigation water, whether from ground or surface water sources, has a natural base load of dissolved mineral salts. As the water is consumed by plants or lost to the atmosphere by evaporation, the salts remain and become concentrated in the soil. This is referred to as the "concentrating effect."

The total salt load carried by irrigation return flow is the sum of the salt remaining in the applied water plus any salt picked up from the irrigated land. Irrigation return flows provide the means for conveying the salts to the receiving streams or ground-water reservoirs. If the amount of salt in the return flow is low in comparison to the total stream flow, water quality may not be degraded to the extent that use is impaired. However, if the process of water diversion for irrigation and the return of saline drainage water is repeated many times along a stream or river, water quality will be progressively degraded for downstream irrigation use as well as for other uses.

5. Pesticides

The term *pesticide* includes any substance or mixture of substances intended for preventing, destroying, repelling, or mitigating any pest or intended for use as a plant regulator, defoliant, or desiccant. The principal pesticidal pollutants that may be detected in surface water and in ground water are the active and inert ingredients and any persistent degradation products. Pesticides and their degradation products may enter ground and surface water in solution, in emulsion, or bound to soil colloids. For simplicity, the term *pesticides* will be used to represent "pesticides and their degradation products" in the following sections.

Despite the documented benefits of using pesticides (insecticides, herbicides, fungicides, miticides, nematicides, etc.) to control plant pests and enhance production, these chemicals may, in some instances, cause impairments to the uses of surface water and ground water. Some types of pesticides are resistant to degradation and may persist and accumulate in aquatic ecosystems.

Pesticides may harm the environment by eliminating or reducing populations of desirable organisms, including endangered species. Sublethal effects include the behavioral and structural changes of an organism that jeopardize its survival. For example, certain pesticides have been found to inhibit bone development in young fish or to affect reproduction by inducing abortion.

Herbicides in the aquatic environment can destroy the food source for higher organisms, which may then starve. Herbicides can also reduce the amount of vegetation available for protective cover and the laying of eggs by aquatic species. Also, the decay of plant matter exposed to herbicide-containing water can cause reductions in dissolved oxygen concentration (North Carolina State University, 1984).

Sometimes a pesticide is not toxic by itself but is lethal in the presence of other pesticides. This is referred to as a *synergistic effect*, and it may be difficult to predict or evaluate. *Bioconcentration* is a phenomenon that occurs if an organism ingests more of a pesticide than it excretes. During its lifetime, the organism will accumulate a higher concentration of that pesticide than is present in the surrounding environment. When the organism is eaten by another animal higher in the food chain, the pesticide will then be passed to that animal, and on up the food chain to even higher level animals.

A major source of contamination from pesticide use is the result of normal application of pesticides. Other sources of pesticide contamination are atmospheric deposition, spray drift during the application process, misuse, and spills, leaks, and discharges that may be associated with pesticide storage, handling, and waste disposal.

The primary routes of pesticide transport to aquatic systems are (Maas et al., 1984):

(1) Direct application;
(2) In runoff;
(3) Aerial drift;
(4) Volatilization and subsequent atmospheric deposition; and
(5) Uptake by biota and subsequent movement in the food web.

The amount of field-applied pesticide that leaves a field in the runoff and enters a stream primarily depends on:

(1) The intensity and duration of rainfall or irrigation;
(2) The length of time between pesticide application and rainfall occurrence;
(3) The amount of pesticide applied and its soil/water partition coefficient;
(4) The length and degree of slope and soil composition;
(5) The extent of exposure to bare (vs. residue or crop-covered) soil;

(6) Proximity to streams;
(7) The method of application; and
(8) The extent to which runoff and erosion are controlled with agronomic and structural practices.

Pesticide losses are generally greatest when rainfall is intense and occurs shortly after pesticide application, a condition for which water runoff and erosion losses are also greatest.

The rate of pesticide movement through the soil profile to ground water is inversely proportional to the pesticide adsorption partition coefficient or K_d (a measure of the degree to which a pesticide is partitioned between the soil and water phase). The larger the K_d, the slower the movement and the greater the quantity of water required to leach the pesticide to a given depth.

Pesticides can be transported to receiving waters either in dissolved form or attached to sediment. Dissolved pesticides may be leached to ground-water supplies. Both the degradation and adsorption characteristics of pesticides are highly variable.

6. Habitat Impacts

The functioning condition of riparian-wetland areas is a result of interaction among geology, soil, water, and vegetation. Riparian-wetland areas are functioning properly when adequate vegetation is present to (1) dissipate stream energy associated with high water flows, thereby reducing erosion and improving water quality; (2) filter sediment and aid floodplain development; (3) support denitrification of nitrate-contaminated ground water as it is discharged into streams; (4) improve floodwater retention and ground-water recharge; (5) develop root masses that stabilize banks against cutting action; (6) develop diverse ponding and channel characteristics to provide the habitat and the water depth, duration, and temperature necessary for fish production, waterfowl breeding, and other uses; and (7) support greater biodiversity.

Improper livestock grazing affects all four components of the water-riparian system: banks/shores, water column, channel, and aquatic and bordering vegetation (Platts, 1990). The potential effects of grazing include:

Shore/banks

- Shear or sloughing of streambank soils by hoof or head action.
- Water, ice, and wind erosion of exposed streambank and channel soils because of loss of vegetative cover.
- Elimination or loss of streambank vegetation.
- Reduction of the quality and quantity of streambank undercuts.
- Increasing streambank angle (laying back of streambanks), which increases water width, decreases stream depth, and alters or eliminates fish habitat.

Water Column

- Withdrawal from streams to irrigate grazing lands.
- Drainage of wet meadows or lowering of the ground-water table to facilitate grazing access.
- Pollutants (e.g., sediments) in return water from grazed lands, which are detrimental to the designated uses such as fisheries.

- Changes in magnitude and timing of organic and inorganic energy (i.e., solar radiation, debris, nutrients) inputs to the stream.
- Increase in fecal contamination.
- Changes in stream morphology, such as increases in stream width and decreases in stream depth, including reduction of stream shore water depth.
- Changes in timing and magnitude of stream flow events from changes in watershed vegetative cover.
- Increase in stream temperature.

Channel

- Changes in channel morphology.
- Altered sediment transport processes.

Riparian Vegetation

- Changes in plant species composition (e.g., shrubs to grass to forbs).
- Reduction of floodplain and streambank vegetation including vegetation hanging over or entering into the water column.
- Decrease in plant vigor.
- Changes in timing and amounts of organic energy leaving the riparian zone.
- Elimination of riparian plant communities (i.e., lowering of the water table allowing xeric plants to replace riparian plants).

II. MANAGEMENT MEASURES FOR AGRICULTURAL SOURCES

A. Erosion and Sediment Control Management Measure

Apply the erosion component of a Conservation Management System (CMS) as defined in the Field Office Technical Guide of the U.S. Department of Agriculture - Soil Conservation Service (see Appendix 2A of this chapter) to minimize the delivery of sediment from agricultural lands to surface waters, *or*

Design and install a combination of management and physical practices to settle the settleable solids and associated pollutants in runoff delivered from the contributing area for storms of up to and including a 10-year, 24-hour frequency.

1. Applicability

This management measure is intended to be applied by States to activities that cause erosion on agricultural land and on land that is converted from other land uses to agricultural lands. Agricultural lands include:

- Cropland;
- Irrigated cropland;
- Range and pasture;
- Orchards;
- Permanent hayland;
- Specialty crop production; and
- Nursery crop production.

Under the Coastal Zone Act Reauthorization Amendments of 1990, States are subject to a number of requirements as they develop coastal nonpoint programs in conformity with this measure and will have some flexibility in doing so. The application of management measures by States is described more fully in *Coastal Nonpoint Pollution Control Program: Program Development and Approval Guidance*, published jointly by the U.S. Environmental Protection Agency (EPA) and the National Oceanic and Atmospheric Administration (NOAA) of the U.S. Department of Commerce.

2. Description

The problems associated with soil erosion are the movement of sediment and associated pollutants by runoff into a waterbody. See Section I.F.2 of this chapter for additional information regarding problems.

Application of this management measure will reduce the mass load of sediment reaching a waterbody and improve water quality and the use of the water resource. The measure can be implemented by using one of two different strategies or a combination of both. The first, and most desirable, strategy would be to implement practices on the field that would prevent erosion and the transport of sediment from the field. Practices that could be used to accomplish this are conservation tillage, contour strip-cropping, terraces, and critical area planting.

The second strategy is to route runoff from fields through practices that remove sediment. Practices that could be used to accomplish this are filter strips, field borders, grade stabilization structures, sediment retention ponds, water and sediment control basins, and terraces. Site conditions will dictate the appropriate combination of practices for any given situation.

Conservation management systems (CMS) include any combination of conservation practices and management that achieves a level of treatment of the five natural resources (i.e., soil, water, air, plants, and animals) that satisfies criteria contained in the Soil Conservation Service (SCS) Field Office Technical Guide (FOTG), such as a resource management system (RMS) or an acceptable management system (AMS). These criteria are developed at the State level, with concurrence by the appropriate SCS National Technical Center (NTC). The criteria are then applied in the provision of field office technical assistance, under the direction of the District Conservationist of SCS. In-state coordination of FOTG use is provided by the Area Conservationist and State Conservationist of SCS.

The erosion component of a CMS addresses sheet and rill erosion, wind erosion, concentrated flow, streambank erosion, soil mass movements, road bank erosion, construction site erosion, and irrigation-induced erosion. National (minimum) criteria pertaining to erosion and sediment control under an RMS will be applied to prevent long-term soil degradation and to resolve existing or potential off-site deposition problems. National criteria pertaining to the water resource will be applied to control sediment movement to minimize contamination of receiving waters. The combined effects of these criteria will be to both reduce upland soil erosion and minimize sediment delivery to receiving waters.

The practical limits of resource protection under a CMS within any given area are determined through the application of national social, cultural, and economic criteria. With respect to economics, landowners will not be required to implement an RMS if the system is generally too costly for landowners. Instead, landowners may be required to implement a less costly, and less protective, AMS. In some cases, landowner constraints may be such that an RMS or AMS cannot be implemented quickly. In these situations, a "progressive planning approach" may be used to ultimately achieve planning and application of an RMS or AMS. Progressive planning is the incremental process of building a plan on part or all of the planning unit over a period of time. For additional details regarding CMS, RMS, and AMS, see Appendix 2A of this chapter.

It is recognized that implementation of this measure may increase the potential for movement of water and soluble pollutants through the soil profile to the ground water. It is not the intent of this measure to address a surface water problem at the expense of ground water. Erosion and sediment control systems can and should be designed to protect against the contamination of ground water. Ground-water protection will also be provided through implementation of the nutrient and pesticide management measures to reduce and control the application of nutrients and pesticides.

Operation and Maintenance

Continued performance of this measure will be ensured through supporting maintenance operations where appropriate. Since practices are designed to control a specific storm frequency, they may suffer damage when larger storms occur. It is expected that damage will be repaired after such storms and that practices will be inspected periodically. To ensure that practices selected to implement this measure will continue to function as designed and installed, some operational functions and maintenance will be necessary over the life of the practices.

Most structural practices for erosion and sediment control are designed to operate without human intervention. Management practices such as conservation tillage, however, do require "operation consideration" each time they are used. Field operations should be conducted with such practices in mind to ensure that they are not damaged or destroyed by the operations. For example, herbicides should not be applied to any practice that uses a permanent vegetative cover, such as waterways and filter strips.

Structural practices such as diversions, grassed waterways, and other practices that require grading and shaping may require repair to maintain the original design; reseeding may also be needed to maintain the original vegetative cover.

Trees and brush should not be allowed to grow on berms, dams, or other structural embankments. Cleaning of sediment retention basins will be needed to maintain their original design capacity and efficiency.

Filter strips and field borders must be maintained to prevent channelization of flow and the resulting short-circuiting of filtering mechanisms. Reseeding of filter strips may be required on a frequent basis.

3. Management Measure Selection

This management measure was selected based on an evaluation of available information that documents the beneficial effects of improved erosion and sediment control (see Section II.A.4 of this chapter). Specifically, the available information shows that erosion control practices can be used to greatly reduce the quantity of eroding soil on agricultural land, and that edge-of-field practices can effectively remove sediment from runoff before it leaves agricultural lands. The benefits of this management measure include significant reductions in the mass load of sediment and associated pollutants (e.g., phosphorus, some pesticides) entering waterbodies. By reducing the load of sediment leaving a field, downstream water uses can be maintained and improved.

Two options are provided under this management measure that represent best available technology for minimizing the delivery of sediment from agricultural lands to receiving waters. Different management strategies, are employed, however, with the options. The most desirable option is "(1)" since it not only minimizes the delivery of sediment to receiving waters, but also reduces erosion to provide an agronomic benefit. Option "(2)" minimizes the delivery of sediment to receiving waters, but does not necessarily provide the agronomic benefits of upland erosion control. By providing these two options, States are given the flexibility to address erosion and sediment problems in a manner that best reflects State and local needs and preferences.

By designing the measure to achieve contaminant load reduction objectives, the necessary mix of structural and management practices for a given site should not result in undue economic impact on the operator. Many of the practices that could be used to implement this measure may already be required by Federal, State, or local rules (e.g., filter strips or field borders along streams) or may otherwise be in use on agricultural fields. Since many producers may already be using systems that satisfy or partly satisfy the intent of this management measure, the only action that may be necessary will be to recognize the effectiveness of the existing practices and add additional practices, if needed. By building upon existing erosion and sediment control efforts, the time, effort, and cost of implementing this measure will be reduced.

4. Effectiveness Information

The effectiveness of management practices depends on several factors, including:

- The contaminant to be controlled;
- The types of practices or controls being considered; and
- Site-specific conditions.

Management practices or systems of practices must be designed for site-specific conditions to achieve desired effectiveness levels. Practice systems include combinations of practices that provide source control of the contaminant(s) as well as control or reductions in edge-of-field losses and delivery to receiving waters. Table 2-1 provides a gross estimate of practice effectiveness as reported in research literature. The actual effectiveness of a practice will depend exclusively on site-specific variables such as soil type, crop rotation, topography, tillage, and harvesting methods. Even within relatively small watersheds, extreme spatial and temporal variations are common. With this type of variation, the ranges of likely values associated with the reported observations in Table 2-1 are large.

Table 2-1. Relative Gross Effectiveness[a] of Sediment[b] Control Measures (Pennsylvania State University, 1992a)

Practice Category[c]	Runoff[d] Volume	Total[e] Phosphorus (%)	Total[e] Nitrogen (%)	Sediment (%)
Reduced Tillage Systems[f]	—	45	55	75
Diversion Systems[g]	—	30	10	35
Terrace Systems[h]	—	70	20	85
Filter Strips[i]	—	75	70	65

[a] Actual effectiveness depends on site-specific conditions. Values are not cumulative between practice categories.
[b] Includes data where land application of manure has occurred.
[c] Each category includes several specific types of practices.
[d] - indicates reduction; + increase; 0 no change in surface runoff.
[e] Total phosphorus includes total and dissolved phosphorus, total nitrogen includes organic-N, ammonia-N, and nitrate-N.
[f] Includes practices such as conservation tillage, no-till, and crop residue use.
[g] Includes practices such as grassed waterways and grade stabilization structures.
[h] Includes several types of terraces with safe outlet structures where appropriate.
[i] Includes all practices that reduce contaminant losses using vegetative control methods.

The variability in the effectiveness of selected conservation practices that are frequently recommended by SCS in resource planning is illustrated in Table 2-2. This table can be used as a general guide for estimating the effects of these practices on water quality and quantity. The table references include additional site-specific information. Practice effects shown include changes in the water budget, sediment yield, and the movement of pesticides and nutrients. The impacts of variations in climate and soil conditions are accounted for to some extent through the presentation of effectiveness data for different soil-climate combinations. Data were not available for all soils and climates.

Data for the table were obtained from the research literature and include computer model simulation results. Values are reported as the percentage of change in the mass load of a given parameter that can be expected from installing the practice. Changes are determined versus a base condition of a rain-fed, nonleguminous, continuous, row crop (usually corn) that has been cultivated under conventional tillage.

Data from model studies are marked with an "M." For example, *-27M* indicates that the load reduction estimate of 27 percent is derived from a model simulation. Data obtained from plot studies using rainfall simulators are marked with an "S." For example, *+15S* indicates that the estimated load increase of 15 percent is based on a rainfall simulation study.

The range is reported in parentheses, followed by other reported values within the range, set off by commas. For example, *(-32 to +10), -15, +5* denotes a range from a decrease of 32 percent to an increase of 10 percent, with intermediate reported changes of a 15 percent decrease and 5 percent increase. Some practices have a relatively wide range of values because of the variability in climate, soils, and management that occurs with these practices. Although some of the ranges are large, they can usually be attributed to small changes in very small quantities (that the percentage change is great, yet the magnitude of change is small) or to the variability of site-specific conditions.

Table 2-2 contains the following information:

- Column (a) lists the practice and its SCS reporting code number.
- Column (b) lists the climate and a generalized soil classification for the site under consideration.
- Column (c) is the percentage change in surface runoff and deep percolation, components of the water budget, caused by the applied practice.
- Column (d) is the percentage change in sediment load caused by the applied practice.
- Column (e) is the percentage change in the phosphorus load. Two phases of phosphorus are considered: adsorbed and dissolved.
- Column (f) is the percentage change in the load of nitrogen in the adsorbed phase, nitrate in surface runoff, and nitrate in the leachate.
- Column (g) is the percentage change in the pesticide load. The phases of the pesticide listed are (1) strongly adsorbed in surface water, (2) weakly adsorbed in surface water, and (3) weakly adsorbed in the leachate.

5. Erosion and Sediment Control Management Practices

As discussed more fully at the beginning of this chapter and in Chapter 1, the following practices are described for illustrative purposes only. State programs need not require implementation of these practices. However, as a practical matter, EPA anticipates that the management measure set forth above generally will be implemented by applying one or more management practices appropriate to the source, location, and climate. The practices set forth below have been found by EPA to be representative of the types of practices that can be applied successfully to achieve the management measure described above.

Combinations of the following practices can be used to satisfy the requirements of this management measure. The SCS practice number and definition are provided for each management practice, where available. Also included in italics are SCS statements describing the effect each practice has on water quality (USDA-SCS, 1988).

■ a. *Conservation cover (327): Establishing and maintaining perennial vegetative cover to protect soil and water resources on land retired from agricultural production.*

Agricultural chemicals are usually not applied to this cover in large quantities and surface and ground water quality may improve where these material are not used. Ground cover and crop residue will be increased with this practice. Erosion and yields of sediment and sediment related stream pollutants should decrease. Temperatures of the soil surface runoff and receiving water may be reduced. Effects will vary during the establishment period and include increases in runoff, erosion and sediment yield. Due to the reduction of deep percolation, the leaching of soluble material will be reduced, as will be the potential for causing saline seeps. Long-term effects of the practice would reduce agricultural nonpoint sources of pollution to all water resources.

■ b. *Conservation cropping sequence (328): An adapted sequence of crops designed to provide adequate organic residue for maintenance or improvement of soil tilth.*

This practice reduces erosion by increasing organic matter, resulting in a reduction of sediment and associated pollutants to surface waters. Crop rotations that improve soil tilth may also disrupt disease, insect and weed reproduction cycles, reducing the need for pesticides. This removes or reduces the availability of some pollutants in the watershed. Deep percolation may carry soluble nutrients and pesticides to the ground water. Underlying soil

Table 2-2. Effects of Conservation Practices on Water Resource Parameters (USDA-SCS, 1988)

NOTE: Values in the tables are taken from published research, model simulations, and results of simulated rainfall plots. Both the range (in parentheses) and additional values within the range (after parentheses, separated by comma) are presented. The values describe the percentage change in mass loads caused by the use of the practice on a nonirrigated, nonlegume, continuous row crop that has been grown under conventional tillage. Values inside the range are shown behind the range values and are separated by commas (-30,-90), -78. Values from model simulation are marked by an M, e.g., -30M, and values from a rainfall simulator are marked with an S, e.g., -29S. Few data are available for arid conditions and that zone is not included in the table. Not all soil-climate combinations have available reference data. A minus is a decreased value; a plus is an increase.

(a)	(b)	(c)		(d)	(e)		(f)			(g)		
		Water Budget (% Change)			Phosphorus (% Change)		Nitrogen (% Change)			Pesticides (% Change)		
Practice and Number	Climate and Soil	Surface Runoff	Deep Percolation	Sediment Yield (% Change)	Sediment	Runoff	Nitrogen Adsorbed Phases	Nitrate in Surface Runoff	Nitrate in Percolate	Strongly Adsorbed SW*	Weakly Adsorbed Leachate	Weakly Adsorbed SW*
Contour Farming 330	H-S*											
	Sandy	(-65,-75)	#	(-20,-60)	-20	-10	-15	-5	#	#	#	#
	Silty	(-60,-40)	+10	(-65,-30)	(-60,-65)	(-60,-65)	-(-46,-54)	(-25,-72),-40	+10,+7	#	#	#
	Clayey	(-19,-20)	+5	(-29,-55)	-55	-20	-55	(-12,-25)	+10	#	#	#
	SA-S*											
	Silty	(-27,-59)	#	(-22,-59)	#	#	#	#	#	#	#	#
	Clayey	-54	#	-26	#	#	#	#	+10	#	#	#
	H*											
	Sandy	-30	+10	-60	-60	-30	-60	-35	+10	#	#	#
	Silty	-16	#	(-30,-48)	#	#	#	(-25,-41)	+6	#	#	#
	Clayey	(-17,-29)	#	#	#	#	#	-12	+7	#	#	#
	SA*											
	Clayey	-15	#	#	#	#	#	#	#	#	#	#
Strip-Cropping Contour 585	H-S*											
	Silty	-5M	+9M	(-37,90M),-49	-80M	-86M	-81M	-43M	+158M	#	#	0,+6
	Clayey	-26M	+366M*	-89M	-52M	-89M	-51M	-26M	+220M*	#	#	#
	Sandy	No change	No change	-99M	-89M	-86M	-98M	-39M	+12M	#	#	#

Table 2-2. (Continued)

(a)	(b)	(c)		(d)	(e)		(f)			(g)		
		Water Budget (% Change)			Phosphorus (% Change)		Nitrogen (% Change)			Pesticides (% Change)		
Practice and Number	Climate and Soil	Surface Runoff	Deep Percolation	Sediment Yield (% Change)	Sediment	Runoff	Nitrogen Adsorbed Phases	Nitrate in Surface Runoff	Nitrate in Percolate	Strongly Adsorbed SW[b]	Weakly Adsorbed Leachate	Weakly Adsorbed SW[b]
Cons. Tillage- No Till 329	H[a] -											
	Clayey	(-33,+48)[c]	#	(-73M,-82)	-53M	-30M	-53M	-11	(-49M,+8)	#	#	-51M
	Silty	(-91,+36)[c]	No change	(-75,-99)	(-64,-95)	(+900,-22)[c]	(-60,-94)	(-42,+800) -40,+100	(8M,+16) 1,+8[c]	-78	(+5M,-50)	
	Sandy[d]	(-26M,-88),-61	#	(-68M,-99S)	(-51,-87S)	(0,+155)	(-69s,-90s)	(-67,-60)	0	#	#	#
	SA-S[e] -				[c]-72s,-82		-72,-70	-42s,-45	•			
	Silty	+36	#	-96	(-60,-90)	+138	(-60,-90),-60	(0,+45)	+2	#	#	#
	H-S[e] -											
	Silty	(-21,-90)	#	(-98,-99)	(-75,-90)	(+450,+1800)	#	#	#	(-75,-90)	#	+500
Cons. Tillage (Other types) 329	H-S[e] -											
	Silty	(-15,-73) -61,-20	+6	(-43,+95) -85,-56	-80,-84	+1860,+1780[c]	-91,-82	+1800,+960[c]	#	#	#	#
	Clayey	-30	+10	-70	#	#	#	#	#	#	#	#
	SA-S[e] -											
	Silty	-54	#	#	#	#	#	#	#	#	#	#
	Clayey	(-29,-89)	+10	(-70,-42)	#	#	#	#	#	#	#	#
	H[a] -											
	Sandy	(-40,-89)	+5	(-40,-66)	-91	-3	-96	-98	#	#	#	#
	Silty	(-20,-26)	#	(-49,-61)	#	#	#	#	#	(-69,-51)	#	(+15,+27)
	Clayey	(-10,-61),-20	+10	(-29,-86) -34,-41	#	#	#	#	#	(-33M,-2)	#	(+60M,-2)

Table 2-2. (Continued)

(a) Practice and Number	(b) Climate and Soil	(c) Water Budget (% Change): Surface Runoff	(c) Water Budget (% Change): Deep Percolation	(d) Sediment Yield (% Change)	(e) Phosphorus (% Change): Sediment	(e) Phosphorus (% Change): Runoff	(f) Nitrogen (% Change): Nitrogen Adsorbed Phases	(f) Nitrogen (% Change): Nitrate in Surface Runoff	(f) Nitrogen (% Change): Nitrate in Percolate	(g) Pesticides (% Change): Strongly Adsorbed SW[b]	(g) Pesticides (% Change): Weakly Adsorbed Leachate	(g) Pesticides (% Change): Weakly Adsorbed SW[b]
	SA[a] •											
	Silty	(-16,-25),-20	ø	(-38,-92),-69	ø	ø	ø	ø	ø	(-38,-81)	ø	+63,+27
	Sandy	-31	ø	-45	ø	ø	ø	ø	ø	ø	ø	ø
	Clayey	-88M	ø	-90M	ø	ø	ø	Not sig.	ø	ø	ø	ø
Terraces with Under-ground Outlets 600	H-S[a] •											
	Sandy	-14	ø	(-95,-98)	ø	ø	ø	ø	ø	ø	ø	ø
	Silty	(-24,-60)	(+12,+500)[d]	(-87,-95)	-95	-60	-95	(-70,+55)[d]	+15	ø	ø	ø
	Clayey	(-30,-36)	(+5,+380)[d]	(-90,-95)	ø	-30	-96	-30	+10	ø	ø	ø
	SA-S[a] •											
	Sandy	-14M	+67M	(-95,-98)	-99M	-42M	-99M	-42M	+20M	ø	ø	(-73,-91M)
	Silty	(-73,+43M)	+162M	(-95,-92M)	-97M	-72M	-97M	-78M	+37M	ø	ø	(-84,-91M)
	Clayey	(-15,-36M)	(+5,+293M)[d]	(-95,-91M)	-96M	-65M	-96M	-91M	(10 to high values)			(-69M,-78M)
WASCOB[f] 638	H[a] •											
	Sandy	-40	+15	(-95,-99)	ø	-40	-95	-50	+15	ø	ø	ø
	Silty	(-88,-42)	ø	(-95,-50),-86	ø	-71	-95	(-88,-44)	+8	ø	ø	-4
	Clayey	ø	ø	(-90,-95)	ø	ø	ø	ø	ø	ø	ø	ø
	SA[a] •											
	Sandy	ø	ø	(-95,-98)	ø	ø	ø	ø	ø	ø	ø	ø
	Silty	-73	ø	-95	-73	+58[c]	ø	-50	ø	ø	ø	ø
	Clayey	-30	+5	(-90,-95)	ø	ø	ø	ø	ø	ø	ø	ø

[a] Climatic conditions: H-S = Humid - Snow; H = Humid; SAS = Semi-Arid - Snow; and SA = Semi-Arid.
[b] SW = Surface Water.
[c] Measured values were small numbers; percentage change may have large values.
[d] Data have scattered values.
[e] Measured values were large numbers.
[f] Water and Sediment Control Basin
• = Unknown, site-dependent, or conflicting values.
ø = No reported value.

layers, rock and unconsolidated parent material may block, delay, or enhance the delivery of these pollutants to ground water. The fate of these pollutants will be site specific, depending on the crop management, the soil and geologic conditions.

c. Conservation tillage (329): Any tillage or planting system that maintains at least 30 percent of the soil surface covered by residue after planting to reduce soil erosion by water; or, where soil erosion by wind is the primary concern, maintains at least 1,000 pounds of flat, small-grain residue equivalent on the surface during the critical erosion period.

This practice reduces soil erosion, detachment and sediment transport by providing soil cover during critical times in the cropping cycle. Surface residues reduce soil compaction from raindrops, preventing soil sealing and increasing infiltration. This action may increase the leaching of agricultural chemicals into the ground water.

In order to maintain the crop residue on the surface it is difficult to incorporate fertilizers and pesticides. This may increase the amount of these chemicals in the runoff and cause more surface water pollution.

The additional organic material on the surface may increase the bacterial action on and near the soil surface. This may tie-up and then breakdown many pesticides which are surface applied, resulting in less pesticide leaving the field. This practice is more effective in humid regions.

With a no-till operation the only soil disturbance is the planter shoe and the compaction from the wheels. The surface applied fertilizers and chemicals are not incorporated and often are not in direct contact with the soil surface. This condition may result in a high surface runoff of pollutants (nutrient and pesticides). Macropores develop under a no-till system. They permit deep percolation and the transmittal of pollutants, both soluble and insoluble to be carried into the deeper soil horizons and into the ground water.

Reduced tillage systems disrupt or break down the macropores, incidentally incorporate some of the materials applied to the soil surface, and reduce the effects of wheeltrack compaction. The results are less runoff and less pollutants in the runoff.

d. Contour farming (330): Farming sloping land in such a way that preparing land, planting, and cultivating are done on the contour. This includes following established grades of terraces or diversions.

This practice reduces erosion and sediment production. Less sediment and related pollutants may be transported to the receiving waters.

Increased infiltration may increase the transportation potential for soluble substances to the ground water.

e. Contour orchard and other fruit area (331): Planting orchards, vineyards, or small fruits so that all cultural operations are done on the contour.

Contour orchards and fruit areas may reduce erosion, sediment yield, and pesticide concentration in the water lost. Where inward sloping benches are used, the sediment and chemicals will be trapped against the slope. With annual events, the bench may provide 100 percent trap efficiency. Outward sloping benches may allow greater sediment and chemical loss. The amount of retention depends on the slope of the bench and the amount of cover. In addition, outward sloping benches are subject to erosion form runoff from benches immediately above them. Contouring allows better access to rills, permitting maintenance that reduces additional erosion. Immediately after establishment, contour orchards may be subject to erosion and sedimentation in excess of the now contoured orchard. Contour orchards require more fertilization and pesticide application than did the native grasses that frequently covered the slopes before orchards were started. Sediment leaving the site may carry more adsorbed nutrients and pesticides than did the sediment before the benches were established from uncultivated slopes. If contoured orchards *replace other crop or intensive land use, the increase or decrease in chemical transport from the site may be determined by examining the types and amounts of chemicals used on the prior land use as compared to the contour orchard condition.*

Soluble pesticides and nutrients may be delivered to and possibly through the root zone in an amount proportional to the amount of soluble pesticides applied, the increase in infiltration, the chemistry of the pesticides, organic and clay content of the soil, and amounts of surface residues. Percolating water below the root zone may carry excess solutes or may dissolve potential pollutants as they move. In either case, these solutes could reach ground water supplies and/or surface downslope from the contour orchard area. The amount depends on soil type, surface water quality, and the availability of soluble material (natural or applied).

■ f. Cover and green manure crop (340): A crop of close-growing grasses, legumes, or small grain grown primarily for seasonal protection and soil improvement. It usually is grown for 1 year or less, except where there is permanent cover as in orchards.

Erosion, sediment and adsorbed chemical yields could be decreased in conventional tillage systems because of the increased period of vegetal cover. Plants will take up available nitrogen and prevent its undesired movement. Organic nutrients may be added to the nutrient budget reducing the need to supply more soluble forms. Overall volume of chemical application may decrease because the vegetation will supply nutrients and there may be allelopathic effects of some of the types of cover vegetation on weeds. Temperatures of ground and surface waters could slightly decrease.

■ g. Critical area planting (342): Planting vegetation, such as trees, shrubs, vines, grasses, or legumes, on highly erodible or critically eroding areas (does not include tree planting mainly for wood products).

This practice may reduce soil erosion and sediment delivery to surface waters. Plants may take up more of the nutrients in the soil, reducing the amount that can be washed into surface waters or leached into ground water.

During grading, seedbed preparation, seeding, and mulching, large quantities of sediment and associated chemicals may be washed into surface waters prior to plant establishment.

■ h. Crop residue use (344): Using plant residues to protect cultivated fields during critical erosion periods.

When this practice is employed, raindrops are intercepted by the residue reducing detachment, soil dispersion, and soil compaction. Erosion may be reduced and the delivery of sediment and associated pollutants to surface water may be reduced. Reduced soil sealing, crusting and compaction allows more water to infiltrate, resulting in an increased potential for leaching of dissolved pollutants into the ground water.

Crop residues on the surface increase the microbial and bacterial action on or near the surface. Nitrates and surface-applied pesticides may be tied-up and less available to be delivered to surface and ground water. Residues trap sediment and reduce the amount carried to surface water. Crop residues promote soil aggregation and improve soil tilth.

■ i. Delayed seed bed preparation (354): Any cropping system in which all of the crop residue and volunteer vegetation are maintained on the soil surface until approximately 3 weeks before the succeeding crop is planted, thus shortening the bare seedbed period on fields during critical erosion periods.

The purpose is to reduce soil erosion by maintaining soil cover as long as practical to minimize raindrop splash and runoff during the spring erosion period. Other purposes include moisture conservation, improved water quality, increased soil infiltration, improved soil tilth, and food and cover for wildlife.

j. **Diversion (362): A channel constructed across the slope with a supporting ridge on the lower side (Figure 2-3).**

This practice will assist in the stabilization of a watershed, resulting in the reduction of sheet and rill erosion by reducing the length of slope. Sediment may be reduced by the elimination of ephemeral and large gullies. This may reduce the amount of sediment and related pollutants delivered to the surface waters.

k. **Field border (386): A strip of perennial vegetation established at the edge of a field by planting or by converting it from trees to herbaceous vegetation or shrubs.**

This practice reduces erosion by having perennial vegetation on an area of the field. Field borders serve as "anchoring points" for contour rows, terraces, diversions, and contour strip cropping. By elimination of the practice of tilling and planting the ends up and down slopes, erosion from concentrated flow in furrows and long rows may be reduced. This use may reduce the quantity of sediment and related pollutants transported to the surface waters.

l. **Filter strip (393): A strip or area of vegetation for removing sediment, organic matter, and other pollutants from runoff and wastewater.**

Filter strips for sediment and related pollutants meeting minimum requirements may trap the coarser grained sediment. They may not filter out soluble or suspended fine-grained materials. When a storm causes runoff in excess When the field borders are located such that runoff flows across them in sheet flow, they may cause the deposition of sediment and prevent it from entering the surface water. Where these practice are between cropland and a stream

Figure 2-3. Diversion (USDA-SCS, 1984).

or water body, the practice may reduce the amount of pesticide application drift from entering the surface water of the design runoff, the filter may be flooded and may cause large loads of pollutants to be released to the surface water. This type of filter requires high maintenance and has a relatively short service life and is effective only as long as the flow through the filter is shallow sheet flow.

Filter strips for runoff from concentrated livestock areas may trap organic material, solids, materials which become adsorbed to the vegetation or the soil within the filter. Often they will not filter out soluble materials. This type of filter is often wet and is difficult to maintain.

Filter strips for controlled overland flow treatment of liquid wastes may effectively filter out pollutants. The filter must be properly managed and maintained, including the proper resting time. Filter strips on forest land may trap coarse sediment, timbering debris, and other deleterious material being transported by runoff. This may improve the quality of surface water and has little effect on soluble material in runoff or on the quality of ground water.

All types of filters may reduce erosion on the area on which they are constructed.

Filter strips trap solids from the runoff flowing in sheet flow through the filter. Coarse-grained and fibrous materials are filtered more efficiently than fine-grained and soluble substances. Filter strips work for design conditions, but when flooded or overloaded they may release a slug load of pollutants into the surface water.

■ m. **Grade stabilization structure (410): A structure used to control the grade and head cutting in natural or artificial channels.**

Where reduced stream velocities occur upstream and downstream from the structure, streambank and streambed erosion will be reduced. This will decrease the yield of sediment and sediment-attached substances. Structures that trap sediment will improve downstream water quality. The sediment yield change will be a function of the sediment yield to the structure, reservoir trap efficiency and of velocities of released water. Ground water recharge may affect aquifer quality depending on the quality of the recharging water. If the stored water contains only sediment and chemical with low water solubility, the ground water quality should not be affected.

■ n. **Grassed waterway (412): A natural or constructed channel that is shaped or graded to required dimensions and established in suitable vegetation for the stable conveyance of runoff.**

This practice may reduce the erosion in a concentrated flow area, such as in a gully or in ephemeral gullies. This may result in the reduction of sediment and substances delivered to receiving waters. Vegetation may act as a filter in removing some of the sediment delivered to the waterway, although this is not the primary function of a grassed waterway.

Any chemicals applied to the waterway in the course of treatment of the adjacent cropland may wash directly into the surface waters in the case where there is a runoff event shortly after spraying.

When used as a stable outlet for another practice, waterways may increase the likelihood of dissolved and suspended pollutants being transported to surface waters when these pollutants are delivered to the waterway.

■ o. **Grasses and legumes in rotation (411): Establishing grasses and legumes or a mixture of them and maintaining the stand for a definite number of years as part of a conservation cropping system.**

Reduced runoff and increased vegetation may lower erosion rates and subsequent yields of sediment and sediment-attached substances. Less applied nitrogen may be required to grow crops because grasses and legumes will supply organic nitrogen. During the period of the rotation when the grasses and legumes are growing, they will take up more phosphorus. Less pesticides may similarly be required with this practice. Downstream water temperatures may be lower depending on the season when this practice is applied. There will be a greater opportunity for animal *waste management on grasslands because manures and other wastes may be applied for a longer part of the crop year.*

p. Sediment basins (350): Basins constructed to collect and store debris or sediment.

Sediment basins will remove sediment, sediment associated materials and other debris from the water which is passed on downstream. Due to the detention of the runoff in the basin, there is an increased opportunity for soluble materials to be leached toward the ground water.

q. Contour stripcropping (585): Growing crops in a systematic arrangement of strips or bands on the contour to reduce water erosion.

The crops are arranged so that a strip of grass or close-growing crop is alternated with a strip of clean-tilled crop or fallow or a strip of grass is alternated with a close-growing crop (Figure 2-4).

This practice may reduce erosion and the amount of sediment and related substances delivered to the surface waters. The practice may increase the amount of water which infiltrates into the root zone, and, at the time there is an overabundance of soil water, this water may percolate and leach soluble substances into the ground water.

r. Field strip-cropping (586): Growing crops in a systematic arrangement of strips or bands across the general slope (not on the contour) to reduce water erosion.

The crops are arranged so that a strip of grass or a close-growing crop is alternated with a clean-tilled crop or fallow.

This practice may reduce erosion and the delivery of sediment and related substances to the surface waters. The practice may increase infiltration and, when there is sufficient water available, may increase the amount of leachable pollutants moved toward the ground water.

Since this practice is not on the contour there will be areas of concentrated flow, from which detached sediment, adsorbed chemicals and dissolved substances will be delivered more rapidly to the receiving waters. The sod strips will not be efficient filter areas in these areas of concentrated flow.

s. Terrace (600): An earthen embankment, a channel, or combination ridge and channel constructed across the slope (Figures 2-5 and 2-6).

This practice reduces the slope length and the amount of surface runoff which passes over the area downslope from an individual terrace. This may reduce the erosion rate and production of sediment within the terrace interval. Terraces trap sediment and reduce the sediment and associated pollutant content in the runoff water which enhance surface water quality. Terraces may intercept and conduct surface runoff at a nonerosive velocity to stable outlets, thus, reducing the occurrence of ephemeral and classic gullies and the resulting sediment. Increases in infiltration can cause a greater amount of soluble nutrients and pesticides to be leached into the soil. Underground outlets may collect highly soluble nutrient and pesticide leachates and convey runoff and conveying it directly to an outlet, terraces may increase the delivery of pollutants to surface waters. Terraces increase the opportunity to leach salts below the root zone in the soil. Terraces may have a detrimental effect on water quality if they concentrate and accelerate delivery of dissolved or suspended nutrient, salt, and pesticide pollutants to surface or ground waters.

t. Water and sediment control basin (638): An earthen embankment or a combination ridge and channel generally constructed across the slope and minor watercourses to form a sediment trap and water detention basin.

Contour strip cropping systems can involve up to 10 strips in a field. A strip cropping system could involve the following:

Corn (either for grain and/or silage)

Soybeans

1st year Meadow

Established Meadow (2-4 years)

Oats

Grassed waterway or diversion

Tillage systems may include two kinds in the same year such as chisel plowing for the for crop and moldboard plowing for the oats.

See the following figure showing typical patterns of stripcropping.

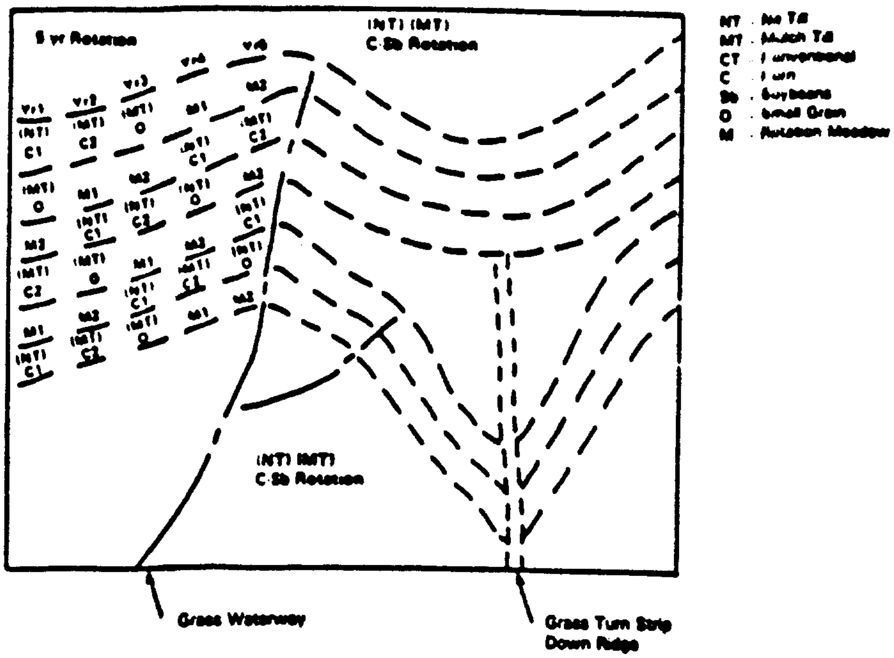

Figure 2-4. Strip-cropping and rotations (USDA-ARS, 1987).

The practice traps and removes sediment and sediment-attached substances from runoff. Trap control efficiencies for sediment and total phosphorus, that are transported by runoff, may exceed 90 percent in silt loam soils. Dissolved substances, such as nitrates, may be removed from discharge to downstream areas because of the increased infiltration. Where geologic condition permit, the practice will lead to increased loadings of dissolved substances toward ground water. Water temperatures of surface runoff, released through underground outlets, may increase slightly because of longer exposure to warming during its impoundment.

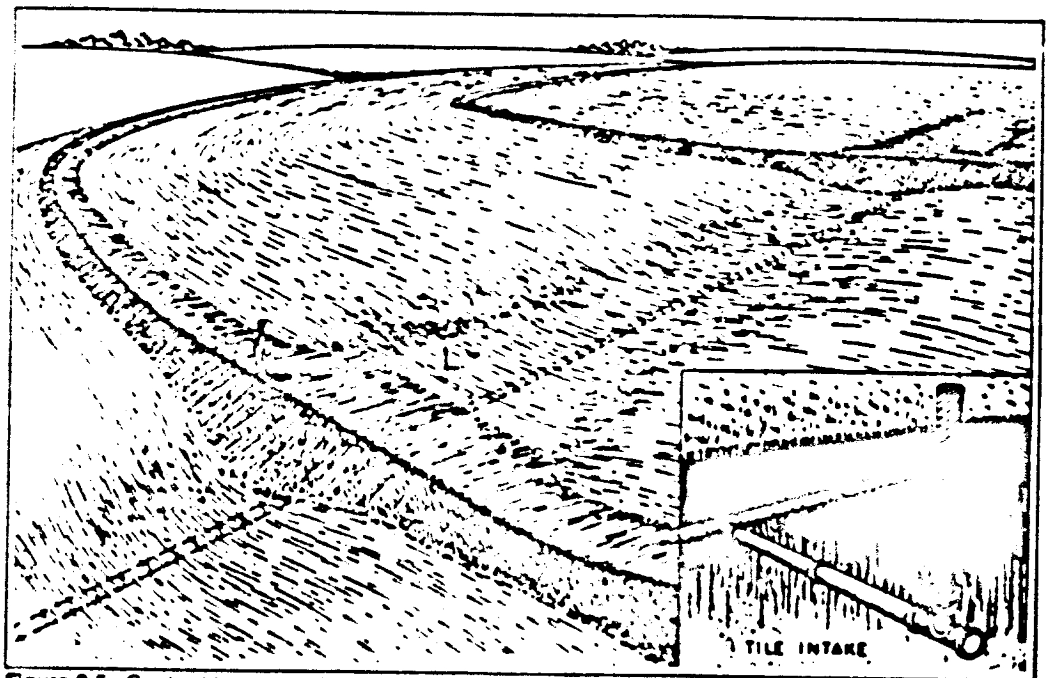

Figure 2-5. Gradient terraces with tile outlets (USDA-SCS, 1984).

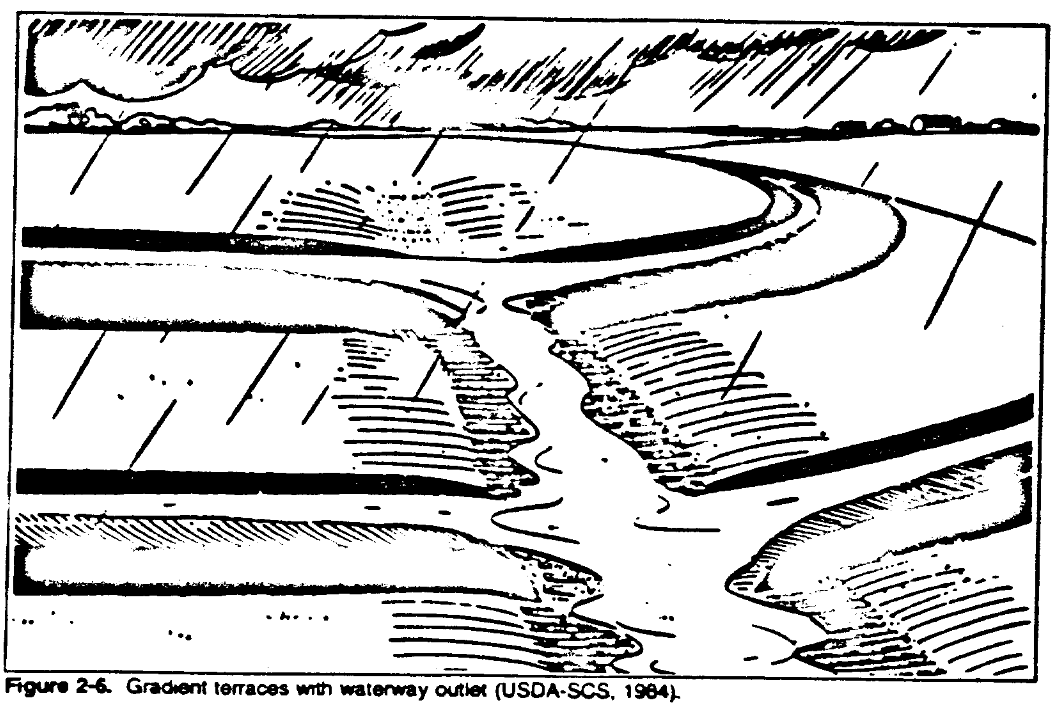

Figure 2-6. Gradient terraces with waterway outlet (USDA-SCS, 1984).

u. Wetland and riparian zone protection

Wetland and riparian zone protection practices are described in Chapter 7.

6. Cost Information

Both national and selected State costs for a number of common erosion control practices are presented in Tables 2-3 through 2-7. The variability in costs for practices can be accounted for primarily through differences in site-specific applications and costs, differences in the reporting units used, and differences in the interpretation of reporting units.

The cost estimates for control of erosion and sediment transport from agricultural lands in Table 2-8 are based on experiences in the Chesapeake Bay Program, but are illustrative of the costs that could be incurred in coastal areas across the Nation. It is important to note that for some practices, such as conservation tillage, the net costs often approach zero and in some cases can be negative because of the savings in labor and energy.

The annual cost of operation and maintenance is estimated to range from zero to 10 percent of the investment cost (USDA-SCS-Michigan, 1988).

Table 2-3. Cost of Diversions

Location	Year	Unit	Reported Capital Costs ($/unit)	Constant Dollar Capital Costs ($/unit)[a]	Reference
National	1985	ac	49.45	61.8	Barbarika, 1987.
North Carolina	1980	ac	120.00	164.35	NCAES, 1982
Maryland	1991	ft	3.12	3.12	Sanders et al., 1991.
Maryland	1987	ft	2.25	2.89	Smolen and Humenik, 1989.
Michigan	1981	ft	3.75	4.79	Smolen and Humenik, 1989.
Wisconsin	1987	ft	1.57	2.02	Smolen and Humenik, 1989.
Minnesota	1987	ft	1.43	1.84	Smolen and Humenik, 1989.
Virginia	1987	ft	1.33	1.71	Smolen and Humenik, 1989.

[a] Reported costs inflated to 1991 dollars by the ratio of indices of prices paid by farmers for all production items, 1977=100. Diversion lifetime is expected to be 10 years, but costs are not annualized.

Table 2-4. Cost of Terraces

Location	Year	Unit	Reported Capital Costs ($/unit)	Constant Dollar Capital Costs ($/unit)[a]	Reference
National	1985	ac	91.43	114.44	Barbarika, 1987.
Alabama	1982	a.s.	45.00	55.58	Russell and Christensen, 1984.
Florida	1982	a.s.	40.00	49.41	Russell and Christensen, 1984.
Georgia	1982	a.s.	39.00	48.18	Russell and Christensen, 1984.
North Carolina	1982	a.s.	47.00	58.06	Russell and Christensen, 1984.
South Carolina	1982	a.s.	17.00	21.00	Russell and Christensen, 1984.
Virginia	1982	a.s.	39.00	48.18	Russell and Christensen, 1984.
Wisconsin	1987	ft	10.00	12.86	Smolen and Humenik, 1989.
Minnesota	1987	ft	2.25	2.89	Smolen and Humenik, 1989.

a.s. = acres served

[a] Reported costs inflated to 1991 dollars by the ratio of indices of prices paid by farmers for all production items, 1977=100. Terrace lifetime is expected to be 10 years, but costs are not annualized.

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Table 2-5. Cost of Waterways

Location	Year	Unit	Reported Capital Costs ($/unit)	Constant Dollar Capital Costs ($/unit)*	Reference
National	1985	ac	94.22	117.93	Barbarika, 1987.
Michigan	1981	ac	150.00	191.55	Smolen and Humenik, 1989.
Wisconsin	1987	ac	2880.00	3702.86	Smolen and Humenik, 1989.
North Carolina	1980	ac	72.00	98.61	NCAES, 1982.
Alabama	1982	a.e.	1088.00	1344.00	Russell and Christensen, 1984.
Florida	1982	a.e.	1026.00	1267.41	Russell and Christensen, 1984.
Georgia	1982	a.e.	880.00	1087.06	Russell and Christensen, 1984.
North Carolina	1982	a.e.	1232.00	1521.88	Russell and Christensen, 1984.
South Carolina	1982	a.e.	1442.00	1781.29	Russell and Christensen, 1984.
Virginia	1982	a.e.	1530.00	1890.00	Russell and Christensen, 1984.
Maryland	1991	ft	5.11	5.11	Sanders et al, 1991.
Maryland	1987	ft	6.00	7.71	Smolen and Humenik, 1989.

a.e. = acres established
* Reported costs inflated to 1991 dollars by the ratio of indices of prices paid by farmers for all production items, 1977=100. Waterway lifetime is expected to be 10 years, but costs are not annualized.

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Table 2-6. Cost of Permanent Vegetative Cover

Location	Year	Unit	Reported Capital Costs ($/unit)	Constant Dollar Capital Costs ($/unit)[a]	Reference
National	1985	ac	48.10	60.20	Barbarika, 1987.
Maryland	1991	ac	235.48	235.48	Sanders et al., 1991.
Maryland	1987	ac	120.00	154.29	Smolen and Humenik, 1989.
Michigan	1981	ac	62.50	79.81	Smolen and Humenik, 1989.
Wisconsin	1987	ac	70.00	90.00	Smolen and Humenik, 1989.
Minnesota	1987	ac	233.00	299.57	Smolen and Humenik, 1989.
Virginia	1987	ac	133.00	171.00	Smolen and Humenik, 1989.
Alabama	1982	ac	98.78	122.02	Russell and Christensen, 1984.
Florida	1982	ac	98.24	121.36	Russell and Christensen, 1984.
Georgia	1982	ac	98.52	121.70	Russell and Christensen, 1984.
North Carolina	1982	ac	73.74	91.09	Russell and Christensen, 1984.
South Carolina	1982	ac	121.54	150.14	Russell and Christensen, 1984.
Virginia	1982	ac	101.36	125.21	Russell and Christensen, 1984.

[a] Reported costs inflated to 1991 dollars by the ratio of indices of prices paid by farmers for all production items, 1977=100. Permanent vegetative cover lifetime is expected to be 10 years, but costs are not annualized.

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Table 2-7. Cost of Conservation Tillage

Location	Year	Unit	Reported Capital Costs ($/unit)	Constant Dollar Capital Costs ($/unit)[a]	Reference
Maryland	1987	ac	18.00	21.99	Smolen and Humenik, 1989.
Michigan	1987	ac	6.75	8.25	Smolen and Humenik, 1989.
Wisconsin	1981	ac	27.55	42.65	Smolen and Humenik, 1989.
Minnesota	1987	ac	13.40	16.37	Smolen and Humenik, 1989.
Virginia	1987	ac	29.30	35.79	Smolen and Humenik, 1989.
North Carolina	1980	ac	10.00	17.12	NCAES, 1982.
Alabama	1982	ac[b]	19.00	26.84	Russell and Christensen, 1984.
Florida	1982	ac[b]	39.00	55.09	Russell and Christensen, 1984.
Georgia	1982	ac[b]	33.00	46.61	Russell and Christensen, 1984.
North Carolina	1982	ac[b]	12.00	16.95	Russell and Christensen, 1984.
South Carolina	1982	ac[b]	27.00	38.14	Russell and Christensen, 1984.
Virginia	1982	ac[b]	16.00	22.60	Russell and Christensen, 1984.

[a] Reported costs inflated to 1991 dollars by the ratio of indices of prices paid by farmers for other machinery, 1977=100. Conservation tillage lifetime is expected to be 10 years, but costs are not annualized.

[b] Per acre of planting and herbicides.

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Table 2-8. Annualized Cost Estimates for Selected Management Practices from Chesapeake Bay Installations[a] (Camacho, 1991)

Practice	Practice Life Span (Years)	Median Annual Costs[b] (EAC[c])($/acre/yr)
Nutrient Management	3	2.40
Strip-cropping	5	11.60
Terraces	10	84.53
Diversions	10	52.09
Sediment Retention Water Control Structures	10	89.22
Grassed Filter Strips	5	7.31
Cover Crops	1	10.00
Permanent Vegetative Cover on Critical Areas	5	70.70
Conservation Tillage[d]	1	17.34
Reforestation of Crop and Pasture[d]	10	46.66
Grassed Waterways[e]	10	1.00/LF/yr
Animal Waste System[f]	10	3.76/ton/yr

[a] Median costs (1990 dollars) obtained from the Chesapeake Bay Program Office (CBPO) BMP tracking data base and Chesapeake Bay Agreement Jurisdictions' unit data cost. Costs per acre are for acres benefited by the practice.
[b] Annualized BMP total cost including O&M, planning, and technical assistance costs.
[c] EAC = Equivalent annual cost: annualized total costs for the life span. Interest rate = 10%.
[d] Government incentive costs.
[e] Annualized unit cost per linear foot of constructed waterway.
[f] Units for animal waste are given as $/ton of manure treated.

[illegible]

Limit the discharge from the confined animal facility to surface waters by:

(1) Storing both the facility wastewater *and* the runoff from confined animal facilities that is caused by storms up to and including a 25-year, 24-hour frequency storm. Storage structures should:

(a) Have an earthen lining or plastic membrane lining, or
(b) Be constructed with concrete, or
(c) Be a storage tank;

and

(2) Managing stored runoff and accumulated solids from the facility through an appropriate waste utilization system.

1. Applicability

This management measure is intended for application by States to all new facilities regardless of size and to all new or existing confined animal facilities that contain the following number of head or more:

	Head	Animal Units[2]
Beef Feedlots	300	300
Stables (horses)	200	400
Dairies	70	98
Layers	15,000	150[3]
		495[4]
Broilers	15,000	150[3]
		495[4]
Turkeys	13,750	2,475
Swine	200	80

except those facilities that are required by Federal regulation 40 CFR 122.23 to apply for and receive discharge permits. That section applies to "concentrated animal feeding operations," which are defined in 40 CFR Part 122, Appendix B. In addition, 40 CFR 122.23(c) provides that the Director of an NPDES discharge permit program may designate any animal feeding operation as a concentrated animal feeding operation (which has the effect of subjecting

[2] See *animal unit* in Glossary.

[3] If facility has a liquid manure system, as used in 40 CFR Section 122, Appendix B.

[4] If facility has continuous overflow watering, as used in 40 CFR Section 122, Appendix B.

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the operation to the NPDES permit program requirements) upon determining that it is a significant contributor of water pollution. In such cases, upon issuance of a permit, the terms of the permit apply and this management measure ceases to apply.

Under the Coastal Zone Act Reauthorization Amendments, States are subject to a number of requirements as they develop coastal nonpoint programs in conformity with this measure and will have some flexibility in doing so. The application of management measures by States is described more fully in *Coastal Nonpoint Pollution Control Program: Program Development and Approval Guidance*, published jointly by the U.S. Environmental Protection Agency (EPA) and the National Oceanic and Atmospheric Administration (NOAA) of the U.S. Department of Commerce.

A *confined animal facility* is a lot or facility (other than an aquatic animal production facility) where the following conditions are met:

- Animals (other than aquatic animals) have been, are, or will be stabled or confined and fed or maintained for a total of 45 days or more in any 12-month period, and
- Crops, vegetation forage growth, or post-harvest residues are not sustained in the normal growing season over any portion of the lot or facility.

Two or more animal facilities under common ownership are considered, for the purposes of these guidelines, to be a single animal facility if they adjoin each other or if they use a common area or system for the disposal of wastes.

Confined animal facilities, as defined above, include areas used to grow or house the animals, areas used for processing and storage of product, manure and runoff storage areas, and silage storage areas.

Facility wastewater and runoff from confined animal facilities are to be controlled under this management measure (Figure 2-7). Runoff includes any precipitation (rain or snow) that comes into contact with any manure, litter, or bedding. Facility wastewater is water discharged in the operation of an animal facility as a result of any or all of the following: animal or poultry watering; washing, cleaning, or flushing pens, barns, manure pits, or other animal facilities; washing or spray cooling of animals; and dust control.

2. Description

The problems associated with animal facilities result from runoff, facility wastewater, and manure. For additional information regarding problems, see Section I.F.3 of this chapter.

Application of this management measure will greatly reduce the volume of runoff, manure, and facility wastewater reaching a waterbody, thereby improving water quality and the use of the water resource. The measure can be implemented by using practices that divert runoff water from upslope sites and roofs away from the facility, thereby minimizing the amount of water to be stored and managed. Runoff water and facility wastewater should be routed through a settling structure or debris basin to remove solids, and then stored in a pit, pond, or lagoon for application on agricultural land (Figure 2-8). If manure is managed as a liquid, all manure, runoff, and facility wastewater can be stored in the same structure and there is no need for a debris basin.

For new facilities and expansions to existing facilities, consideration should be given to siting the facility:

- Away from surface waters;
- Away from areas with high leaching potential; and
- In areas where adequate land is available to apply animal wastes in accordance with the nutrient management measure.

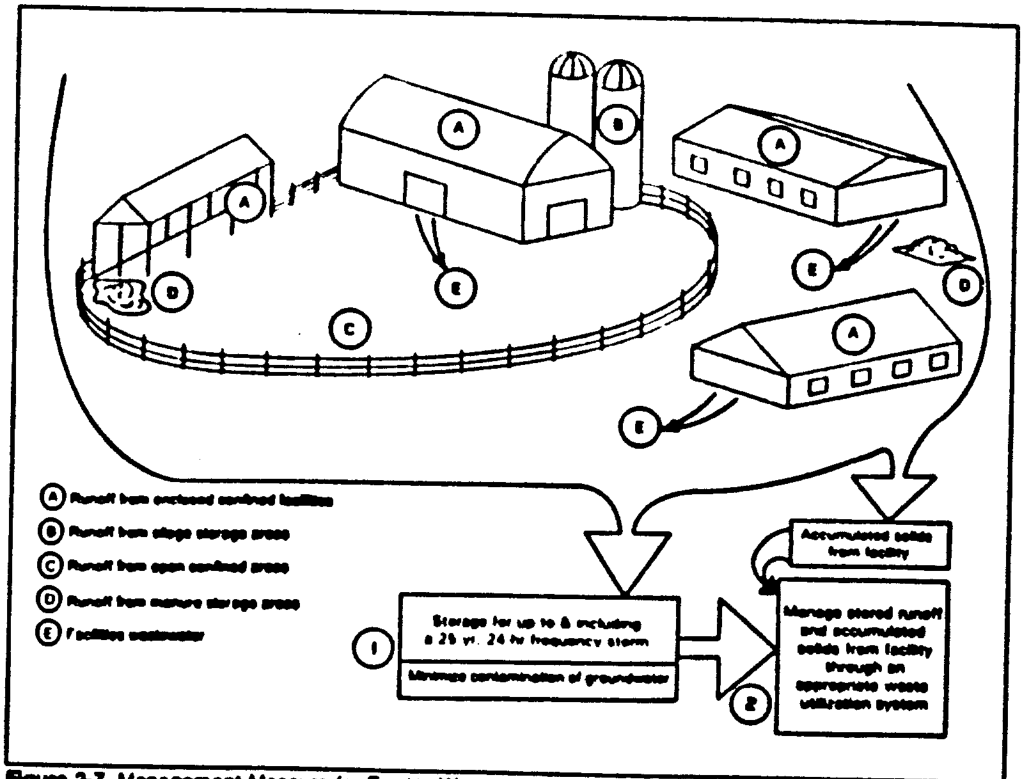

Figure 2-7. Management Measure for Facility Wastewater and Runoff from Confined Animal Facilities (Large Units).

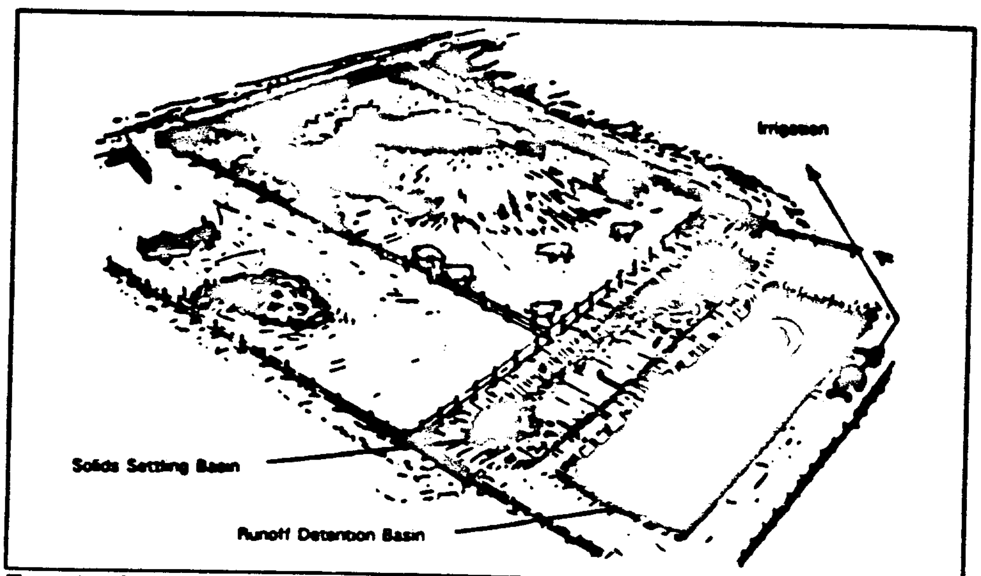

Figure 2-8. Example of manure and runoff storage system (Sutton, 1990).

This management measure does *not* require manure storage structures or areas, nor does it specify required manure management practices. This management measure does, however, address the management of *runoff* from manure storage areas. Manure may be stacked in the confined lot or other appropriate area as long as the storage and management of runoff from the confined lot are in accordance with this management measure. If manure is managed as a solid, any drainage from the storage area or structure area or structure should be routed to the runoff storage system.

When applied to agricultural lands, manure, stored runoff water, stored facility wastewater, and accumulated solids from the facility are to be applied in accordance with the nutrient management measure. An appropriate waste utilization system to minimize impacts to surface water and protect ground water may be achieved through implementation of the SCS Waste Utilization practice (633).

It is recognized that implementation of this measure may increase the potential for movement of water and soluble pollutants through the soil profile to the ground water. It is not the intent of this measure to address a surface water problem at the expense of ground water. Facility wastewater and runoff control systems can and should be designed to protect ground water. Ground-water protection will also be provided by minimizing seepage to ground water, if soil conditions require further protection, and by using the nutrient and pesticide management measures to reduce and control the application of nutrients and pesticides.

Seepage to ground water can be minimized by lining the runoff or manure storage structure with an earthen lining or plastic membrane lining, by constructing with concrete, or by constructing a storage tank. This is not difficult to accomplish and should be achieved in the initial design to reduce costs. For some soils and locations, movement of pollutants to the ground water is not a concern, but site evaluations are needed to determine the appropriate action to take to protect the resources at the site.

Operation and Maintenance of This Measure

Operation

Holding ponds and treatment lagoons should be operated such that the design storm volume is available for storage of runoff. Facilities filled to or near capacity should be drawn down as soon as all site conditions permit the safe removal and appropriate use of stored materials. Solids should be removed from solids separation basins as soon as possible following storm events to ensure that needed solids storage volume is available for subsequent storms.

Maintenance

Diversions will need periodic reshaping and should be free of trees and brush growth. Gutters and downspouts should be inspected annually and repaired when needed. Established grades for lot surfaces and conveyance channels are to be maintained at all times.

Channels should be free of trees and brush growth. Cleaning of debris basins, holding ponds, and lagoons will be needed to ensure that design volumes are maintained. Clean water should be excluded from the storage structure unless it is needed for further dilution in a liquid system.

3. Management Measure Selection

This management measure was selected for larger-sized animal production facilities because it can eliminate the pollutants leaving a facility by storing runoff from storms up to and including the 25-year, 24-hour frequency storm. It also uses practices that reduce the amount of water that comes into contact with animal waste materials. It requires that stored runoff and accumulated solids from the facility are managed through an appropriate waste utilization system. Any stored water, accumulated solids, processed dead animals, or manure are to be applied in accordance with the nutrient management measure.

The size limitations that define a large unit are based on EPA's analysis of the economic achievability of the management measure.

4. Effectiveness Information

The effectiveness of management practices to control contaminant losses from confined livestock facilities depends on several factors including:

- The contaminant(s) to be controlled and their likely pathways in surface, subsurface, and ground-water flows;
- The types of practices (section 5) and how these practices control surface, subsurface, and ground-water contaminant pathways; and
- Site-specific variables such as soil type, topography, precipitation characteristics, type of animal housing and waste storage facilities, method of waste collection, handling and disposal, and seasonal variations. The site-specific conditions must be considered in system design, thus having a large effect on practice effectiveness levels.

The gross effectiveness estimates reported in Table 2-9 simply indicate summary literature values. For specific cases, a wide range of effectiveness can be expected depending on the value and interaction of the site-specific variables cited above.

When runoff from storms up to and including the 24-hour, 25-year frequency storm is stored, there will be no release of pollutants from a confined animal facility via the surface runoff route. Rare storms of a greater magnitude or sequential storms of combined greater magnitude may produce runoff, however. Table 2-10 reflects the occurrence of such storms by indicating less than 100 percent control for runoff control systems.

Table 2-9. Relative Gross Effectiveness[a] of Confined Livestock Control Measures (Pennsylvania State University, 1992a)

Practice[b] Category	Runoff[c] Volume	Total[d] Phosphorus (%)	Total[d] Nitrogen (%)	Sediment (%)	Fecal Coliform (%)
Animal Waste Systems[e]	-	90	80	60	85
Diversion Systems[f]	-	70	45	NA	NA
Filter Strips[g]	-	85	NA	60	55
Terrace System	-	85	55	80	NA
Containment Structures[h]	-	60	65	70	90

NA = not available.
[a] Actual effectiveness depends on site-specific conditions. Values are not cumulative between practice categories.
[b] Each category includes several specific types of practices.
[c] - = reduction; + = increase; 0 = no change in surface runoff.
[d] Total phosphorus includes total and dissolved phosphorus; total nitrogen includes organic-N, ammonia-N, and nitrate-N.
[e] Includes methods for collecting, storing, and disposing of runoff and process-generated wastewater.
[f] Specific practices include diversion of uncontaminated water from confinement facilities.
[g] Includes all practices that reduce contaminant losses using vegetative control measures.
[h] Includes such practices as waste storage ponds, waste storage structures, waste treatment lagoons.

Table 2-10. Effectiveness of Runoff Control Systems (DPRA, 1986)

	Removal Efficiency (%)	
Management Practice	Solids	Phosphorus
Runoff Control System	80 - 90	70 - 95

5. Confined Animal Facility Management Practices

As discussed more fully at the beginning of this chapter and in Chapter 1, the following practices are described for illustrative purposes only. State programs need not require implementation of these practices. However, as a practical matter, EPA anticipates that the management measure set forth above generally will be implemented by applying one or more management practices appropriate to the source, location, and climate. The practices set forth below have been found by EPA to be representative of the types of practices that can be applied successfully to achieve the management measure described above.

Combinations of the following practices can be used to satisfy the requirements of this management measure. The U.S. Soil Conservation Service (SCS) practice number and definition are provided for each management practice, where available. Also included in italics are SCS statements describing the effect each practice has on water quality (USDA-SCS, 1988).

■ a. ***Dikes (356): An embankment constructed of earth or other suitable materials to protect land against overflow or to regulate water.***

Where dikes are used to prevent water from flowing onto the floodplain, the pollution dispersion effect of the temporary wetlands and backwater are decreased. The sediment, sediment-attached, and soluble materials being transported by the water are carried farther downstream. The final fate of these materials must be investigated on site. Where dikes are used to retain runoff on the floodplain or in wetlands the pollution dispersion effects of these areas may be enhanced. Sediment and related materials may be deposited, and the quality of the water flowing into the stream from this area will be improved.

Dikes are used to prevent wetlands and to form wetlands. The formed areas may be fresh, brackish, or saltwater wetlands. In tidal areas dikes are used to stop saltwater intrusion, and to increase the hydraulic head of fresh water which will force intruded salt water out the aquifer. During construction there is a potential of heavy sediment loadings to the surface waters. When pesticides are used to control the brush on the dikes and fertilizers are used for the establishment and maintenance of vegetation there is the possibility for these materials to be washed into the surface waters.

■ b. ***Diversions (362): A channel constructed across the slope with a supporting ridge on the lower side.***

This practice will assist in the stabilization of a watershed, resulting in the reduction of sheet and rill erosion by reducing the length of slope. Sediment may be reduced by the elimination of ephemeral and large gullies. This may reduce the amount of sediment and related pollutants delivered to the surface waters.

■ c. ***Grassed waterway (412): A natural or constructed channel that is shaped or graded to required dimensions and established in suitable vegetation for the stable conveyance of runoff.***

This practice may reduce the erosion in a concentrated flow area, such as in a gully or in ephemeral gullies. This may result in the reduction of sediment and substances delivered to receiving waters. Vegetation may act as a filter *in removing some of the sediment delivered to the waterway, although this is not the primary function of a grassed waterway.*

Any chemicals applied to the waterway in the course of treatment of the adjacent cropland may wash directly into the surface waters in the case where there is a runoff event shortly after spraying.

When used as a stable outlet for another practice, waterways may increase the likelihood of dissolved and suspended pollutants being transported to surface waters when these pollutants are delivered to the waterway.

d. Heavy use area protection (561): Protecting heavily used areas by establishing vegetative cover, by surfacing with suitable materials, or by installing needed structures.

Protection may result in a general improvement of surface water quality through the reduction of erosion and the resulting sedimentation. Some increase in erosion may occur during and immediately after construction until the disturbed areas are fully stabilized.

Some increase in chemicals in surface water may occur due to the introduction of fertilizers for vegetated areas and oils and chemicals associated with paved areas. Fertilizers and pesticides used during operation and maintenance may be a source of water pollution.

Paved areas installed for livestock use will increase organic, bacteria, and nutrient loading to surface waters. Changes in ground water quality will be minor. Nitrate nitrogen applied as fertilizer in excess of vegetation needs may move with infiltrating waters. The extent of the problem, if any, may depend on the actual amount of water percolating below the root zone.

e. Lined waterway or outlet (468): A waterway or outlet having an erosion-resistant lining of concrete, stone, or other permanent material.

The lined section extends up the side slopes to a designed depth. The earth above the permanent lining may be vegetated or otherwise protected.

This practice may reduce the erosion in concentrated flow areas resulting in the reduction of sediment and substances delivered to the receiving waters.

When used as a stable outlet for another practice, lined waterways may increase the likelihood of dissolved and suspended substances being transported to surface waters due to high flow velocities.

f. Roof runoff management (558): A facility for controlling and disposing of runoff water from roofs.

This practice may reduce erosion and the delivery of sediment and related substances to surface waters. It will reduce the volume of water polluted by animal wastes. Loadings of organic waste, nutrients, bacteria, and salts to surface water are prevented from flowing across concentrated waste areas, barnyards, roads and alleys will be reduced. Pollution and erosion will be reduced. Flooding may be prevented and drainage may improve.

g. Terrace (600): An earthen embankment, a channel, or combination ridge and channel constructed across the slope.

This practice reduces the slope length and the amount of surface runoff which passes over the area downslope from an individual terrace. This may reduce the erosion rate and production of sediment within the terrace interval. Terraces trap sediment and reduce the sediment and associated pollutant content in the runoff water which enhances surface water quality. Terraces may intercept and conduct surface runoff at a nonerosive velocity to stable outlets, thus reducing the occurrence of ephemeral and classic gullies and the resulting sediment. Increases in infiltration *can cause a greater amount of soluble nutrients and pesticides to be leached into the soil. Underground outlets may collect highly soluble nutrient and pesticide leachates and convey runoff and conveying it directly to an outlet, terraces may increase the delivery of pollutants to surface waters. Terraces increase the opportunity to leach salts below the root zone in the soil. Terraces may have a detrimental effect on water quality if they concentrate and accelerate delivery of dissolved or suspended nutrient, salt, and pesticide pollutants to surface or ground waters.*

■ *h. Waste storage pond (425): An impoundment made by excavation or earth fill for temporary storage of animal or other agricultural wastes.*

This practice reduces the direct delivery of polluted water, which is the runoff from manure stacking areas and feedlots and barnyards, to the surface waters. This practice may reduce the organic, pathogen, and nutrient loading to surface waters. This practice may increase the dissolved pollutant loading to ground water by leakage through the sidewalls and bottom.

■ *i. Waste storage structure (313): A fabricated structure for temporary storage of animal wastes or other organic agricultural wastes.*

This practice may reduce the nutrient, pathogen, and organic loading to the surface waters. This is accomplished by intercepting and storing the polluted runoff from manure stacking areas, barnyards and feedlots. This practice will not eliminate the possibility of contaminating surface and ground water; however, it greatly reduces this possibility.

■ *j. Waste treatment lagoon (359): An impoundment made by excavation or earth fill for biological treatment of animal or other agricultural wastes.*

This practice may reduce polluted surficial runoff and the loading of organics, pathogens, and nutrients into the surface waters. It decreases the nitrogen content of the surface runoff from feedlots by denitrification. Runoff is retained long enough that the solids and insoluble phosphorus settle and form a sludge in the bottom of the lagoon. There may be some seepage through the sidewalls and the bottom of the lagoon. Usually the long-term seepage rate is low enough, so that the concentration of substances transported into the ground water does not reach an unacceptable level.

■ *k. Application of manure and/or runoff water to agricultural land*

Manure and runoff water are applied to agricultural lands and incorporated into the soil in accordance with the management measures for nutrients.

■ *l. Waste utilization (633): Using agricultural wastes or other wastes on land in an environmentally acceptable manner while maintaining or improving soil and plant resources.*

Waste utilization helps reduce the transport of sediment and related pollutants to the surface water. Proper site selection, timing of application and rate of application may reduce the potential for degradation of surface and ground water. This practice may increase microbial action in the surface layers of the soil, causing a reaction which assists in controlling pesticides and other pollutants by keeping them in place in the field.

Mortality and other compost, when applied to agricultural land, will be applied in accordance with the nutrient management measure. The composting facility may be subject to State regulations and will have a written operation and management plan if SCS practice 317 (composting facility) is used.

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■ *m. Composting facility (317): A facility for the biological stabilization of waste organic material.*

The purpose is to treat waste organic material biologically by producing a humus-like material that can be recycled as a soil amendment and fertilizer substitute or otherwise utilized in compliance with all laws, rules, and regulations.

■ *n. Commercial rendering or disposal services*

■ *o. Incineration*

■ *p. Approved burial sites*

6. Cost Information

Construction costs for control of runoff and manure from confined animal facilities are provided in Table 2-11. The annual operation and maintenance costs average 4 percent of construction costs for diversions, 3 percent of construction costs for settlement basins, and 5 percent of construction costs for retention ponds (DPRA, 1992). Annual costs for repairs, maintenance, taxes, and insurance are estimated to be 5 percent of investment costs for irrigation systems (DPRA, 1992).

Table 2-11. Costs for Runoff Control Systems (DPRA, 1992)

Practice[a]	Unit	Cost/Unit Construction ($)[b]
Diversion	foot	2.00
Irrigation		
- Piping (4-inch)	foot	1.75
- Piping (6-inch)	foot	2.25
- Pumps (10 hp)	unit	1,750.00
- Pumps (15 hp)	unit	2,000.00
- Pumps (30 hp)	unit	3,000.00
- Pumps (45 hp)	unit	3,500.00
- Sprinkler/gun (150 gpm)	unit	875.00
- Sprinkler/gun (250 gpm)	unit	1,750.00
- Sprinkler/gun (400 gpm)	unit	3,200.00
- Contracted service to empty retention pond	1,000 gallon	3.00
Infiltration[c]	acre	2,500.00
Manure Hauling	mile per 4.5-ton load	2.15
Dead Animal Composting Facility	cubic foot	5.00
Retention Pond		
- 241 cubic feet in size	cubic foot	2.58
- 2,678 cubic feet in size	cubic foot	1.24
- 28,638 cubic feet in size	cubic foot	0.60
- 267,123 cubic feet in size	cubic foot	0.31
Settling Basin		
- 53 cubic feet in size	cubic foot	4.28
- 488 cubic feet in size	cubic foot	2.74
- 5,088 cubic feet in size	cubic foot	1.71
- 49,950 cubic feet in size	cubic foot	1.08

[a] Expected lifetimes of practices are 20 years for diversions, settling basins, retention ponds, and infiltration areas and 15 years for irrigation equipment.
[b] 1990 dollars. This table does not present annualized costs.
[c] Does not include land costs.

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[illegible] Management (Small Units)

Design and implement systems that collect solids, reduce contaminant concentrations, and reduce runoff to minimize the discharge of contaminants in both facility wastewater and in runoff that is caused by storms up to and including a 25-year, 24-hour frequency storm. Implement these systems to substantially reduce significant increases in pollutant loadings to ground water.

Manage stored runoff and accumulated solids from the facility through an appropriate waste utilization system.

1. Applicability

This management measure is intended for application by States to all existing confined animal facilities that contain the following number of head:

	Head	Animal Units[3]
Beef Feedlots	50-299	50-299
Stables (horses)	100-199	200-399
Dairies	20-69	28-97
Layers	5,000-14,999	50-149[6]
		165-494[7]
Broilers	5,000-14,999	50-149[6]
		165-494[7]
Turkeys	5,000-13,749	900-2,474
Swine	100-199	40-79

except those facilities that are required by Federal regulation 40 CFR 122.23(c) to apply for and receive discharge permits. 40 CFR 122.23(c) provides that the Director of an NPDES discharge permit program may designate any animal feeding operation as a concentrated animal feeding operation (which has the effect of subjecting the operation to the NPDES permit program requirements) upon determining that it is a significant contributor of water pollution. In such cases, upon issuance of a permit, the terms of the permit apply and this management measure ceases to apply.

Facilities containing fewer than the number of head listed above are not subject to the requirements of this management measure. Existing facilities that meet the requirements of Management Measure B1 for large units are in compliance with the requirements of this management measure. Existing and new facilities that already minimize

[3] See *animal unit* in Glossary.

[6] If facility has a liquid manure system, as used in 40 CFR Section 122, Appendix B.

[7] If facility has continuous overflow watering, as used in 40 CFR Section 122, Appendix B.

the discharge of contaminants to surface waters, protect against contamination of ground water, and have an appropriate waste utilization system may already meet the requirements of this management measure. Such facilities may not need additional controls for the purposes of this management measure.

Under the Coastal Zone Act Reauthorization Amendments, States are subject to a number of requirements as they develop coastal nonpoint programs in conformity with this measure and will have some flexibility in doing so. The application of management measures by States is described more fully in *Coastal Nonpoint Pollution Control Program: Program Development and Approval Guidance*, published jointly by the U.S. Environmental Protection Agency (EPA) and the National Oceanic and Atmospheric Administration (NOAA) of the U.S. Department of Commerce.

A *confined animal facility* is a lot or facility (other than an aquatic animal production facility) where the following conditions are met:

- Animals (other than aquatic animals) have been, are, or will be stabled or confined and fed or maintained for a total of 45 days or more in any 12-month period, and

- Crops, vegetation forage growth, or post-harvest residues are not sustained in the normal growing season over any portion of the lot or facility.

Two or more animal facilities under common ownership are considered, for the purposes of these guidelines, to be a single animal facility if they adjoin each other or if they use a common area or system for the disposal of wastes.

Confined animal facilities, as defined above, include areas used to grow or house the animals, areas used for processing and storage of product, manure and runoff storage areas, and silage storage areas.

Facility wastewater and runoff from confined animal facilities are to be controlled under this management measure (Figure 2-9). Runoff includes any precipitation (rain or snow) that comes into contact with any manure, litter, or bedding. Facility wastewater is water discharged in the operation of an animal facility as a result of any or all of the following: animal or poultry watering; washing, cleaning, or flushing pens, barns, manure pits, or other animal facilities; washing or spray cooling of animals; and dust control.

2. Description

The goal of this management measure is to minimize the discharge of contaminants in both facility wastewater and in runoff that is caused by storms up to and including a 25-year, 24-hour frequency storm by using practices such as solids separation basins in combination with vegetative practices and other practices that reduce runoff and are also protective of ground water.

The problems associated with animal facilities are the control of runoff, facility wastewater, and manure. For additional information regarding problems, see Section I.F.3. of this chapter.

Application of this management measure will greatly reduce the volume of runoff, manure, and facility wastewater reaching a waterbody, thereby improving water quality and the use of the water resource. The measure can be implemented by using practices that divert runoff water from upslope sites and roofs away from the facility, thereby minimizing the amount of water that must be managed (Figure 2-10). Runoff water and facility wastewater from the facility should be routed through a settling structure or debris basin to remove solids. If manure is managed as a liquid, all manure, runoff, and facility wastewater can be stored in the same structure and there is no need for a debris basin.

This management measure does *not* require manure storage structures or areas, nor does it specify required manure management practices. This management measure does, however, address the management of *runoff* from manure

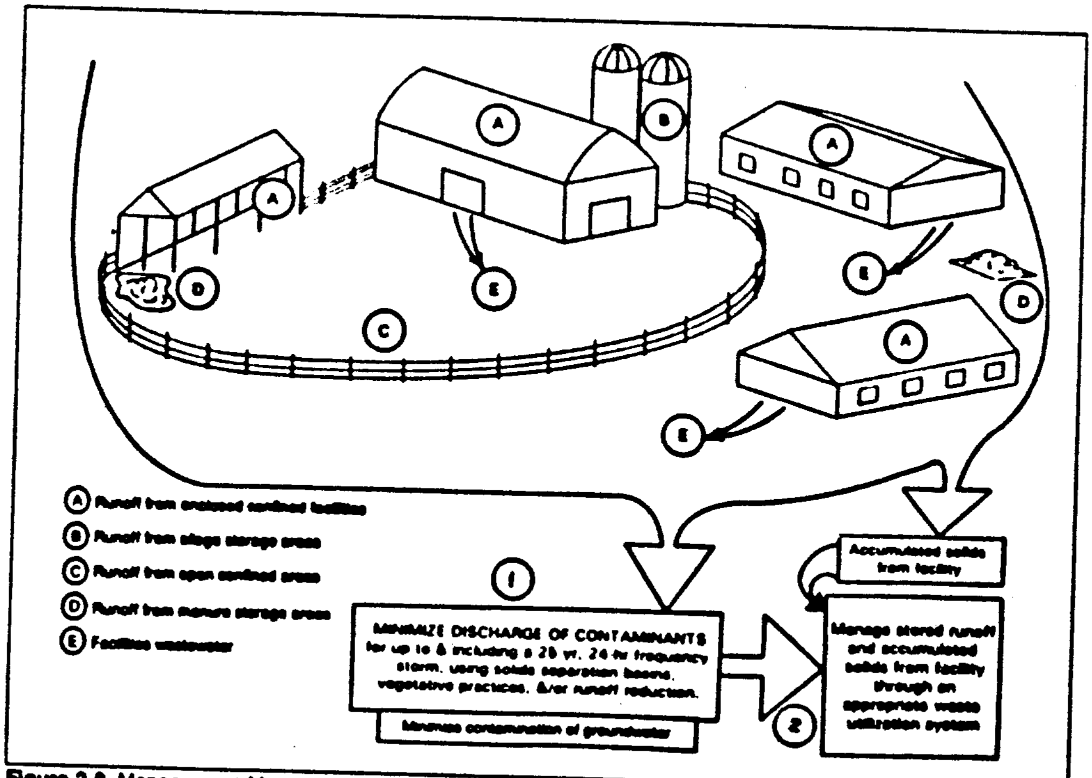

Figure 2-9. Management Measure for Facility Wastewater and Runoff from Confined Animal Facilities (Small Units).

storage areas. Manure may be stacked in the confined lot or other appropriate area as long as the discharge is minimized and any stored runoff is managed in accordance with this management measure. If manure is managed as a solid, any drainage from the storage area or structure should be routed to the runoff control practices.

When applied to agricultural lands, manure, stored runoff water, stored facility wastewater, and accumulated solids from the facility are to be applied in accordance with the nutrient management measure. An appropriate waste utilization system to minimize impacts to surface water and protect ground water may be achieved through implementation of the SCS Waste Utilization practice (633).

It is recognized that implementation of this measure may increase the potential for movement of water and soluble pollutants through the soil profile to the ground water. It is not the intent of this measure to address a surface water problem at the expense of ground water. Facility wastewater and runoff control systems can and should be designed to protect against the contamination of ground water. Ground-water protection will also be provided by minimizing seepage to ground water, if soil conditions require further protection, and by using the nutrient and pesticide management measures to reduce and control the application of nutrients and pesticides. While a nutrient management plan is not required to be implemented on the vegetative control practices themselves, ground water should be protected by taking extreme care to not exceed the capacity of the practices to assimilate nutrients.

When storage structures are used to meet the requirements of this management measure, seepage to ground water can be minimized by lining the runoff or manure storage structure with an earthen lining or plastic membrane lining, by constructing with concrete, or by constructing a storage tank. This is not difficult to accomplish and should be achieved in the initial design to reduce costs. For some soils and locations movement of pollutants to the ground

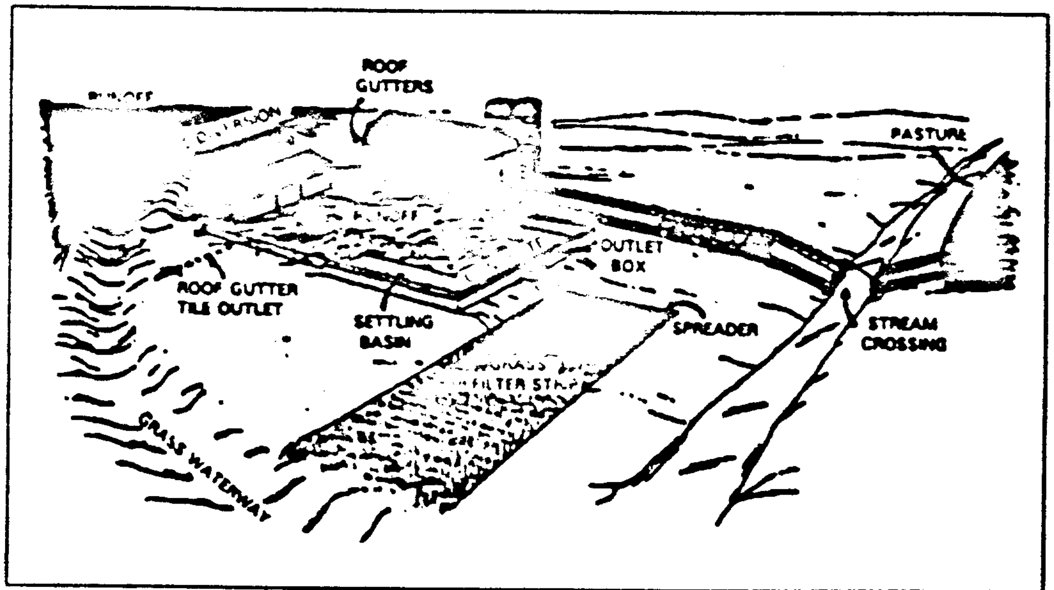

Figure 2-10. Typical barnyard runoff management system (Wisconsin Dept. of Agriculture, Trade and Consumer Protection, 1989).

water is not a concern, but each site must be evaluated and the appropriate action taken to protect the resources at the site.

Operation and Maintenance of This Measure

Operation

Holding ponds and treatment lagoons should be operated such that the design storm volume is available for storage of runoff. Facilities that have filled should be drawn down as soon as all site conditions permit the safe removal and appropriate use of stored materials. Solids should be removed from solids separation basins as soon as possible following storm events to ensure that needed solids storage volume is available for subsequent storms.

Maintenance

Diversions will need periodic reshaping and should be free of trees and brush growth. Gutters and downspouts should be inspected annually and repaired when needed. Established grades for lot surfaces and conveyance channels must be maintained at all times.

Channels must be free of trees and brush growth. Cleaning of debris basins, holding ponds, and lagoons will be needed to ensure that design volumes are maintained. Clean water should be excluded from the storage structure unless it is needed for further dilution in a liquid system.

3. Management Measure Selection

This management measure was selected for smaller-sized animal production facilities based on an evaluation of available information that documents the beneficial effects of improved management of confined livestock facilities. Specifically, the management measure reduces the amount of pollutants leaving a facility by using practices that reduce the amount of water that comes into contact with animal waste materials. It also uses solid removal and filtration of runoff water to remove a significant amount of the pollutants contained in the runoff waters. This can be accomplished without the expense of constructing a runoff storage structure and purchasing the equipment necessary to apply the stored water to the land.

This management measure also requires that stored runoff and accumulated solids from the facility are managed through an appropriate waste utilization system. The size limitations that define a small unit are based on EPA's analysis of the economic achievability of the management measure.

4. Effectiveness Information

The effectiveness information presented for large units (Tables 2-9 and 2-10) also applies to this management measure.

Pollutant loads from runoff caused by storms up to and including the 25-year, 24-hour frequency storm can be reduced by decreasing the potential for runoff contamination (e.g., by keeping accumulations of manure off the open lots), and by removing the contaminants to the fullest extent practicable through vegetative and structural practices (e.g., solids separation devices, sediment basins, filter strips, and constructed wetlands). Pollutant loads can also be reduced by storing and applying the runoff to the land with any manure and facility wastewater in accordance with the nutrient management measure.

Table 2-12 shows reductions in pollutant concentrations that are achievable with solids separation basins that receive runoff from barnyards and feedlots. Concentration reductions may differ from the load reductions presented in Tables 2-9 and 2-10 since loads are determined by both concentration and discharge volume. Solids separation basins combined with drained infiltration beds and vegetated filter strips (VFS) provide additional reductions in contaminant concentrations. The effectiveness of solids separation basins is highly dependent on site variables. Solids separation; basin sizing and management (clean-out); characteristics of VFS areas such as soil type, land slope, length, vegetation type, vegetation quality; and storm amounts and intensities all play important roles in the performance of the system. Appropriate operation and maintenance are critical to success.

Table 2-12. Concentrated Reductions in Barnyard and Feedlot Runoff Treated with Solids Separation

Site Location	Constituent Reduction (%)			
	TS	COD	Nitrogen	TP
Ohio - basin only[a,b]	49-54	51-56	35	21-41
Ohio - basin combined w/infiltration bed[a]	82	85	—	80
VFS[a]	87	89	83	84
Canada - basin only[c]	56	38	14(TKN)	—
Canada - basin w/VFS[c]	(High 90's in fall and spring)			
Illinois - basin w/VFS[d]	73		80(TKN)	78

[a] Edwards et al., 1986.
[b] Edwards et al., 1983.
[c] Adam et al., 1986.
[d] Dickey, 1981.

5. Confined Animal Facility Management Practices

As discussed more fully at the beginning of this chapter and in Chapter 1, the following practices are described for illustrative purposes only. State programs need not require implementation of these practices. However, as a practical matter, EPA anticipates that the management measure set forth above generally will be implemented by applying one or more management practices appropriate to the source, location, and climate. The practices set forth below have been found by EPA to be representative of the types of practices that can be applied successfully to achieve the management measure described above.

Combinations of the following practices can be used to satisfy the requirements of this management measure. The U.S. Soil Conservation Service (SCS) practice number and definition are provided for each management practice, where available. Also included in italics are SCS statements describing the effect each practice has on water quality (USDA-SCS, 1988).

■ a. ***Waste storage pond (425): An impoundment made by excavation or earth fill for temporary storage of animal or other agricultural waste.***

This practice reduces the direct delivery of polluted water, which is the runoff from manure stacking areas and feedlots and barnyards, to the surface waters. This practice may reduce the organic, pathogen, and nutrient loading to surface waters. This practice may increase the dissolved pollutant loading to ground water by leakage through the sidewalls and bottom.

■ b. ***Waste storage structure (313): A fabricated structure for temporary storage of animal waste or other organic agricultural waste.***

This practice may reduce the nutrient, pathogen, and organic loading to the surface waters. This is accomplished by intercepting and storing the polluted runoff from manure stacking areas, barnyards and feedlots. This practice will not eliminate the possibility of contaminating surface and ground water; however, it greatly reduces this possibility.

■ c. ***Waste treatment lagoon (359): An impoundment made by excavation or earth fill for biological treatment of animal or other agricultural waste.***

This practice may reduce polluted surficial runoff and the loading of organics, pathogens, and nutrients into the surface waters. It decreases the nitrogen content of the surface runoff from feedlots by denitrification. Runoff is retained long enough that the solids and insoluble phosphorus settle and form a sludge in the bottom of the lagoon. There may be some seepage through the sidewalls and the bottom of the lagoon. Usually the long-term seepage rate is low enough, so that the concentration of substances transported into the ground water does not reach an unacceptable level.

■ d. ***Sediment basin (350): A basin constructed to collect and store debris or sediment.***

Sediment basins will remove sediment, sediment associated materials and other debris from the water which is passed on downstream. Due to the detention of the runoff in the basin, there is an increased opportunity for soluble materials to be leached toward the ground water.

■ e. ***Water and sediment control basin (638): An earth embankment or a combination ridge and channel generally constructed across the slope and minor water courses to form a sediment trap and a water detention basin.***

The practice traps and removes sediment and sediment-attached substances from runoff. Trap control efficiencies for sediment and total phosphorus, that are transported by runoff, may exceed 90 percent in silt loam soils. Dissolved substance, such as nitrates, may be removed from discharge to downstream areas because of the increased infiltration. Where geologic condition permit, the practice will lead to increased loadings of dissolved substances toward ground water. Water temperatures of surface runoff, released through underground outlets, may increase slightly because of longer exposure to warming during its impoundment.

f. *Filter strip (393): A strip or area of vegetation for removing sediment, organic matter, and other contaminants from runoff and wastewater.*

Filter strips for sediment and related pollutants meeting minimum requirements may trap the coarser grained sediment. They may not filter out soluble or suspended fine-grained materials. When a storm caused runoff in excess of the design runoff, the filter may be flooded and may cause large loads of pollutants to be released to the surface water. This type of filter requires high maintenance and has a relatively short service life and is effective only as long as the flow through the filter is shallow sheet flow.

Filter strips for runoff from concentrated livestock areas may trap organic material, solids, materials which become adsorbed to the vegetation or the soil within the filter. Often they will not filter out soluble materials. This type of filter is often wet and is difficult to maintain.

Filter strips for controlled overland flow treatment of liquid wastes may effectively filter out pollutants. The filter must be properly managed and maintained, including the proper resting time. Filter strips on forest land may trap coarse sediment, timbering debris, and other deleterious material being transported by runoff. This may improve the quality of surface water and has little effect on soluble material in runoff or on the quality of ground water.

All types of filters may reduce erosion on the area on which they are constructed.

Filter strips trap solids from the runoff flowing in sheet flow through the filter. Coarse-grained and fibrous materials are filtered more efficiently than fine-grained and soluble substances. Filter strips work for design conditions, but when flooded or overloaded they may release a slug load of pollutants into the surface water.

g. *Grassed waterway (412): A natural or constructed channel that is shaped or graded to required dimensions and established in a suitable vegetation for the stable conveyance of runoff.*

This practice may reduce the erosion in a concentrated flow area, such as in a gully or in ephemeral gullies. This may result in the reduction of sediment and substances delivered to receiving waters. Vegetation may act as a filter in removing some of the sediment delivered to the waterway, although this is not the primary function of a grassed waterway.

Any chemicals applied to the waterway in the course of treatment of the adjacent cropland may wash directly into the surface waters in the case where there is a runoff event shortly after spraying.

When used as a stable outlet for another practice, waterways may increase the likelihood of dissolved and suspended pollutants being transported to surface waters when these pollutants are delivered to the waterway.

h. *Constructed wetland (ASCS-999): A constructed aquatic ecosystem with rooted emergent hydrophytes designed and managed to treat agricultural wastewater.*

This is a conservation practice for which SCS has developed technical requirements under a trial program leading to the development of a conservation practice standard.

i. Dikes (356): An embankment constructed of earth or other suitable materials to protect land against overflow or to regulate water.

Where dikes are used to prevent water from flowing onto the floodplain, the pollution dispersion effects of the temporary wetlands and backwater are decreased. The sediment, sediment-attached, and soluble materials being transported by the water are carried further downstream. The final fate of these materials must be investigated on site. Where dikes are used to retain runoff on the floodplain or in wetlands the pollution dispersion effects of these areas may be enhanced. Sediment and related materials may be deposited, and the quality of the water flowing into the stream from this area will be improved.

Dikes are used to prevent wetlands and to form wetlands. The formed areas may be fresh, brackish, or saltwater wetlands. In tidal areas dikes are used to stop saltwater intrusion, and to increase the hydraulic head of fresh water which will force intruded salt water out the aquifer. During construction there is a potential of heavy sediment loadings to the surface waters. When pesticides are used to control the brush on the dikes and fertilizers are used for the establishment and maintenance of vegetation there is the possibility for these materials to be washed into the surface waters.

j. Diversion (362): A channel constructed across the slope with a supporting ridge on the lower side.

This practice will assist in the stabilization of a watershed, resulting in the reduction of sheet and rill erosion by reducing the length of slope. Sediment may be reduced by the elimination of ephemeral and large gullies. This may reduce the amount of sediment and related pollutants delivered to the surface waters.

k. Heavy use area protection (561): Protecting heavily used areas by establishing vegetative cover, by surfacing with suitable materials, or by installing needed structures.

Protection may result in a general improvement of surface water quality through the reduction of erosion and the resulting sedimentation. Some increase in erosion may occur during and immediately after construction until the disturbed areas are fully stabilized.

Some increase in chemicals in surface water may occur due to the introduction of fertilizers for vegetated areas and oils and chemicals associated with paved areas. Fertilizers and pesticides used during operation and maintenance may be a source of water pollution.

Paved areas installed for livestock use will increase organic, bacteria, and nutrient loading to surface waters. Changes in ground water quality will be minor. Nitrate nitrogen applied as fertilizer in excess of vegetation needs may move with infiltrating waters. The extent of the problem, if any, may depend on the actual amount of water percolating below the root zone.

l. Lined waterway or outlet (468): A waterway or outlet having an erosion-resistant lining of concrete, stone, or other permanent material.

The lined section extends up the side slopes to a designed depth. The earth above the permanent lining may be vegetated or otherwise protected.

This practice may reduce the erosion in concentrated flow areas resulting in the reduction of sediment and substances delivered to the receiving waters.

When used as a stable outlet for another practice, lined waterways may increase the likelihood of dissolved and suspended substances being transported to surface waters due to high flow velocities.

m. *Roof runoff management (558): A facility for controlling and disposing of runoff water from roofs.*

This practice may reduce erosion and the delivery of sediment and related substances to surface waters. It will reduce the volume of water polluted by animal wastes. Loadings of organic waste, nutrients, bacteria, and salts to surface water are prevented from flowing across concentrated waste areas, barnyards, roads and alleys. Pollution and erosion will be reduced. Flooding may be prevented and drainage may improve.

n. *Terrace (600): An earthen embankment, a channel, or combination ridge and channel constructed across the slope.*

This practice reduces the slope length and the amount of surface runoff which passes over the area downslope from an individual terrace. This may reduce the erosion rate and production of sediment within the terrace interval. Terraces trap sediment and reduce the sediment and associated pollutant content in the runoff water which enhance surface water quality. Terraces may intercept and conduct surface runoff at a nonerosive velocity to stable outlets, thus reducing the occurrence of ephemeral and classic gullies and the resulting sediment. Increases in infiltration can cause a greater amount of soluble nutrients and pesticides to be leached into the soil. Underground outlets may collect highly soluble nutrient and pesticide leachates and convey runoff and conveying it directly to an outlet, terraces may increase the delivery of pollutants to surface waters. Terraces increase the opportunity to leach salts below the root zone in the soil. Terraces may have a detrimental effect on water quality if they concentrate and accelerate delivery of dissolved or suspended nutrient, salt, and pesticide pollutants to surface or ground waters.

o. *Waste utilization (633): Using agricultural wastes or other wastes on land in an environmentally acceptable manner while maintaining or improving soil and plant resources.*

Waste utilization helps reduce the transport of sediment and related pollutants to the surface water. Proper site selection, timing of application and rate of application may reduce the potential for degradation of surface and ground water. This practice may increase microbial action in the surface layers of the soil, causing a reaction which assists in controlling pesticides and other pollutants by keeping them in place in the field.

Mortality and other compost, when applied to agricultural land, will be applied in accordance with the nutrient management measure. The composting facility may be subject to State regulations and will have a written operation and management plan if SCS practice 317 (composting facility) is used.

p. *Composting facility (317): A facility for the biological stabilization of waste organic material.*

The purpose is to treat waste organic material biologically by producing a humus-like material that can be recycled as a soil amendment and fertilizer substitute or otherwise used in compliance with all laws, rules, and regulations.

q *Commercial rendering or disposal services*

r. *Incineration*

s. *Approved burial site*

6. Cost Information

The construction costs for large units (Table 2-11) also apply to this measure. The annual operation and maintenance costs average 4 percent of construction costs for diversions, 3 percent of construction costs for settlement basins, and 5 percent of construction costs for retention ponds (DPRA, 1992). Annual costs for repairs, maintenance, taxes, and insurance are estimated to be 5 percent of investment costs for irrigation systems (DPRA, 1992).

[illegible]

Develop, implement, and periodically update a nutrient management plan to: (1) apply nutrients at rates necessary to achieve realistic crop yields, (2) improve the timing of nutrient application, and (3) use agronomic crop production technology to increase nutrient use efficiency. When the source of the nutrients is other than commercial fertilizer, determine the nutrient value and the rate of availability of the nutrients. Determine and credit the nitrogen contribution of any legume crop. Soil and plant tissue testing should be used routinely. Nutrient management plans contain the following core components:

(1) Farm and field maps showing acreage, crops, soils, and waterbodies.

(2) Realistic yield expectations for the crop(s) to be grown, based primarily on the producer's actual yield history, State Land Grant University yield expectations for the soil series, or SCS Soils-5 information for the soil series.

(3) A summary of the nutrient resources available to the producer, which at a minimum include:

- Soil test results for pH, phosphorus, nitrogen, and potassium;
- Nutrient analysis of manure, sludge, mortality compost (birds, pigs, etc.), or effluent (if applicable);
- Nitrogen contribution to the soil from legumes grown in the rotation (if applicable); and
- Other significant nutrient sources (e.g., irrigation water).

(4) An evaluation of field limitations based on environmental hazards or concerns, such as:

- Sinkholes, shallow soils over fractured bedrock, and soils with high leaching potential,
- Lands near surface water,
- Highly erodible soils, and
- Shallow aquifers.

(5) Use of the limiting nutrient concept to establish the mix of nutrient sources and requirements for the crop based on a realistic yield expectation.

(6) Identification of timing and application methods for nutrients to: provide nutrients at rates necessary to achieve realistic crop yields; reduce losses to the environment; and avoid applications as much as possible to frozen soil and during periods of leaching or runoff.

(7) Provisions for the proper calibration and operation of nutrient application equipment.

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1. Applicability

This management measure is intended to be applied by States to activities associated with the application of nutrients to agricultural lands. Under the Coastal Zone Act Reauthorization Amendments of 1990, States are subject to a number of requirements as they develop coastal nonpoint programs in conformity with this measure and will have some flexibility in doing so. The application of management measures by States is described more fully in *Coastal Nonpoint Pollution Control Program: Program Development and Approval Guidance*, published jointly by the U.S. Environmental Protection Agency (EPA) and the National Oceanic and Atmospheric Administration (NOAA) of the U.S. Department of Commerce.

2. Description

The goal of this management measure is to minimize edge-of-field delivery of nutrients and minimize leaching of nutrients from the root zone. Nutrient management is pollution prevention achieved by developing a nutrient budget for the crop, applying nutrients at the proper time, applying only the types and amounts of nutrients necessary to produce a crop, and considering the environmental hazards of the site. In cases where manure is used as a nutrient source, manure holding areas may be needed to provide capability to avoid application to frozen soil.

This measure may result in some reduction in the amount of nutrients being applied to the land, thereby reducing the cost of production as well as protecting both ground water and surface water quality. However, application of the measure may in some cases cause more nutrients to be applied where there has not been a balanced use of nutrients in the past. This will usually allow all the nutrients to be used more efficiently, thereby reducing the amount of nutrients that will be available for transport from the field during the non-growing season. While the use of nutrient management should reduce the amount of nutrients lost with surface runoff to some degree, the primary control for the transport of nutrients that are attached to soil particles will be accomplished through the implementation of erosion and sediment control practices (Section II.A of this chapter). For information regarding the potential problems caused by nutrients see Section I.F.1 of this chapter.

Operation and Maintenance for Nutrient Management

The use of a nutrient management plan requires accurate information on the nutrient resources available to the producer. Management practices typically used to obtain this information include periodic soil testing for each field; soil and/or tissue testing during the early growth stages of the crop; and testing of manure, sludge, and irrigation water if they are used. The plan may call for multiple applications of nutrients that require more than one field operation to apply the total nutrients needed by the crop.

A nutrient management plan should be reviewed and updated at least once every 3 years, or whenever the crop rotation is changed or the nutrient source is changed. Application equipment should be calibrated and inspected for wear and damage periodically, and repaired when necessary. Records of nutrient use and sources should be maintained along with other management records for each field. This information will be useful when it is necessary to update or modify the management plan.

3. Management Measure Selection

This management measure was selected as a method (1) to minimize the amount of nutrients entering ground water through root zone leaching and entering surface water from edge-of-field delivery and (2) to promote more efficient use of all sources of nutrients that are available to the producer. The practices and concepts that can be used to implement this measure on a given site are those commonly used and recommended by States and USDA for general use on agricultural lands. By implementing the measure using the necessary mix of practices for a given site there should not be a negative economic impact on the operator, and in most cases the impact will be positive. Many of the practices that can be used to implement this measure may already be required by Federal, State, or local rules (e.g., field borders along streams) or may otherwise be in use on agricultural fields. Since many producers may

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already be using systems that satisfy or partly satisfy the intent of this management measure, the only action that may be necessary will be to determine the effectiveness of the existing practices and add additional practices, if needed. Use of existing practices will reduce the time, effort, and cost of implementing this measure.

4. Effectiveness Information

Following is a summary of information regarding pollution reductions that can be expected from installation of nutrient management practices.

The State of Maryland estimates that average reductions of 34 pounds of nitrogen and 41 pounds of phosphorus per acre can be achieved through the implementation of nutrient management plans (Maryland Department of Agriculture, 1990). These average reductions may be high because they apply mostly to farms that use animal wastes; average reductions for farms that use only commercial fertilizer may be lower. The reduction in the loading of these nutrients to coastal waters is difficult to measure or predict. Field-scale and watershed models, however, can be used to estimate the reduction in nutrients moving to the edges of fields and to ground water.

As of July 1990, the Chesapeake Bay drainage basin States of Pennsylvania, Maryland, and Virginia reported that approximately 114,300 acres (1.4 percent of eligible cropland in the basin) had nutrient management plans in place (USEPA, 1991a). The average nutrient reductions of total nitrogen and total phosphorus were 31.5 and 37.5 pounds per acre, respectively. The States initially focused nutrient management efforts on animal waste utilization. Because initial planning was focused on animal wastes (which have a relatively high total nitrogen and phosphorus loading factor), estimates of nutrient reductions attributed to nutrient management may decrease as more cropland using only commercial fertilizer is enrolled in the program.

In Iowa, average corn yields remained constant while nitrogen use dropped from 145 pounds per acre in 1985 to less than 130 pounds per acre in 1989 and 1990 as a result of improved nutrient management (Iowa State University, 1991b). In addition, data supplied from nitrate soil tests indicated that at least 32 percent of the soils sampled did not need additional nitrogen for optimal yields (Iowa State University, 1991b).

In a pilot program in Butler County, Iowa, 48 farms operating 25,000 acres reduced fertilizer nitrogen use by 240,000 pounds through setting realistic yield goals by soils, giving appropriate crop rotation and manure credits, and some use of the pre-sidedress soil nitrate test (Hallberg et al., 1991). Other data from Iowa showed that in some areas fields have enough potassium and phosphorus to last for at least another decade (Iowa State University, 1991b).

In Garvin Brook, Minnesota, fertilizer management on corn resulted in nitrogen savings of 29 to 49 pounds per acre from 1985 to 1988 (Wall et al., 1989). In this Rural Clean Water Program (RCWP) project, fertilizer management consisted of split applications and rates based upon previous yields, manure application, previous crops, and soil test results.

Berry and Hargett (1984) showed a 40 percent reduction in statewide nitrogen use over 8 years following introduction of improved fertilizer recommendations in Pennsylvania. Findings from the RCWP project in Pennsylvania indicate that, for 340 nutrient management plans, overall recommended reductions (corn, hay, and other crops) were 27 percent for nitrogen, 14 percent for phosphorus, and 12 percent for potash (USDA-ASCS, 1992a). Producers achieved 79 percent of the recommended nitrogen reductions and 45 percent of the recommended phosphorus reductions.

In Vermont, research suggests that a newly introduced, late spring soil test results in about a 50 percent reduction in the nitrogen recommendation compared to conventional technologies (Magdoff et al., 1984). Research in New York and other areas of the Nation documents fertilizer use reductions of 30 to 50 percent for late spring versus preplant and fall applications, with yields comparable to those of the preplant and fall applications (Bouldin et al., 1971).

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USDA reports that improved nutrient management has resulted in nitrogen application reductions of 33.1 pounds/acre treated for surface water protection, 28.4 pounds/acre treated for ground water protection, and 62.1 pounds of phosphorus per acre treated for water quality protection in its 16 Water Quality Demonstration Projects and 74 Hydrologic Unit Areas (USDA, 1992). The Hydrologic Unit Areas begun in 1990 show the greatest reductions in fertilizer use per acre (Table 2-13).

A summary of the effectiveness of nutrient management in controlling nitrogen and phosphorus is given in Table 2-14. This summary is based on an extensive search of the published literature.

Table 2-13. Nutrient Reductions Achieved Under USDA's Water Quality Program (USDA, 1992)

Projects	Cumulative: Pounds Reduced N	Cumulative: Pounds Reduced P	Cumulative: Acres Treated N	Cumulative: Acres Treated P	Average Reduction in Pounds/Acre Treated
1990 Demos (8 projects)	284,339 SW 556,437 GW	178,204	5,980 SW 18,771 GW	5,184	47.5 N-SW 29.6 N-GW 34.4 P
1991 Demos (8 projects)	34,672 SW	38,080	788 SW	692	44 N-SW 55 P
1990 HUAs (37 areas)	656,374 SW 601,646 GW	1,344,260	13,761 SW 18,808 GW	15,962	47.7 N-SW 35.8 N-GW 84.2 P
1991 HUAs (37 areas)	156,552 SW 366,890 GW	118,037	13,658 SW 16,115 GW	5,188	11.5 N-SW 20.2 N-GW 22.8 P
1990/1991 Demo/HUA Overall	1,131,937 SW 1,524,973 GW	1,678,561	34,187 SW 53,694 GW	27,026	33.1 N-SW 28.4 N-GW 62.1 P

SW = surface water
GW = ground water

Table 2-14. Relative Effectiveness[a] of Nutrient Management (Pennsylvania State University, 1992a)

Practice	Percent Change in Total Phosphorus Loads	Percent Change in Total Nitrogen Loads
Nutrient Management[b]	-35	-15

[a] Most observations from reported computer modeling studies.
[b] An agronomic practice related to source management; actual change in contaminant load to surface and ground water is highly variable.

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5. Nutrient Management Practices

As discussed more fully at the beginning of this chapter and in Chapter 1, the following practices are described for illustrative purposes only. State programs need not require implementation of these practices. However, as a practical matter, EPA anticipates that the management measure set forth above generally will be implemented by applying one or more management practices appropriate to the source, location, and climate. The practices set forth below have been found by EPA to be representative of the types of practices that can be applied successfully to achieve the management measure described above.

Following are practices, components, and sources of information that should be considered in the development of a nutrient management plan:

(1) Use of soil surveys in determining soil productivity and identifying environmentally sensitive sites.

(2) Use of producer-documented yield history and other relevant information to determine realistic crop yield expectations. Appropriate methods include averaging the three highest yields in five consecutive crop years for the planning site, or other methods based on criteria used in developing the State Land Grant University's nutrient recommendations. In lieu of producer yield histories, university recommendations based on interpretation of SCS Soils-5 data may be used. Increased yields due to the use of new and improved varieties and hybrids should be considered when yield goals are set for a specific site.

(3) Soil testing for pH, phosphorus (Figure 2-11), potassium, and nitrogen (Figure 2-12).

(4) Plant tissue testing.

(5) Manure (Figure 2-13), sludge, mortality compost, and effluent testing.

(6) Use of proper timing, formulation, and application methods for nutrients that maximize plant utilization of nutrients and minimize the loss to the environment, including split applications and banding of the nutrients, use of nitrification inhibitors and slow-release fertilizers, and incorporation or injection of fertilizers, manures, and other organic sources.

(7) Use of small grain cover crops to scavenge nutrients remaining in the soil after harvest of the principal crop, particularly on highly leachable soils. Consideration should be given to establishing a cover crop on land receiving sludge or animal waste if there is a high leaching potential. Sludge and animal waste should be incorporated.

(8) Use of buffer areas or intensive nutrient management practices to manage field limitations based on environmentally high risk areas such as:

- Karst topographic areas containing sinkholes and shallow soils over fractured bedrock;
- Lands near surface water;
- High leaching index soils;
- Irrigated land in humid regions;
- Highly erodible soils;
- Lands prone to surface loss of nutrients; and
- Shallow aquifers.

(9) Control of phosphorus losses from fields through a combination of the Erosion and Sediment Control Measure (Section II.A of this chapter) and the Nutrient Management Measure. Limit manure and sludge applications to phosphorus crop needs when possible, supplying any additional nitrogen needs with nitrogen fertilizers or legumes. If this is not practical, route excess phosphorus in manures or sludge to

07/31/84	C004	700234	SOMERSET	25	NPBUU1	READINGTON
DATE	LAB NO.	SERIAL NO.	COUNTY	ACRES	FIELD	SOIL

THE PENNSYLVANIA STATE UNIVERSITY
COLLEGE OF AGRICULTURE
MERKLE LABORATORY - SOIL & FORAGE TESTING
UNIVERSITY PARK, PA 16802

SOIL TEST REPORT FOR

P.A. PENN
RD1
ANYTOWN, PA 10000

COPY SENT TO:

ACME FERTILIZER CO.
MAIN STREET
ANYTOWN, PA 10000

SOIL NUTRIENT LEVELS

				LOW	OPTIMUM	HIGH	EXCESSIVE
Soil pH		6.2					
Phosphate	(P_2O_5)	114	lb/A	XXXXXXXXXXXXXXX			
Potash	(K_2O)	178	lb/A	XXXXXXXXXXXX			
Magnesium	(MgO)	230	lb/A	XXXXXXXXXXXXXX			

RECOMMENDATIONS FOR *PLANTING CORN FOR GRAIN* (For other crops see ST 2 column ( ))

YIELD GOAL 125.0 BUSHELS (PER ACRE)

See Back For Comments

LIMESTONE: 3400 lb/A Calcium Carbonate Equivalent 1,2 3,4

PLANT NUTRIENT NEEDS:

NITROGEN (N)	PHOSPHATE (P_2O_5)	POTASH (K_2O)	MAGNESIUM (MgO)
130 lb/A	70 lb/A	90 lb/A	10 lb/A

5,11

MESSAGES

- USE A STARTER FERTILIZER 6,7
- LIMESTONE RECOMMENDATION, IF ANY, IS TO BRING THE SOIL PH TO 6.0 - 6.5. MULTIPLY THE EXCHANGABLE ACIDITY BY 1000 TO ESTIMATE THE LIME REQUIREMENT FOR PH 6.5 - 7.0.
- RECOMMENDED LIMESTONE CONTAINING .5% MGO WILL MEET THE MG REQUIREMENT.
- IF MANURE WILL BE APPLIED, SEE ST-10 "USE OF MANURE" 9

LABORATORY RESULTS

6.2	50	4.1	0.19	0.6	7.8	12.6	1.5	4.7	61.5
SOIL pH	P lb/A	ACIDITY	K	Mg	Ca	CEC	K	Mg	Ca
		EXCHANGEABLE CATIONS (meq/100 g)					% SATURATION		

OTHER TESTS: ORGANIC MATTER - 2.2 %

Figure 2-11. Example of soil test report (Pennsylvania State University, 1992b).

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PRE-SIDEDRESS SOIL NITROGEN TEST FOR CORN QUICKTEST EVALUATION PROJECT

• SOIL TEST INFORMATION AND REPORT FORM •

Best time to call (8 am - 4:30 pm): ________

Please answer all of the following questions about this field:

1. What is the field ID (name or number)? ____________ Corn Height ________ in.
2. What is the expected yield of the corn crop (bu/A or ton/A) in this field? ________
3. What was the previous crop? ____________________

   If this was a forage legume what was the % stand?

   (check one): ☐ 0-25% ☐ 25-50 % ☐ 50-100%
4. Was manure applied to this field? ☐ Yes ☐ No If "yes" answer the following questions:

   When? ☐ Fall ☐ Spring ☐ Both ☐ Daily

   Type? ☐ Cattle ☐ Poultry ☐ Swine ☐ Horse ☐ Sheep

   Estimate manure rate: _____ tons/acre - OR - _____ gallons/acre

   If incorporated how many days were there between spreading and incorporation? ______
5. What is the tillage program on this field? ☐ Conventional Tillage ☐ Minimum Tillage ☐ No-till
6. What would be your normal N fertilizer application rate for this field? ______ lbs. N/acre

Quicktest Analysis Result & Recommendation

Individual Meter Readings	Average meter reading		Conversion factor		Average standard reading		Soil Nitrate-N (ppm)
		x	20	+		=	

Sidedress N Fertilizer Recommendation ______ **lbs. N/acre**

(See table and guidelines on back of form)

If you have any questions about this test contact your Penn State Cooperative Extension Office

White copy- Grower
Yellow copy- Analyst
Pink copy- Agronomy Extension

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Figure 2-12. Example of Penn State's soil quicktest form (Pennsylvania State University, 1992b).

```
            WORKSHEET FOR CALCULATING             Prepared by:
              APPLICATION RATES OF                JOE CONSULTANT
          ANIMAL MANURE ON         CROPLAND       Nut. Mgt. Consult.
                                                  CECIL
                                                           County
*********************************************************************
Name..............                        *
Address...........                        *  LIST FERTILIZER PRICES
          ........                        *
Field Number..... G-1                     *
Field Location... ____________________    *  N....   $0.25 /lb
Acres in Field...     14.0                *  P2O5.   $0.25 /lb
Manure Source.... BROILER                 *  K2O..   $0.12 /lb
Date/Time........ 03/07/90    ***   04:08 PM *
*********************************************************************

ENTER MANURE ANALYSIS DATA AND SOIL TEST INFORMATION.

MANURE COMPOSITION                     SOIL TEST INFORMATION

Total N...........    3.70 %     **    Texture.........SILT
Ammonium N........    0.43 %     **    pH.............      5.8
P2O5..............    3.70 %     **    Mg.............   278.0 lb/A
K2O...............    3.10 %     **    P2O5...........   112.0 lb/A
Calcium...........    1.40 %     **    K2O............   123.0 lb/A
Magnesium.........    0.56 %     **    Calcium........  1328.0 lb/A
Sulfur............    0.59 %     **    Sulfur.........     6.8 lb/A
Manganese.........  361.50 ppm   **    Manganese......    18.0 lb/A
Zinc..............  380.60 ppm   **    Zinc...........     4.4 lb/A
Copper............  352.80 ppm   **    Copper.........     1.3 lb/A
Moisture..........   13.10 %     **    Org. Matter....     2.5  %
Liquid Wt.........__________lb/100gal   (Leave blank if not liquid.)
*********************************************************************

IF MANURE WAS APPLIED PREVIOUSLY TO THIS FIELD, ENTER DATA REQUESTED FOR
    PRIOR YEARS. IF NONE APPLIED, LEAVE BLANK.

                    Yr. 1-2           Yr. 2-3           Yr. 3-4
Total N...........__________%      __________%      __________%
Ammonium N........__________%      __________%      __________%
Rate..............__________T/A    __________T/A    __________T/A
*********************************************************************

                    **** PHOSPHORUS NOTE ****
          Soil tests indicate that phosphorus levels are NOT EXCESSIVE.
          Additional phosphorus may be applied in animal manure. For max-
          imum economic and environmental benefits, phosphorus levels
          should be monitored regularly by soil test and manure applica-
          tions made ONLY to fields less than VERY HIGH in PHOSPHATE.

*********************************************************************
```

Figure 2-13. Example of work sheet for applying manure to cropland (University of Maryland, 1990).

fields that will be rotated into legumes, to other fields that will not receive manure applications the following year, or to sites with low runoff and low soil erosion potential.

(10) A narrative accounting of the nutrient management plan that explains the plan and its use.

6. Cost Information

In general, most of the costs are associated with providing additional technical assistance to landowners to develop nutrient management plans. In many instances landowners can actually save money by implementing nutrient management plans. For example, Maryland has estimated (based on the over 750 nutrient management plans that were completed prior to September 30, 1990) that if plan recommendations are followed, the landowners will save an average of $23 per acre per year (Maryland Dept. of Agriculture, 1990). The average savings may be high because most plans were for farms using animal waste. Future savings may be reduced as more farms using commercial fertilizer are included in the program.

In the South Dakota RCWP project, the total cost (1982-1991) for implementing fertilizer management on 46,571 acres was $50,109, or $1.08 per acre (USDA-ASCS, 1991a). In the Minnesota RCWP project, the average cost for fertilizer management for 1982-1988 was $20 per acre (Wall et al., 1989). Assuming a cost of $0.15 per pound of nitrogen, the savings in fertilizer cost due to improved nutrient management on Iowa corn was about $2.25 per acre as rates dropped from 145 pounds per acre in 1985 to about 130 pounds per acre in 1989 and 1990 (Iowa State University, 1991a).

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[illegible] Management [illegible]

To reduce contamination of surface water and ground water from pesticides:

(1) Evaluate the pest problems, previous pest control measures, and cropping history;

(2) Evaluate the soil and physical characteristics of the site including mixing, loading, and storage areas for potential leaching or runoff of pesticides. If leaching or runoff is found to occur, steps should be taken to prevent further contamination;

(3) Use integrated pest management (IPM) strategies that:

(a) Apply pesticides only when an economic benefit to the producer will be achieved (i.e., applications based on economic thresholds); and

(b) Apply pesticides efficiently and at times when runoff losses are unlikely;

(4) When pesticide applications are necessary and a choice of registered materials exists, consider the persistence, toxicity, runoff potential, and leaching potential of products in making a selection;

(5) Periodically calibrate pesticide spray equipment; and

(6) Use anti-backflow devices on hoses used for filling tank mixtures.

1. Applicability

This management measure is intended to be applied by States to activities associated with the application of pesticides to agricultural lands. Under the Coastal Zone Act Reauthorization Amendments of 1990, States are subject to a number of requirements as they develop coastal nonpoint programs in conformity with this measure and will have some flexibility in doing so. The application of management measures by States is described more fully in *Coastal Nonpoint Pollution Control Program: Program Development and Approval Guidance*, published jointly by the U.S. Environmental Protection Agency (EPA) and the National Oceanic and Atmospheric Administration (NOAA) of the U.S. Department of Commerce.

2. Description

The goal of this management measure is to reduce contamination of surface water and ground water from pesticides. The basic concept of the pesticide management measure is to foster effective and safe use of pesticides without causing degradation to the environment. The most effective approach to reducing pesticide pollution of waters is, first, to release fewer pesticides and/or less toxic pesticides into the environment and, second, to use practices that minimize the movement of pesticides to surface water and ground water (Figure 2-14). In addition, pesticides should

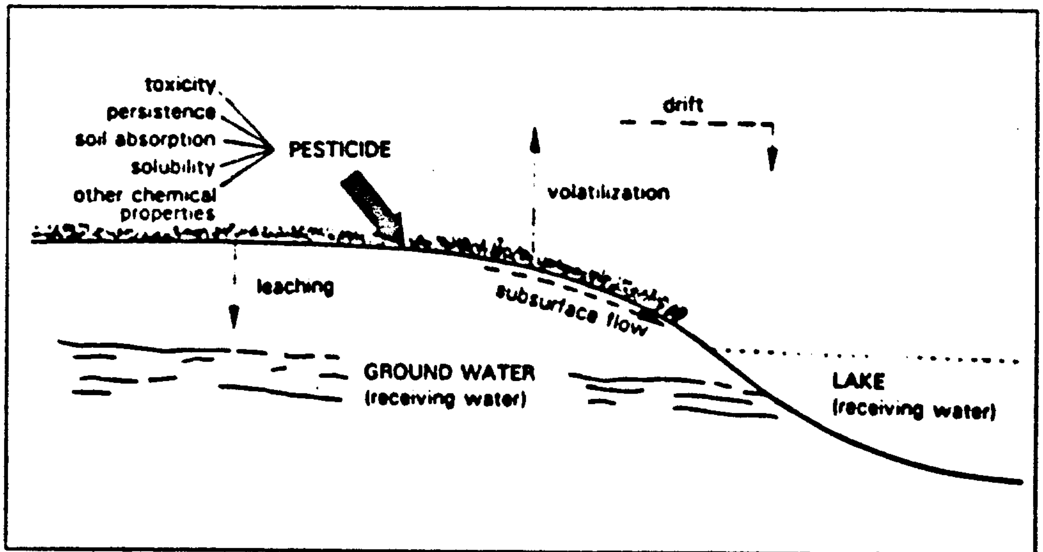

Figure 2-14. Factors affecting the transport and water quality impact of a pesticide (USEPA, 1982).

be applied only when an economic benefit to the producer will be achieved. Such an approach emphasizes using pesticides only when, and to the extent, necessary to control the target pest. This usually results in some reduction in the amount of pesticides being applied to the land, plants, or animals, thereby enhancing the protection of water quality and possibly reducing production costs as well.

The pesticide management measures identify a series of steps or thought processes that producers should use in managing pesticides. First, the pest problems, previous pest control measures, and cropping history should be evaluated. Then the physical characteristics of the soil and the site—including mixing, loading, and storage areas—should be evaluated for potential leaching and/or runoff potential. Integrated pest management (IPM) strategies should be used to minimize the amount of pesticides applied. It is understood that IPM practices are not available for some commodities or in certain regions. An effective IPM strategy should call for pesticide applications only when an economic benefit to the producer will be achieved. In addition, pesticides should be applied efficiently and at times when runoff losses are unlikely.

When pesticide applications are necessary and a choice of materials exists, producers are encouraged to choose the most environmentally benign pesticide products. Users must apply pesticides in accordance with the instructions on the label of each pesticide product. Labels include a number of requirements including allowable use rates; whether the pesticide is classified as "restricted use" for application only by certified and trained applicators; safe handling, storage, and disposal requirements; whether the pesticide can be used only under the provisions of an approved Pesticide State Management Plan; and other requirements. If label requirements include use only under an approved Pesticide State Management Plan, pesticide management measures and practices under the State Coastal Nonpoint Pollution Control Program should be consistent with and/or complement those in EPA-approved Pesticide State Management Plans.

Section 1491 of the 1990 Farm Bill requires users to maintain records of application of restricted use pesticides for a 2-year period after such use. Section 1491 of the 1990 Farm Bill also includes provisions for access to such pesticide records by Federal and State agency staff.

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Operation and Maintenance for Pesticide Management

At a minimum, effective pest management requires evaluating past and current pest problems and cropping history; evaluating the physical characteristics of the site; applying pesticides only when an economic benefit to the producer will be achieved; applying pesticides efficiently and at times when runoff losses are unlikely; selecting pesticides (when a choice exists) that are the most environmentally benign; using anti-backflow devices on hoses used for filling tank mixtures; and providing suitable mixing, loading, and storage areas.

Pest management practices should be updated whenever the crop rotation is changed, pest problems change, or the type of pesticide used is changed. Application equipment should be calibrated and inspected for wear and damage each spray season, and repaired when necessary. Anti-backflow devices should also be inspected each spray season and repaired when necessary.

3. Management Measure Selection

This management measure was selected as a method to reduce the amount of pesticides entering ground water and surface water, and to foster effective and safe use of pesticides. The practices and concepts that can be used to implement this measure on a given site are those commonly used and recommended by States and USDA for general use on agricultural lands. When this measure is implemented by using the necessary mix of practices for a given site, there should be a relatively small negative economic impact on the operator's net costs and farm income, and in some cases the impact will be positive (U.S. Environmental Protection Agency, 1992). Many of the practices that can be used to implement this measure may already be required by Federal, State, or local rules, or may otherwise be in use on agricultural fields. Since many producers may already be using systems that satisfy or partly satisfy the intent of this management measure, the only action that may be necessary will be to determine the effectiveness of the existing practices and implement additional practices, if needed. Use of existing practices will reduce the time, effort, and cost of implementing this measure.

4. Effectiveness Information

Following is a summary of available information regarding pollution reductions that can be expected from using various pesticide management practices.

Use of IPM strategies is a key element of the pesticide management measures. Table 2-15 summarizes the findings of several empirical IPM studies on a variety of crops (Virginia Cooperative Extension Service et al., 1987). The summary table indicates that many studies have found IPM to reduce pesticide use. While all these studies indicate a reduction or no change in pesticide use, it is understood that in a small percentage of cases IPM can result in an increased use of pesticides as producers become more aware of what pests are present in the field and then take action to control problems.

Table 2-16 summarizes estimates of reductions in pesticide loss using various management practices and combinations of practices for cotton (North Carolina State University, 1984). These estimates are made at the field level as compared with a hypothetical field using cropping practices that were typical until the late 1970s. The uncertainty of the estimates is a function of the rapid transitions in production methods coupled with the variance among regions and seasons. Traditional sediment and erosion control practices are not as effective on cotton as on corn and soybeans because much cotton is grown on relatively flat land with little or no water erosion problem (Heimlich and Bills, 1984).

Table 2-17 summarizes the estimates of pesticide loss reductions from various management practices and combinations of practices for corn (North Carolina State University, 1984). These estimates are also made at the field level as compared with a hypothetical field using conventional, traditional, or typical cropping practices, realizing that these practices may vary considerably between geographic regions.

Banding of herbicide applications is one of the more recent and promising methods of reducing herbicide applications to corn (NRDC, 1991). Instead of applying herbicides to the entire row, herbicides are applied in a band near to the corn plant. One 3-year study conducted in Iowa on two fields of corn and one of soybeans monitored the effect of different herbicide treatments on yields and herbicide concentrations in tile-drainage water. Over the 3-year period, corn acreage with banded treatments produced equal or slightly higher yields than acreage receiving broadcast herbicides (Baker, 1988). Analysis of water samples for herbicide residues in water beneath herbicide-treated areas revealed that, during this 3-year period, atrazine was detected more often and at higher concentrations in the areas where atrazine was broadcast. Banding of herbicides means, however, that farmers have to rely more extensively on mechanical tillage and cultivation to control weeds.

Table 2-15. Results of IPM Evaluation Studies (Virginia Cooperative Extension Service et al., 1987)

Author	Study Object[a]	Pesticide Use and/or Cost of Production with IPM[b]	Yield with IPM[b]	Net Return with IPM[b]	Level of Risk with IPM[b]
Sprott et al., 1976	C	D	I	I	-
Condra et al., 1977	C	D	D	I	-
Lacewell et al., 1977	C	-	-	I	-
Clarke et al., 1980	C	-	I	I	-
Von Rumker et al., 1975	T	D	-	I	-
Von Rumker et al., 1975	P	D	I	I	-
Burrows, 1983	C,Ci	D,D	-,-	-,-	-,-
Rajotte et al., 1984	S	D	-	I	-
Thompson et al., 1980	A	D	C	-	-
Larson et al., 1975	C	D	-	I	-
Masud et al., 1981	C	D	I	I	-
Huffaker and Croft, 1978	C,A	D,D	I,-	-,-	-,-
Teage and Schulstad, 1981	C	D	-	-	-
Weathers, 1979-1980	Co,S,P	D,D,D	I,I,D	I,I	-,-,-
Lacewell et al., 1974	C	D	I	I	-
Lacewell et al., 1976	C	D	-	-	-
Casey et al., 1975	C	D	I	I	-
Allen and Roberts, 1974	S	D	-	I	-
Greene et al., 1985	S	D	-	-	-
Lindsey et al., 1976	C	-	-	I	-
Frisbie et al., 1974	C	D	I	I	-
Frisbie, 1976	C	D	-	I	-
Hoyt and Callagirone, 1971	M	D	-	-	-

Table 2-15. (Continued)

Author	Study Object[a]	Pesticide Use and/or Cost of Production with IPM[b]	Yield with IPM[c]	Net Return with IPM[d]	Level of Risk with IPM[e]
Croft et al., 1975	M	D	-	-	-
Howitt et al., 1966	A	D	-	-	-
Batiste et al., 1973	A	D	-	-	-
Eves et al., 1975	A	D	-	-	-
Hall, 1977	C	D	N	N	D
Prokopy et al., 1973	A	-	-	I	-
McGuckin, 1983	Al	D	-	I	D
King and O'Rourke, 1977	A	D	-	-	-
Cammell and Way, 1977	F	-	-	I	D
Liapis and Moffit, 1983	C	-	-	-	D
Miranowski, 1974	C	D	-	-	-
Huffaker, 1980	C	D	-	-	-
Reichelderfer, 1979	Pe	D	-	I	-
Carlson, 1969	Pc	-	-	-	D
Carlson, 1979	C	-	-	-	D
Lazarus and Swanson, 1983	Co,S	-,-	-,-	-,-	I,I
Moffitt et al., 1982	S	-	-	-	D
Hatcher et al., 1984	C,P,S	-,-,-	I,I,I	N,I,I	-,-,-
White and Thompson, 1982	A	D	-	-	-

[a] C = cotton; T = tobacco; P = peanut; Ci = citrus; S = soybean; A = apple; Co = corn; M = mite; Al = alfalfa; F = field bean; Pe = pecan; Pc = peach.
[b,c,d,e] C = constant; D = decreased; I = increased; N = no impact; - = no information.

Table 2-16. Estimates of Potential Reductions in Field Losses of Pesticides for Cotton Compared to a Conventionally and/or Traditionally Cropped Field[a] (North Carolina State University, 1984)

Management Practice	Transport Route(s)	Range of Pesticide Loss Reduction (%)[b]
SWCPs		
Terracing	SR and SL	0 - (20)[c]
Contouring	SR and SL	0 - (20)[c]
Reduced Tillage	SR and SL	-40 - +20 AB
Grassed Waterways	SR and SL	0 - 10 AB
Sediment Basins	SR	0 - 10 AB
Filter Strips	SR	0 - 10 A
Cover Crops	SR and SL	-20 - +10 B
Optimal Application Techniques[d]	All Routes[e]	40 - 80 A
Nonchemical Methods	All Routes	
Scouting Economic Thresholds	All Routes	40 - 65 A 0 - 30 B
Crop Rotations	All Routes	0 - 20 A 10 - 30 B
Pest-Resistant Varieties	All Routes	0 - 80 A 0 - 30 B
Alternative Pesticides	All Routes	80 - 95 A 0 - 20 B

SR = surface runoff
SL = soil leaching

[a] The hypothetical traditionally cropped comparison field uses the following management system:
(1) conventional tillage without other soil and water conservation practices;
(2) aerial application of all pesticides with timing based only on field operation convenience;
(3) ten insecticide treatments annually with a total application of 12 kg/ha based on a prescribed schedule;
(4) cotton grown in 3 out of 4 years; and
(5) long-season cotton varieties.

[b] Assumes field loss reductions are proportional to application rate reductions.
A = insecticides (toxaphene, methylparathion, synthetic pyrethroids).
B = herbicides (trifluralin, fluometron).
Ranges allow for variation in production region, climate, slope and soils.

[c] Refers to estimated increases in movement through soil profile.

[d] Defined for cotton as ground application using optimal droplet or granular size ranges with spraying restricted to calm periods in late afternoon or at night when precipitation is not imminent.

[e] Particularly drift and volatilization.

Table 2-17. Estimates of Potential Reductions in Field Losses of Pesticides for Corn Compared to a Conventionally and/or Traditionally Cropped Field[a] (North Carolina State University, 1984)

Management Practice	Transport Route(s) Affected	Range of Pesticide Loss Reduction (%)[b]
SWCPs	SR and/or SL([c])	
Terracing	SR and/or SL	40 - 75 AB (25[c])
Contouring	SR and/or SL	15 - 55 AB (20[c])
No-till	SR and/or SL	-10 - +40 B 60 - +10 A (10[c])
Other Reduced Tillage	SR and/or SL	-10 - +60 B -40 - +20 A (15[c])
Grassed Waterways	SR	-10 - 20 AB
Sediment Basins	SR	0 - 10 AB
Filter Strips	SR	0 - 10 AB
Cover Crops	SR and/or SL	0 - 20 B[d]
Optimal Application Techniques[e]	All Routes[f]	10 - 20 20 - 40 B
Nonchemical Methods	All Routes	
Adequate Monitoring	All Routes	40 - 66 A
Crop Rotations	All Routes	40 - 70 A 10 - 30 B

SR = surface runoff
SL = soil leaching

[a] The hypothetical field used as the basis for comparison uses the following management system:
(1) conventional tillage without other soil and water conservation practices;
(2) ground application with timing based only on field operation convenience;
(3) little or no pest monitoring; spraying on prescribed schedule; and
(4) corn grown in 3 out of 4 years.

[b] Assumes field loss reductions are proportional to application rate reductions.
A = insecticides (carbofuran and organophosphates)
B = herbicides (Triazine, Alachlor, Butylate, Parquat)
Ranges allow for variation in climate, slope, soils, and types of pesticides used. Ranges for no-till and reduced-till are derived from a combination of increased application rates and decreased runoff losses.

[c] Refers to estimated increases in movement through soil profile.

[d] Cover crops will affect runoff and leaching losses only for pesticides persistent enough to be available over the non-growing season. In the case of pesticides used on corn only the triazine and anilide herbicides will generally meet this criterion.

[e] Defined here for corn as ground application using optimal droplet or granular size ranges, with spraying restricted to calm periods in late afternoon or evening.

[f] Particularly drift and volatilization.

5. Pesticide Management Practices

As discussed more fully at the beginning of this chapter and in Chapter 1, the following practices are described for illustrative purposes only. State programs need not require implementation of these practices. However, as a practical matter, EPA anticipates that the management measure set forth above generally will be implemented by applying one or more management practices appropriate to the source, location, and climate. The practices set forth below have been found by EPA to be representative of the types of practices that can be applied successfully to achieve the management measure described above. The U.S. Soil Conservation Service practice number and definition are provided for management practices, where available.

■ *a. Inventory current and historical pest problems, cropping patterns, and use of pesticides for each field.*

This can be accomplished by using a farm and field map, and by compiling the following information for each field:

- Crops to be grown and a history of crop production;
- Information on soils types;
- The exact number of acres within each field; and
- Records on past pest problems, pesticide use, and other information for each field.

■ *b. Consider the soil and physical characteristics of the site including mixing, loading and storage areas for potential for the leaching and/or runoff of pesticides.*

In situations where the potential for loss is high, emphasis should be given to practices and/or management practices that will minimize these potential losses. The physical characteristics to be considered should include limitations based on environmental hazards or concerns such as:

- Sinkholes, wells, and other areas of direct access to ground water such as karst topography;
- Proximity to surface water;
- Runoff potential;
- Wind erosion and prevailing wind direction;
- Highly erodible soils;
- Soils with poor adsorptive capacity;
- Highly permeable soils;
- Shallow aquifers; and
- Wellhead protection areas.

■ *c. Use IPM strategies to minimize the amount of pesticides applied.*

Following is a list of IPM strategies:

- Use of biological controls:
    - introduction and fostering of natural enemies;
    - preservation of predator habitats; and
    - release of sterilized male insects;
- Use of pheromones:
    - for monitoring populations;
    - for mass trapping;
    - for disrupting mating or other behaviors of pests; and
    - to attract predators/parasites;
- Use of crop rotations to reduce pest problems;
- Use of improved tillage practices such as ridge tillage;

- Use of cover crops in the system to promote water use and reduce deep percolation of water that contributes to leaching of pesticides into ground water;
- Destruction of pest breeding, refuge, and overwintering sites (this may result in loss of crop residue cover and an increased potential for erosion);[8]
- Use of mechanical destruction of weed seed;[8]
- Habitat diversification;
- Use of allelopathy characteristics of crops;
- Use of resistant crop strains;
- Pesticide application based on economic thresholds, i.e., apply pesticides when an economic threshold level has been reached as opposed to applying pesticides in anticipation of pest problems;
- Use of periodic scouting to determine when pest problems reach the economic threshold on each field;
- Use of less environmentally persistent, toxic, and/or mobile pesticides;
- Use of timing of field operations (planting, cultivating, irrigation, and harvesting) to minimize application and/or runoff of pesticides; and
- Use of more efficient application methods, e.g., spot spraying and banding of pesticides.

■ d. *When pesticide applications are necessary and a choice of materials exists, consider the persistence, toxicity, and runoff and leaching potential of products along with other factors, including current label requirements, in making a selection.*

Users must apply pesticides in accordance with the instructions on the label of each pesticide product and, when required, must be trained and certified in the proper use of the pesticide. Labels include a number of requirements including allowable use rates; classification of pesticides as "restricted use" for application only by certified applicators; safe handling, storage, and disposal requirements; restrictions required by State Pesticide Management Plans to protect ground water; and other requirements. If label requirements include use only under an approved State Pesticide Management Plan, pesticide management measures and practices under the State Coastal Nonpoint Program should be consistent with and/or complement those in approved State Pesticide Management Plans.

■ e. *Maintain records of application of restricted use pesticides (product name, amount, approximate date of application, and location of application of each such pesticide used) for a 2-year period after such use, pursuant to the requirements in section 1491 of the 1990 Farm Bill.*

Section 1491 requires that such pesticide records shall be made available to any Federal or State agency that deals with pesticide use or any health or environmental issue related to the use of pesticides, on the request of such agency. Section 1491 also provides that Federal or State agencies may conduct surveys and record the data from individual applicators to facilitate statistical analysis for environmental and agronomic purposes, but in no case may a government agency release data, including the location from which the data was derived, that would directly or indirectly reveal the identity of individual producers. Section 1491 provides that in the case of Federal agencies, access to records maintained under section 1491 shall be through the Secretary of Agriculture, or the Secretary's designee. This section also provides that State agency requests for access to records maintained under section 1491 shall be through the lead State agency so designated by the State.

Section 1491 includes special access provisions for health care personnel. Specifically, when a health professional determines that pesticide information maintained under this section is necessary to provide medical treatment or first aid to an individual who may have been exposed to pesticides for which the information is maintained, upon request persons required to maintain records under section 1491 shall promptly provide record and available label information to that health professional. In the case of an emergency, such record information shall be provided immediately.

[8] Several IPM strategies listed above emphasize the use of mechanical tillage and removal of crop residue cover. Such IPM strategies may result in some producers being out of compliance with the U.S. Department of Agriculture's requirements for highly erodible land, and such producers may need to consider other IPM strategies on such highly erodible land.

Operators may consider maintaining records beyond those required by section 1491 of the 1990 Farm Bill. For example, operators may want to maintain records of *all* pesticides used for each field, i.e., not just restricted use pesticides. In addition, operators may want to maintain records of other pesticide management activities such as scouting records or other IPM techniques used and procedures used for disposal of remaining pesticides after application.

- f. *Use lower pesticide application rates than those called for by the label when the pest problem can be adequately controlled using such lower rates.*

- g. *Consider the use of organic farming techniques that do not rely on the use of synthetically compounded pesticides.*

- h. *Recalibrate spray equipment each spray season and use anti-backflow devices on hoses used for filling tank mixtures.*

Purchase new, more precise application equipment and other related farm equipment (including improved nozzles, computer sensing to control flow rates, radar speed determination, electrostatic applicators, and precision equipment for banding and cultivating) as replacement equipment is needed.

- i. *Integrated crop management system (Pest Management 595): A total crop management system that promotes the efficient use of pesticide and nutrients in an environmentally sound and economically efficient manner.*

6. Cost Information

In general, most of the costs of implementing the pesticide management measure are program costs associated with providing additional educational programs and technical assistance to producers to evaluate pest management needs and for field scouting during the growing season. Producers may actually save money by implementing IPM strategies as indicated by the data in Table 2-15.

Table 2-15 summarizes the findings of several IPM studies on a variety of crops (Virginia Cooperative Extension Service et al., 1987). This summary table indicates that, in general, IPM reduces pesticide use, increases yields, increases net returns, and decreases economic risk.

Table 2-18 shows that IPM scouting costs vary by crop type and by region (USEPA, 1992). High and low scouting costs are given for major crops in each of the coastal regions. These costs reflect variations in the level of service provided by various crop consultants. For example, in the Great Lakes region, the relatively low cost of $4.95 per acre is based on five visits per season at the request of the producer. Higher cost services include scouting and weekly written reports during the growing seasons. Cost differences may also reflect differences in the size of farms (i.e., number of acres) and distance between farms.

The variations in scouting costs between regions and within regions also occur because of differences in the provider of the service. For example, in some States the Cooperative Extension Service provides scouting services at no cost or for a nominal fee. In other areas of the coastal zone, farmer cooperatives have formed crop management associations to provide scouting and crop fertility/pest management recommendations.

Scouting costs also vary by crop type. For example, the data in Table 2-18 indicate that scouting costs for fresh market vegetables are higher than for all other crop types. Scouting services for high-value cash crops, such as fruits and vegetables, must be very intensive given that pest damage is permanent and may make the crop unmarketable.

Costs for erosion and sediment control and for irrigation management are discussed in Sections II.A and II.F, respectively, of this chapter.

Table 2-18. Estimated Scouting Costs (dollars/acre) by Coastal Region and Crop in the Coastal Zone in 1992 (USEPA, 1992)

	Crop						
Coastal Region	Corn	Soybean	Wheat	Rice	Cotton	Fresh Market Vegetables[a]	Hay[b]
Northeast							
Low	5.50	NA	3.75	—	—	25.00	2.50
High	6.25	NA	4.50	—	—	28.00	2.75
Southeast							
Low	5.00	3.25	3.00	8.00	6.00	30.00	2.00
High	6.00	4.00	3.50	12.00	8.00	35.00	3.00
Gulf Coast							
Low	6.00	4.50	—	5.00	6.00	35.00	—
High	8.00	6.50	—	9.00	9.00	40.00	—
Great Lakes							
Low	4.95	4.25	3.75	—	—	—	4.75
High	5.50	5.00	4.00	—	—	—	5.25
West Coast							
Low	NA	NA	3.50	NA	6.75	32.00	NA
High	NA	NA	5.50	NA	9.30	38.00	NA

NA = not available
— = not applicable
[a] Most fresh market vegetables are produced under a regular spraying schedule.
[b] Scouting costs for hay are based on alfalfa insect inspection. The higher cost in the Great Lakes region includes pesticide and soil sampling.

7. Relationship of Pesticide Management Measure to Other Programs

Under the Federal Insecticide, Fungicide and Rodenticide Act (FIFRA), EPA registers pesticides on the basis of evaluation of test data showing whether a pesticide has the potential to cause unreasonable adverse effects on humans, animals, or the environment. Data requirements include environmental fate data showing how the pesticide behaves in the environment, which are used to determine whether the pesticide poses a threat to ground water or surface water. If the pesticide is registered, EPA imposes enforceable label requirements, which can include, among other things, maximum rates of application, classification of the pesticide as a "restricted use" pesticide (which restricts use to certified applicators trained to handle toxic chemicals), or restrictions on use practices, including requiring compliance with EPA-approved Pesticide State Management Plans (described below). EPA and the U.S. Department of Agriculture Cooperative Extension Service provide assistance for pesticide applicator and certification training in each State.

FIFRA allows States to develop more stringent pesticide requirements than those required under FIFRA, and some States have chosen to do this. At a minimum, management measures and practices under State Coastal Nonpoint Source Programs must not be less stringent than FIFRA label requirements or any applicable State requirements.

EPA's *Pesticides and Groundwater Strategy* (USEPA, 1991b) describes the policies and regulatory approaches EPA will use to protect the Nation's ground-water resources from risks of contamination by pesticides under FIFRA. The objective of the strategy is the prevention of ground-water contamination by regulating the use of certain pesticides (i.e., use according to EPA-approved labeling) in order to reduce and, if necessary, eliminate releases of the pesticide in areas vulnerable to contamination. Priority for protection will be based on currently used and reasonably expected sources of drinking water supplies, and ground water that is closely hydrogeologically connected to surface waters. EPA will use Maximum Contaminant Levels (MCLs) under the Safe Drinking Water Act as "reference points" for water resource protection efforts when the ground water in question is a current or reasonably expected source of drinking water.

The Strategy describes a significant new role for States in managing the use of pesticides to protect ground water from pesticides. In certain cases, when there is sufficient evidence that a particular use of a pesticide has the potential for ground-water contamination to the extent that it might cause unreasonable adverse effects, EPA may (through the use of existing statutory authority and regulations) limit legal use of the product to those States with an acceptable Pesticide State

Management Plan, approved by EPA. Plans would tailor use to local hydrologic conditions and would address:

- State philosophy;
- Roles and responsibilities of State and local agencies;
- Legal and enforcement authority;
- Basis for assessment and planning;
- Prevention measures;
- Ground-water monitoring;
- Response to detections;
- Information dissemination; and
- Public participation.

In the absence of such an approved plan, affected pesticides could not be legally used in the State.

Since areas to be managed under Pesticide State Management Plans and Coastal Nonpoint Pollution Control Programs can overlap, State coastal zone and nonpoint source agencies should work with the State lead agency for pesticides (or the State agency that has a lead role in developing and implementing the Pesticide State Management Plan) in the development of pesticide management measures and practices under both programs. This is necessary to avoid duplication of effort and conflicting pesticide requirements between programs. Further, ongoing coordination will be necessary since both programs and management measures will evolve and change with increasing technology and data.

Section 1491 of the 1990 Farm Bill requires recordkeeping for restricted use pesticides for a 2-year period after such use. Specifically, records of pesticide applications are to include product name, amount, approximate date of application, and location of application of each pesticide used. Section 1491 also specifies the limitations on access to these records by governmental agencies and health care personnel (see practice "e" under "Pesticide Management Practices" for additional information regarding access to such records).

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E. Grazing Management Measure

Protect range, pasture and other grazing lands:

(1) By implementing one or more of the following to protect sensitive areas (such as streambanks, wetlands, estuaries, ponds, lake shores, and riparian zones):

(a) Exclude livestock,
(b) Provide stream crossings or hardened watering access for drinking,
(c) Provide alternative drinking water locations,
(d) Locate salt and additional shade, if needed, away from sensitive areas, or
(e) Use improved grazing management (e.g., herding)

to reduce the physical disturbance and reduce direct loading of animal waste and sediment caused by livestock; *and*

(2) By achieving either of the following on all range, pasture, and other grazing lands not addressed under (1):

(a) Implement the range and pasture components of a Conservation Management System (CMS) as defined in the Field Office Technical Guide of the USDA-SCS (see Appendix 2A of this chapter) by applying the progressive planning approach of the USDA-Soil Conservation Service (SCS) to reduce erosion, or
(b) Maintain range, pasture, and other grazing lands in accordance with activity plans established by either the Bureau of Land Management of the U.S. Department of the Interior or the Forest Service of USDA.

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1. Applicability

The management measure is intended to be applied by States to activities on range, irrigated and nonirrigated pasture, and other grazing lands used by domestic livestock. Under the Coastal Zone Act Reauthorization Amendments of 1990, States are subject to a number of requirements as they develop coastal nonpoint programs in conformity with this measure and will have some flexibility in doing so. The application of management measures by States is described more fully in *Coastal Nonpoint Pollution Control Program: Program Development and Approval Guidance*, published jointly by the U.S. Environmental Protection Agency (EPA) and the National Oceanic and Atmospheric Administration (NOAA) of the U.S. Department of Commerce.

Range is those lands on which the native vegetation (climax or natural potential plant community) is predominantly grasses, grasslike plants, forbs, or shrubs suitable for grazing or browsing use. Range includes natural grassland, savannas, many wetlands, some deserts, tundra, and certain forb and shrub communities. Pastures are those lands that are primarily used for the production of adapted, domesticated forage plants for livestock. Other grazing lands include woodlands, native pastures, and croplands producing forages.

The major differences between range and pasture are the kind of vegetation and level of management that each land area receives. In most cases, range supports native vegetation that is extensively managed through the control of livestock rather than by agronomy practices, such as fertilization, mowing, irrigation, etc. Range also includes areas that have been seeded to introduced species (e.g., crested wheatgrass), but which are extensively managed like native range. Pastures are represented by those lands that have been seeded, usually to introduced species (e.g., tall fescue) or in some cases to native plants (e.g., switchgrass), and which are intensively managed using agronomy practices and control of livestock.

2. Description

The focus of the grazing management measure is on the riparian zone, yet the control of erosion from range, pasture, and other grazing lands above the riparian zone is also encouraged. Application of this management measure will reduce the physical disturbance to sensitive areas and reduce the discharge of sediment, animal waste, nutrients, and chemicals to surface waters. For information regarding potential problems caused by grazing, see Sections I.F.2 and I.F.6 of this chapter.

The key options to consider (all are not required by this management measure) when developing a comprehensive grazing management approach at a particular location include the development of one or more of the following:

- Grazing management systems. These systems ensure proper grazing use through:
  - Grazing frequency (includes complete rest);
  - Livestock stocking rates;
  - Livestock distribution;
  - Timing (season of forage use) and duration of each rest and grazing period;
  - Livestock kind and class; and
  - Forage use allocation for livestock and wildlife.
- Proper water and salt supplement facilities.
- Livestock access control.
- Range or pasture rehabilitation.

For any grazing management system to work, it must be tailored to fit the needs of the vegetation, terrain, class or kind of livestock, and particular operation involved.

For both pasture and range, areas should be provided for livestock watering, salting, and shade that are located away from streambanks and riparian zones where necessary and practical. This will be accomplished by managing livestock grazing and providing facilities for water, salt, and shade as needed.

Special attention must be given to grazing management in riparian and wetland areas if management measure objectives are to be met. For purposes of this guidance, riparian areas are defined (Mitsch and Gosselink, 1986; Lowrance et al., 1988) as:

> Vegetated ecosystems along a waterbody through which energy, materials, and water pass. Riparian areas characteristically have a high water table and are subject to periodic flooding and influence from the adjacent waterbody.

The health of the riparian system, and thus the quality of water, is dependent on the use, management, and condition of the related uplands. Therefore, the proper management of riparian and wetland ecosystems will involve the correct management of livestock grazing and other land uses in the total watershed.

Conservation management systems (CMS) include any combination of conservation practices and management that achieves a level of treatment of the five natural resources (i.e., soil, water, air, plants, and animals) that satisfies criteria contained in the Soil Conservation Service (SCS) Field Office Technical Guide (FOTG), such as a resource management system (RMS) or an acceptable management system (AMS). These criteria are developed at the State level, with concurrence by the appropriate SCS National Technical Center (NTC). The criteria are then applied in the provision of field office technical assistance, under the direction of the District Conservationist of SCS. In-state coordination of FOTG use is provided by the Area Conservationist and State Conservationist of SCS.

The range and pasture components of a CMS address erosion control, proper grazing, adequate pasture stand density, and range condition. National (minimum) criteria pertaining to range and pasture under an RMS are applied to achieve environmental objectives, conserve natural resources, and prevent soil degradation.

The practical limits of resource protection under a CMS within any given area are determined through the application of national social, cultural, and economic criteria. With respect to economics, landowners will not be required to implement an RMS if the system is generally too costly for landowners. Instead, landowners may be required to implement a less costly, and less protective, AMS. In some cases, landowner constraints may be such that an RMS or AMS cannot be implemented quickly. In these situations, a "progressive planning approach" may be used to ultimately achieve planning and application of an RMS or AMS. Progressive planning is the incremental process of building a plan on part or all of the planning unit over a period of time. For additional details regarding CMS, RMS, and AMS, see Appendix 2A of this chapter.

3. Management Measure Selection

This management measure was selected based on an evaluation of available information that documents the beneficial effects of improved grazing management (see "Effectiveness Information" below). Specifically, the available information shows that (1) aquatic habitat conditions are improved with proper livestock management; (2) pollution from livestock is decreased by reducing the amount of time spent in the stream through the provision of supplemental water; and (3) sediment delivery is reduced through the proper use of vegetation, streambank protection, planned grazing systems, and livestock management.

4. Effectiveness Information

Hubert et al. (1985) showed in plot studies in Wyoming that livestock exclusion and reductions in stocking rates can result in improved habitat conditions for brook trout (Table 2-19). In this study, the primary vegetation was willows, Pete Creek stocking density was 7.88 ac/AUM (acres per animal unit month), and Cherry Creek stocking density was 10 cows per acre.

Platts and Nelson (1989) used plot studies in Utah to evaluate the effects of livestock exclusion on riparian plant communities and streambanks. Several streambank characteristics that are related to the quality of fish habitat were measured, including bank stability, stream shore depth, streambank angle, undercut, overhang, and streambank alteration. The results clearly show better fish habitat in the areas where livestock were excluded (Table 2-20).

Kauffman et al. (1983) showed that fall cattle grazing decreases the standing phytomass of some riparian plant communities by as much as 21 percent versus areas where cattle are excluded, while causing increases for other plant communities. This study, conducted in Oregon from 1978 to 1980, incorporated stocking rates of 3.2 to 4.2 ac/AUM.

Eckert and Spencer (1987) studied the effects of a three-pasture, rest-rotation management plan on the growth and reproduction of heavily grazed native bunchgrasses in Wyoming. The results indicated that range improvement under this otherwise appropriate rotation grazing system is hindered by heavy grazing. Stocking rates on the study plots ranged from 525 to 742 cow-calf AUMs.

Table 2-19. Grazing Management Influences on Two Brook Trout Streams in Wyoming (Hubert et al., 1985)

	Pete Creek (n=3)		Cherry Creek (n=4)	
Parameter	Heavily Grazed (mean)	Lightly Grazed (mean)	Outside Exclosure (mean)	Inside Exclosure (mean)
Width	2.9	2.2[a]	2.9	2.5[a]
Depth	0.07	0.11[b]	0.08	0.09[a]
Width/depth ratio	43	21	37	28[a]
Coefficient of variation in depth	47.3	66.6[a]	57	71
Percent greater than 22 cm deep	9.0	22.3[b]	6.7	21.0[a]
Percent overhanging bank cover	2.7	30.0[a]	24.0	15.3
Percent overhanging vegetation	0	11.7[a]	8.5	18.0
Percent shaded area	0.7	18.3[a]	23.5	28.0
Percent silt substrate	35	52	22	13[a]
Percent bare soil along banks	19.7	13.3	22.6	12.3[a]
Percent litter along banks	7.0	6.0	10.0	6.8[a]

[a] Indicates statistical significance at p<=0.05.
[b] Indicates statistical significance at p<=0.1.

In a literature review, Van Poollen and Lacey (1979) showed that herbage production was greater for managed grazing versus continuous grazing, greater for moderate versus heavy intensity grazing, and greater for light- versus moderate-intensity grazing.

McDougald et al. (1989) tested the effects of moving supplemental feeding locations on riparian areas of hardwood range in California. With stocking rates of approximately 1 ac/AUM, they found that moving supplemental feeding locations away from water sources into areas with high amounts of forage greatly reduces the impacts of cattle on riparian areas (Table 2-21).

Table 2-20. Streambank Characteristics for Grazed Versus Rested Riparian Areas (Platts and Nelson, 1989)

Streambank Characteristic (unit)	Grazed	Rested
Extent (m)	4.1	2.5
Bank stability (%)	32.0	88.5
Stream-short depth (cm)	6.4	14.9
Bank angle (°)	127.0	81.0
Undercut (cm)	6.4	16.5
Overhang (cm)	1.8	18.3
Streambank alteration (%)	72.0	19.0

Table 2-21. The Effects of Supplemental Feeding Location on Riparian Area Vegetation (McDougald et al., 1989)

Practice	Percentage of riparian area with the following levels of residual dry matter in early October		
	Low	Moderate	High
Supplemental feeding located close to riparian areas:			
1982-85 Range Unit 1	48	39	13
1982-85 Range Unit 8	59	29	12
1986-87 Range Unit 8	54	33	13
Supplemental feeding moved away from riparian area:			
1986-87 Range Unit 1	1	27	72

Miner et al. (1991) showed that the provision of supplemental water facilities reduced the time each cow spent in the stream within 4 hours of feeding from 14.5 minutes to 0.17 minutes (8-day average). This pasture study in Oregon showed that the 90 cows without supplemental water spent a daily average of 25.6 minutes per cow in the stream. For the 60 cows that were provided a supplemental water tank, the average daily time in the stream was 1.6 minutes per cow, while 11.6 minutes were spent at the water tank. Based on this study, the authors expect that decreased time spent in the stream will decrease bacterial loading from the cows.

Tiedemann et al. (1988) studied the effects of four grazing strategies on bacteria levels in 13 Oregon watersheds in the summer of 1984. Results indicate that lower fecal coliform levels can be achieved at stocking rates of about 20 ac/AUM if management for livestock distribution, fencing, and water developments are used (Table 2-22). The study also indicates that, even with various management practices, the highest fecal coliform levels were associated with the higher stocking rates (6.9 ac/AUM) employed in strategy D.

Lugbill (1990) estimates that stream protection in the Potomac River Basin will reduce total nitrogen (TN) and total phosphorus (TP) loads by 15 percent, while grazing land protection and permanent vegetation improvement will reduce TN and TP loads by 60 percent. Owens et al. (1982) measured nitrogen losses from an Ohio pasture under a medium-fertility, 12-month pasture program from 1974 to 1979. The results included no measurable soil loss from three watersheds under summer grazing only, and increased average TN concentrations and total soluble N loads from watersheds under summer grazing and winter feeding versus watersheds under summer grazing only (Table 2-23).

Table 2-22. Bacterial Water Quality Response to Four Grazing Strategies (Tiedemann et al., 1988)

Practice	Geometric Mean Fecal Coliform Count
Strategy A: Ungrazed.	40/L
Strategy B: Grazing without management for livestock distribution; 20.3 ac/AUM.	150/L
Strategy C: Grazing with management for livestock distribution: fencing and water developments; 19.0 ac/AUM.	90/L
Strategy D: Intensive grazing management, including practices to attain uniform livestock distribution and improve forage production with cultural practices such as seeding, fertilizing, and forest thinning; 6.9 ac/AUM.	920/L

Table 2-23. Nitrogen Losses from Medium-Fertility, 12-Month Pasture Program (Owens et al., 1982)

Practice	Soil Loss (kg/ha)	Total Sediment N Transport (kg/ha)	Total N Concentration (mg/l)*	Total Soluble N Transport (kg/ha)*
Summer Grazing Only				
Growing season	—	—	3.7	0.4
Dormant season	—	—	1.8	0.1
Year	—	—	3.0	0.5
Summer Grazing - Winter Feeding				
Growing season	251	1.4	4.9	2.5
Dormant season	1,104	6.6	14.6	11.3
Year	1,355	8.0	10.7	13.8

* Five-year average (1974-1979)

Data from a comparison of the expected effectiveness of various grazing and streambank practices in controlling sedimentation in the Molar Flats Pilot Study Area in Fresno County, California indicate that planned grazing systems are the most effective single practice for reducing sheet and rill erosion (Fresno Field Office, 1979). Streambank protection is expected to be the most effective single practice for reducing streambank erosion. Other practices evaluated are proper grazing use, deferred grazing, emergency seeding, and livestock exclusion.

5. Range and Pasture Management Practices

As discussed more fully at the beginning of this chapter and in Chapter 1, the following practices are described for illustrative purposes only. State programs need not require implementation of these practices. However, as a practical matter, EPA anticipates that the management measure set forth above generally will be implemented by applying one or more management practices appropriate to the source, location, and climate. The practices set forth below have been found by EPA to be representative of the types of practices that can be applied successfully to achieve the management measure described above.

The U.S. Soil Conservation Service practice number and definition are provided for each management practice, where available. Also included in italics are SCS statements describing the effect each practice has on water quality (USDA-SCS, 1988.)

Grazing Management System Practices

Appropriate grazing management systems ensure proper grazing use by adjusting grazing intensity and duration to reflect the availability of forage and feed designated for livestock uses, and by controlling animal movement through the operating unit of range or pasture. Proper grazing use will maintain enough live vegetation and litter cover to protect the soil from erosion; will achieve riparian and other resource objectives; and will maintain or improve the quality, quantity, and age distribution of desirable vegetation. Practices that accomplish this are:

■ a. *Deferred grazing (352): Postponing grazing or resting grazing land for prescribed period.*

In areas with bare ground or low percent ground cover, deferred grazing will reduce sediment yield because of increased ground cover, less ground surface disturbance, improved soil bulk density characteristics, and greater infiltration rates. Areas mechanically treated will have less sediment yield when deferred to encourage re-vegetation. Animal waste would not be available to the area during the time of deferred grazing and there would be less opportunity for adverse runoff effects on surface or aquifer water quality. As vegetative cover increases, the filtering processes are enhanced, thus trapping more silt and nutrients as well as snow if climatic conditions for snow exist. Increased plant cover results in a greater uptake and utilization of plant nutrients.

b. *Planned grazing system (556): A practice in which two or more grazing units are alternately rested and grazed in a planned sequence for a period of years, and rest periods may be throughout the year or during the growing season of key plants.*

Planned grazing systems normally reduce the system time livestock spend in each pasture. This increases quality and quantity of vegetation. As vegetation quality increases, fiber content in manure decreases which speeds manure decomposition and reduces pollution potential. Freeze-thaw, shrink-swell, and other natural soil mechanisms can reduce compacted layers during the absence of grazing animals. This increases infiltration, increases vegetative growth, slows runoff, and improves the nutrient and moisture filtering and trapping ability of the area.

Decreased runoff will reduce the rate of erosion and movement of sediment and dissolved and sediment-attached substances to downstream water courses. No increase in ground water pollution hazard would be anticipated from the use of this practice.

c. *Proper grazing use (528): Grazing at an intensity that will maintain enough cover to protect the soil and maintain or improve the quantity and quality of desirable vegetation.*

Increased vegetation slows runoff and acts as a sediment filter for sediments and sediment attached substances, uses more nutrients, and reduces raindrop splash. Adverse chemical effects should not be anticipated from the use of this practice.

d. *Proper woodland grazing (530): Grazing wooded areas at an intensity that will maintain adequate cover for soil protection and maintain or improve the quantity and quality of trees and forage vegetation.*

This practice is applicable on wooded areas producing a significant amount of forage that can be harvested without damage to other values. In these areas there should be no detrimental effects on the quality of surface and ground water. Any time this practice is applied there must be a detailed management and grazing plan.

e. *Pasture and hayland management (510): Proper treatment and use of pasture or hayland.*

With the reduced runoff there will be less erosion, less sediment and substances transported to the surface waters. The increased infiltration increases the possibility of soluble substances leaching into the ground water.

Alternate Water Supply Practices

Providing water and salt supplement facilities away from streams will help keep livestock away from streambanks and riparian zones. The establishment of alternate water supplies for livestock is an essential component of this measure when problems related to the distribution of livestock occur in a grazing unit. In most western states, securing water rights may be necessary. Access to a developed or natural water supply that is protective of streambank and riparian zones can be provided by using the stream crossing (interim) technology to build a watering site. In some locations, artificial shade may be constructed to encourage use of upland sites for shading and loafing. Providing water can be accomplished through the following Soil Conservation Service practices and the stream crossing (interim) practice (practice "m") of the following section. Descriptions have been modified to meet CZM needs:

f. *Pipeline (516): Pipeline installed for conveying water for livestock or for recreation.*

Pipelines may decrease sediment, nutrient, organic, and bacteria pollution from livestock. Pipelines may afford the opportunity for alternative water sources other than streams and lakes, possibly keeping the animals away from the stream or impoundment. This will prevent bank destruction with resulting sedimentation, and will reduce animal *waste deposition directly in the water. The reduction of concentrated livestock areas will reduce manure solids, nutrients, and bacteria that accompany surface runoff.*

■ g. Pond (378): A water impoundment made by constructing a dam or an embankment or by excavation of a pit or dugout.

Ponds may trap nutrients and sediment which wash into the basin. This removes these substances from downstream. Chemical concentrations in the pond may be higher during the summer months. By reducing the amount of water that flows in the channel downstream, the frequency of flushing of the stream is reduced and there is a collection of substances held temporarily within the channel. A pond may cause more leachable substance to be carried into the ground water.

■ h. Trough or tank (614): A trough or tank, with needed devices for water control and waste water disposal, installed to provide drinking water for livestock.

By the installation of a trough or tank, livestock may be better distributed over the pasture, grazing can be better controlled, and surface runoff reduced, thus reducing erosion. By itself this practice will have only a minor effect on water quality; however when coupled with other conservation practices, the beneficial effects of the combined practices may be large. Each site and application should be evaluated on their own merits.

■ i. Well (642): A well constructed or improved to provide water for irrigation, livestock, wildlife, or recreation.

When water is obtained, if it has poor quality because of dissolved substances, its use in the surface environment or its discharge to downstream water courses the surface water will be degraded. The location of the well must consider the natural water quality and the hazards of its use in the potential contamination of the environment. Hazard exists during well development and its operation and maintenance to prevent aquifer quality damage from the pollutants through the well itself by back flushing, or accident, or flow down the annular spacing between the well casing and the bore hole.

■ j. Spring development (574): Improving springs and seeps by excavating, cleaning, capping, or providing collection and storage facilities.

There will be negligible long-term water quality impacts with spring developments. Erosion and sedimentation may occur from any disturbed areas during and immediately after construction, but should be short-lived. These sediments will have minor amounts of adsorbed nutrients from soil organic matter.

Livestock Access Limitation Practices

It may be necessary to minimize livestock access to streambanks, ponds or lakeshores, and riparian zones to protect these areas from physical disturbance. This could also be accomplished by establishing special use pastures to manage livestock in areas of concentration. Practices include:

■ k. Fencing (382): Enclosing or dividing an area of land with a suitable permanent structure that acts as a barrier to livestock, big game, or people (does not include temporary fences).

Fencing is a practice that can be on the contour or up and down slope. Often a fence line has grass and some shrubs in it. When a fence is built across the slope it will slow down runoff, and cause deposition of coarser grained materials reducing the amount of sediment delivered downslope. Fencing may protect riparian areas which act as sediment traps and filters along water channels and impoundments.

Livestock have a tendency to walk along fences. The paths become bare channels which concentrate and accelerate runoff causing a greater amount of erosion within the path and where the path/channel outlets into another channel. This can deliver more sediment and associated pollutants to surface waters. Fencing can have the effect of concentrating livestock in small areas, causing a concentration of manure which may wash off into the stream, thus causing surface water pollution.

l. *Livestock exclusion (472): Excluding livestock from an area not intended for grazing.*

Livestock exclusion may improve water quality by preventing livestock from being in the water or walking down the banks, and by preventing manure deposition in the stream. The amount of sediment and manure may be reduced in the surface water. This practice prevents compaction of the soil by livestock and prevents losses of vegetation and undergrowth. This may maintain or increase evapotranspiration. Increased permeability may reduce erosion and lower sediment and substance transportation to the surface waters. Shading along streams and channels resulting from the application of this practice may reduce surface water temperature.

m. *Stream crossing (interim): A stabilized area to provide access across a stream for livestock and farm machinery.*

The purpose is to provide a controlled crossing or watering access point for livestock along with access for farm equipment, control bank and streambed erosion, reduce sediment and enhance water quality, and maintain or improve wildlife habitat.

Vegetative Stabilization Practices

It may be necessary to improve or reestablish the vegetative cover on range and pastures to reduce erosion rates. The following practices can be used to reestablish vegetation:

n. *Pasture and hayland planting (512): Establishing and reestablishing long-term stands of adapted species of perennial, biannual, or reseeding forage plants. (Includes pasture and hayland renovation. Does not include grassed waterways or outlets or cropland.)*

The long-term effect will be an increase in the quality of the surface water due to reduced erosion and sediment delivery. Increased infiltration and subsequent percolation may cause more soluble substances to be carried to ground water.

o. *Range seeding (550): Establishing adapted plants by seeding on native grazing land. (Range does not include pasture and hayland planting.)*

Increased erosion and sediment yield may occur during the establishment of this practice. This is a temporary situation and sediment yields decrease when reseeded area becomes established. If chemicals are used in the reestablishment process, chances of chemical runoff into downstream water courses are reduced if application is applied according to label instructions. After establishment of the grass cover, grass sod slows runoff, acts as a filter to trap sediment, sediment attached substances, increases infiltration, and decreases sediment yields.

p. *Critical area planting (342): Planting vegetation, such as trees, shrubs, vines, grasses, or legumes, on highly erodible or critically eroding areas. (Does not include tree planting mainly for wood products.)*

This practice may reduce soil erosion and sediment delivery to surface waters. Plants may take up more of the nutrients in the soil, reducing the amount that can be washed into surface waters or leached into ground water.

During grading, seedbed preparation, seeding, and mulching, large quantities of sediment and associated chemicals may be washed into surface waters prior to plant establishment.

q. *Brush (and weed) management (314): Managing and manipulating stands of brush (and weeds) on range, pasture, and recreation and wildlife areas by mechanical, chemical, or biological means or by prescribed burning. (Includes reducing excess brush (and weeds) to restore natural plant community balance and manipulating stands of undesirable plants through selective and patterned treatments to meet specific needs of the land and objectives of the land user.)*

Improved vegetation quality and the decrease in runoff from the practice will reduce the amount of erosion and sediment yield. Improved vegetative cover acts as a filter strip to trap the movement of dissolved and sediment attached substances, such as nutrients and chemicals from entering downstream water courses. Mechanical brush management may initially increase sediment yields because of soil disturbances and reduced vegetative cover. This is temporary until revegetation occurs.

r. *Prescribed burning (338): Applying fire to predetermined areas under conditions under which the intensity and spread of the fire are controlled.*

When the area is burned in accordance with the specifications of this practice the nitrates with the burned vegetation will be released to the atmosphere. The ash will contain phosphorous and potassium which will be in a relatively highly soluble form. If a runoff event occurs soon after the burn there is a probability that these two materials may be transported into the ground water or into the surface water. When in a soluble state the phosphorous and potassium will be more difficult to trap and hold in place. When done on range grasses the growth of the grasses is increased and there will be an increased tie-up of plant nutrients as the grasses' growth is accelerated.

Selection of Practices

The selection of management practices for this measure should be based on an evaluation of current conditions, problems identified, quality criteria, and management goals. Successful resource management on range and pasture includes appropriate application of a combination of practices that will meet the needs of the range and pasture ecosystem (i.e., the soil, water, air, plant, and animal (including fish and shellfish) resources) and the objectives of the land user.

For a sound grazing land management system to function properly and to provide for a sustained level of productivity, the following should be considered:

- Know the key factors of plant species management, their growth habits, and their response to different seasons and degrees of use by various kinds and classes of livestock.
- Know the demand for, and seasons of use of, forage and browse by wildlife species.
- Know the amount of plant residue or grazing height that should be left to protect grazing land soils from wind and water erosion, provide for plant regrowth, and provide the riparian vegetation height desired to trap sediment or other pollutants.
- Know the range site production capabilities and the pasture suitability group capabilities so an initial stocking rate can be established.
- Know how to use livestock as a tool in the management of the range ecosystems and pastures to ensure the health and vigor of the plants, soil tilth, proper nutrient cycling, erosion control, and riparian area management, while at the same time meeting livestock nutritional requirements.

- Establish grazing unit sizes, watering, shade and salt locations, etc. to secure optimum livestock distribution and proper vegetation use.
- Provide for livestock herding, as needed, to protect sensitive areas from excessive use at critical times.
- Encourage proper wildlife harvesting to ensure proper population densities and forage balances.
- Know the livestock diet requirements in terms of quantity and quality to ensure that there are enough grazing units to provide adequate livestock nutrition for the season and the kind and classes of animals on the farm/ranch.
- Maintain a flexible grazing system to adjust for unexpected environmentally and economically generated problems.
- Special requirements to protect threatened or endangered species.

6. Cost Information

Much of the cost associated with implementing grazing management practices is due to fencing installation, water development, and system maintenance. Costs vary according to region and type of practice. Generally, the more components or structures a practice requires, the more expensive it is. However, cost-share is usually available from the USDA and other Federal agencies for most of these practices.

a. *Grazing Facilities*

Principal direct costs of providing grazing facilities vary from relatively low variable costs of dispersed salt blocks to higher capital and maintenance costs of supplementary water supply improvements. Improving the distribution of grazing pressure by herding or strategically locating grazing facilities to draw cattle away from streamside areas can result in improved utilization of existing forage.

The availability and feasibility of supplementary water development varies considerably between arid western areas and humid eastern areas, but costs for water development, including spring development and pipeline watering, are similar (Table 2-24).

b. *Livestock Exclusion*

Principal direct costs of livestock exclusion are the capital and maintenance costs for fencing to restrict access to streamside areas or the cost of herders to achieve the same results. In addition, there may be an indirect cost of the forage that is removed from grazing by exclusion.

There is considerable difference between multistrand barbed wire, chiefly used for perimeter fencing and permanent stream exclusion and diversions, and single- or double-strand smoothwire electrified fencing used for stream exclusion and temporary divisions within permanent pastures. The latter may be all that is needed to accomplish most livestock exclusion in smaller, managed pastures in the East (Table 2-25).

c. *Improvement/Reestablishment*

Principal direct costs of improving or reestablishing grazing land include the costs of seed, fertilizer, and herbicides needed to establish the new forage stand and the labor and machinery costs required for preparation, planting, cultivation, and weed control (Table 2-26). An indirect cost may be the forage that is removed from grazing during the reestablishment work and rest for seeding establishment.

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Table 2-24. Cost of Water Development for Grazing Management

Location	Year	Type	Unit	Reported Capital Costs $/Unit	Constant Dollar[a] Capital Costs 1991 $/Unit	Constant Dollar[a] Annualized Costs 1991 $/Unit
California[b]	1979	pipeline	foot	0.28	0.35	0.05
Kansas[c]	1989	spring	each	1,239.00	1,282.94	191.20
		spring	each	1,389.00	1,438.26	214.34
Maine[d]	1988	pipeline	each	831.00	879.17	131.02
Alabama[e]	1990	spring	each	1,500.00	1,520.83	226.65
		pipeline	foot	1.60	1.62	0.24
		trough	each	1,000.00	1,013.89	151.10
Nebraska[f]	1991	pipeline	foot	1.31	1.31	0.20
		tank	each	370.00	370.00	55.14
Utah[g]	1968	spring	each	200.00	389.33	58.02
Oregon[h]	1991	pipeline	foot	0.20	0.20	0.03
		tank	each	183.00	183.00	27.27

[a] Reported costs inflated to 1991 constant dollars by the ratio of indices of prices paid by farmers for building and fencing, 1977=100. Capital costs are annualized at 8 percent interest for 10 years.
[b] Fresno Field Office, 1979.
[c] Northup et al., 1989.
[d] Cumberland County Soil and Water Conservation District, undated.
[e] Alabama Soil Conservation Service, 1990.
[f] Hermemeyer, 1991.
[g] Workman and Hooper, 1968.
[h] ASCS/SCS, 1991.

d. Overall Costs of the Grazing Management Measure

Since the exact combination of practices needed to implement the management measure depends on site-specific conditions that are highly variable, the overall cost of the measure is best estimated from similar combinations of practices applied under the Agricultural Conservation Program (ACP), Rural Clean Water Program (RCWP), and similar activities. Cost data from the ACP programs are summarized in Table 2-27.

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Table 2-25. Cost of Livestock Exclusion for Grazing Management

Location	Year	Type	Unit	Reported Capital Costs $/Unit	Constant Dollar[a] Capital Costs 1991 $/Unit	Constant Dollar[a] Annualized Costs 1991 $/Unit
California[b]	1979	permanent	mile	2,000	2,474.58	368.78
Alabama[c]	1990	permanent	mile	3,960	4,015.00	598.35
		net wire	mile	5,808	5,888.67	877.58
		electric	mile	2,640	2,676.67	398.90
Nebraska[d]	1991	permanent	mile	2,478	2,478.00	369.30
Great Lakes[e]	1989	permanent	mile	2,100 - 2,400	2,174.47 - 2,485.11	324.06 - 370.35
Oregon[f]	1991	permanent	mile	2,640	2,640.00	393.44

[a] Reported costs inflated to 1991 constant dollars by the ratio of indices of prices paid by farmers for building and fencing, 1977=100. Capital costs are annualized at 8 percent interest for 10 years.
[b] Fresno Field Office, 1979.
[c] Alabama Soil Conservation Service, 1990.
[d] Hermsmeyer, 1991.
[e] DPRA, 1989.
[f] ASCS/SCS, 1991.

Table 2-26. Cost of Forage Improvement/Reestablishment for Grazing Management

Location	Year	Type	Unit	Reported Capital Costs $/Unit	Constant Dollar[a] Capital Costs 1991 $/Unit	Constant Dollar[a] Annualized Costs 1991 $/Unit
Alabama[b]	1990	planting (seed, lime & fertilizer)	acre	84 - 197	83 - 195	12.37 - 29.00
Nebraska[c]	1991	establishment	acre	47	47	7.00
		seeding	acre	45	45	6.71
Oregon[d]	1991	establishment	acre	27	27	4.02

[a] Reported costs inflated to 1991 constant dollars by the ratio of indices of prices paid by farmers for seed, 1977=100. Capital costs are annualized at 8 percent interest for 10 years.
[b] Alabama Soil Conservation Service, 1990.
[c] Hermsmeyer, 1991.
[d] ASCS/SCS, 1991.

Table 2-27. Summary of ACP Grazing Management Practice Costs, 1989 (US and 1990 (USDA-ASCS, 1990; USDA-ASCS, 1991)[a]

Region[b]	ASCS Practice Code[c]	Adjusted Cost/Acre Treated[d] ($/acre)		
		Average	Low	High
GL	SL1	17.34	13.01	49.80
GL	SL2	16.18	11.53	24.82
GL	SL6	27.76	17.32	37.92
GL	SL11	31.63	11.95	66.50
GL	SP10	19.13	13.50	52.03
GL	WP2	31.78	16.09	165.37
Gulf	SL1	12.67	9.95	19.19
Gulf	SL2	4.44	4.26	13.43
Gulf	SL6-range	1.81	0.81	12.55
Gulf	SL6-pasture	24.00	9.68	219.45
Gulf	SL11	47.92	27.53	109.96
Gulf	WC3	0.78	0.69	0.96
Gulf	WP2	56.44	36.14	72.84
NE	SL1	23.92	17.18	45.76
NE	SL2	21.06	5.06	45.96
NE	SL6	34.70	19.36	42.20
NE	SL11	109.11	17.62	374.48
NE	SP10	106.53	52.03	1,023.61
NE	WP2	72.75	31.06	1,543.97
Pacific	SL1	9.75	7.92	24.39
Pacific	SL2	3.62	0.61	7.32
Pacific	SL6	1.06	0.51	2.22
Pacific	SL11	12.61	7.20	20.86
Pacific	SP10	100.19	19.59	132.36
Pacific	WP2	14.22	7.53	190.51
SE	SL1	19.54	15.49	24.05
SE	SL2	10.68	5.20	15.81
SE	SL6	10.14	9.49	262.77
SE	SL11	55.20	15.70	116.40
SE	WP2	75.90	13.21	224.73

Table 2-27 Notes:

[a] Acreage-weighted average of 1989 and 1990 costs.

[b] GL=Great Lakes Region (IL, IN, MI, NY, OH, WI)
GULF=Gulf States Region (AL, FL, LA, MS, TX)
NE=Northeast Region (CT, DE, MA, MD, ME, NH, NY, PA, RI)
Pacific=Pacific Region (CA, OR, WA)
SE=Southeast Region (FL, GA, NC, SC, VA)

[c] ASCS practices with description title and technical practice code:

SL1 - Permanent vegetative cover establishment

Conservation tillage	329
Pasture and hayland planting	512
Range seeding	550
Cover and green manure crop (orchard and vineyard only)	340
Field borders	386
Filter strips	393

SL2 - Permanent vegetative cover improvement

Conservation tillage	329
Pasture and hayland management	510
Pasture and hayland Planting	512
Fencing	382
Range seeding	550
Deferred grazing	352
Firebreak	394
Brush management	314

SL6 - Grazing land protection

Critical area planting	342
Pond	378
Fencing	382
Pipeline	516
Spring development	574
Stock trails and walkways	575
Trough or tank	614
Water-harvesting catchment	636
Wells	642

SL11 - Permanent vegetative cover on critical areas

Cover and green manure crop	340
Critical area planting	342
Fencing	382
Field borders	386
Filter strip	393
Forest land erosion control system	408
Mulching	484
Streambank and shoreline protection	580
Tree planting	612

SP10 - Streambank stabilization

Critical area planting	342
Livestock exclusion	472
Mulching	484
Streambank and shoreline protection	580
Tree planting	612

WC3 - Rangeland moisture conservation

Grazing land mechanical treatment	548

WP2 - Stream protection

Filter strip	393
Channel vegetation	322
Fencing	382
Pipeline	516
Streambank and shoreline protection	580
Field border	386
Tree planting	612
Trough or tank	614
Stock trails or walkways	575

[d] Average annual cost, adjusted to 1990 constant dollars using ratio of index of prices paid for production items 1989 to 1990 (171/165). Source: USDA-ERS, 1991.

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E. Irrigation Water Management

To reduce nonpoint source pollution of surface waters caused by irrigation:

(1) Operate the irrigation system so that the timing and amount of irrigation water applied match crop water needs. This will require, as a minimum: (a) the accurate measurement of soil-water depletion volume and the volume of irrigation water applied, and (b) uniform application of water.

(2) When chemigation is used, include backflow preventers for wells, minimize the harmful amounts of chemigated waters that discharge from the edge of the field, and control deep percolation. In cases where chemigation is performed with furrow irrigation systems, a tailwater management system may be needed.

The following limitations and special conditions apply:

(1) In some locations, irrigation return flows are subject to other water rights or are required to maintain stream flow. In these special cases, on-site reuse could be precluded and would not be considered part of the management measure for such locations.

(2) By increasing the water use efficiency, the discharge volume from the system will usually be reduced. While the total pollutant load may be reduced somewhat, there is the potential for an increase in the concentration of pollutants in the discharge. In these special cases, where living resources or human health may be adversely affected and where other management measures (nutrients and pesticides) do not reduce concentrations in the discharge, increasing water use efficiency would not be considered part of the management measure.

(3) In some irrigation districts, the time interval between the order for and the delivery of irrigation water to the farm may limit the irrigator's ability to achieve the maximum on-farm application efficiencies that are otherwise possible.

(4) In some locations, leaching is necessary to control salt in the soil profile. Leaching for salt control should be limited to the leaching requirement for the root zone.

(5) Where leakage from delivery systems or return flows supports wetlands or wildlife refuges, it may be preferable to modify the system to achieve a high level of efficiency and then divert the "saved water" to the wetland or wildlife refuge. This will improve the quality of water delivered to wetlands or wildlife refuges by preventing the introduction of pollutants from irrigated lands to such diverted water.

(6) In some locations, sprinkler irrigation is used for frost or freeze protection, or for crop cooling. In these special cases, applications should be limited to the amount necessary for crop protection, and applied water should remain on-site.

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1. Applicability

This management measure is intended to be applied by States to activities on irrigated lands, including agricultural crop and pasture land (except for isolated fields of less than 10 acres in size that are not contiguous to other irrigated lands); orchard land; specialty cropland; and nursery cropland. Those landowners already practicing effective irrigation management in conformity with the irrigation water management measure may not need to purchase additional devices to measure soil-water depletion or the volume of irrigation water applied, and may not need to expend additional labor resources to manage the irrigation system. Under the Coastal Zone Act Reauthorization Amendments of 1990, States are subject to a number of requirements as they develop coastal nonpoint programs in conformity with this measure and will have some flexibility in doing so. The application of management measures by States is described more fully in *Coastal Nonpoint Pollution Control Program: Program Development and Approval Guidance*, published jointly by the U.S. Environmental Protection Agency (EPA) and the National Oceanic and Atmospheric Administration (NOAA) of the U.S. Department of Commerce.

2. Description

The goal of this management measure is to reduce nonpoint source pollution of surface waters caused by irrigation. For the purposes of this management measure, "harmful amounts" are those amounts that pose a significant risk to aquatic plant or animal life, ecosystem health, human health, or agricultural or industrial uses of the water.

A problem associated with irrigation is the movement of pollutants from the land into ground or surface water. This movement of pollutants is affected by the pathways taken by applied water and precipitation (Figure 2-15); the physical, chemical, and biological characteristics of the irrigated land; the type of irrigation system used; crop type; the degree to which erosion and sediment control, nutrient management, and pesticide management are employed; and the management of the irrigation system (Figure 2-16).

Return flows, runoff, and leachate from irrigated lands may transport the following types of pollutants:

- Sediment and particulate organic solids;
- Particulate-bound nutrients, chemicals, and metals, such as phosphorus, organic nitrogen, a portion of applied pesticides, and a portion of the metals applied with some organic wastes;
- Soluble nutrients, such as nitrogen, soluble phosphorus, a portion of the applied pesticides, soluble metals, salts, and many other major and minor nutrients; and
- Bacteria, viruses, and other microorganisms.

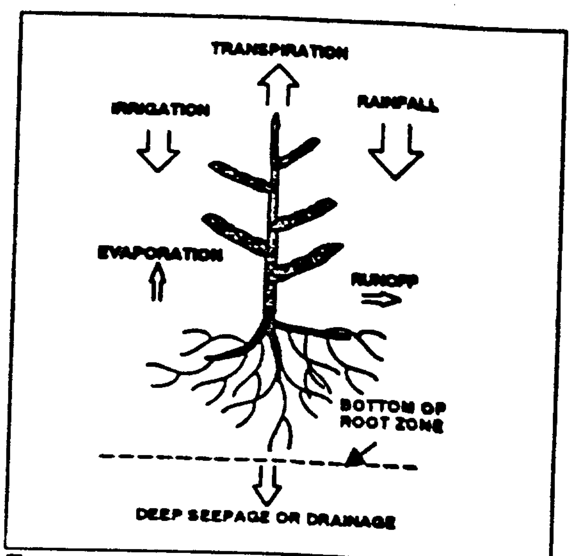

Figure 2-15. Source and fate of water added to a soil system (Evans et al., 1991c).

Transport of irrigation water from the source of supply to the irrigated field via open canals and laterals can be a source of water loss if the canals and laterals are not lined. Water is also transported through the lower ends of canals and laterals because of the flow-through requirements to maintain water levels in them. In many soils, unlined canals and laterals lose water via seepage in bottom and side walls. Seepage water either moves into the ground water through infiltration or forms wet areas near the canal or lateral. This water

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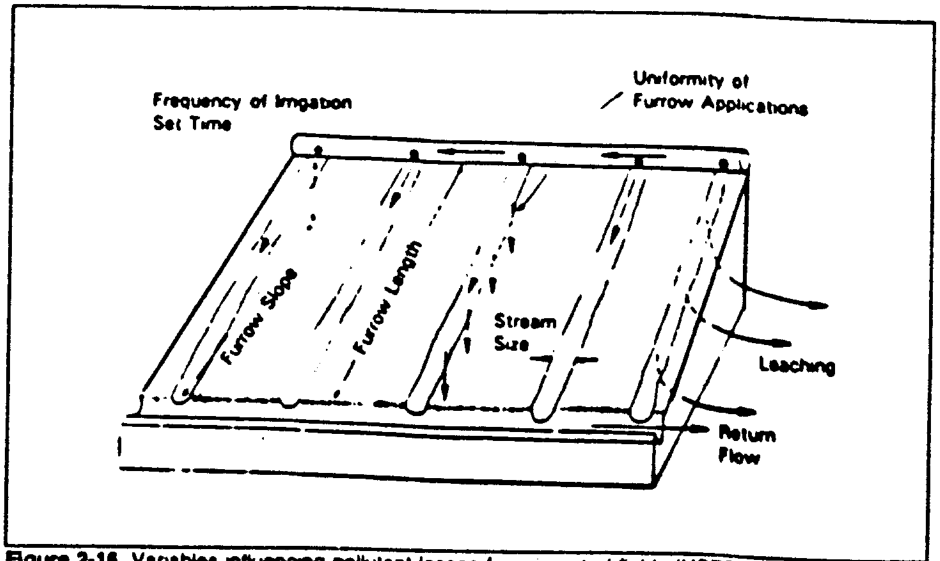

Figure 2-16. Variables influencing pollutant losses from irrigated fields (USEPA, 1982).

will carry with it any soluble pollutants in the soil, thereby creating the potential for pollution of ground or surface water.

Since irrigation is a consumptive use of water, any pollutants in the source waters that are not consumed by the crop (e.g., salts, pesticides, nutrients) can be concentrated in the soil, concentrated in the leachate or seepage, or concentrated in the runoff or return flow from the system. Salts that concentrate in the soil profile must be removed for sustained crop production.

For additional information regarding the problems caused by these pollutants, see Section I.F of this chapter.

Application of this management measure will reduce the waste of irrigation water, improve the water use efficiency, and reduce the total pollutant discharge from an irrigation system. It is not the intent of this management measure to require the replacement of major components of an irrigation system. Instead, the expectation is that components to manage the timing and amount of water applied will be provided where needed, and that special precautions (i.e., backflow preventers, prevent tailwater, and control deep percolation) will be taken when chemigation is used.

Irrigation scheduling is the use of water management strategies to prevent over-application of water while minimizing yield loss due to water shortage or drought stress (Evans et al., 1991d). Irrigation scheduling will ensure that water is applied to the crop when needed and in the amount needed. Effective scheduling requires knowledge of the following factors (Evans et al., 1991c; Evans et al., 1991d):

- Soil properties;
- Soil-water relationships and status;
- Type of crop and its sensitivity to drought stress;
- The stage of crop development;
- The status of crop stress;
- The potential yield reduction if the crop remains in a stressed condition;
- Availability of a water supply; and
- Climatic factors such as rainfall and temperature.

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Much of the above information can be found in Soil Conservation Service soil surveys and Extension Service literature. However, all information should be site-specific and verified in the field.

There are three ways to determine when irrigation is needed (Evans et al., 1991d):

- Measuring soil water;
- Estimating soil water using an accounting approach; and
- Measuring crop stress.

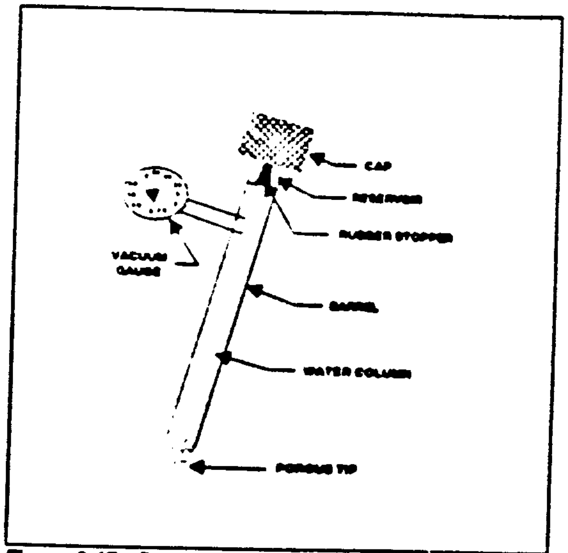

Figure 2-17. Diagram of a tensiometer (Evans et al., 1991b).

Soil water can be measured using a range of devices (Evans et al., 1991b), including tensiometers, which measure soil water suction (Figure 2-17); electrical resistance blocks (also called gypsum blocks or moisture blocks), which measure electrical resistance that is related to soil water by a calibration curve (Figure 2-18); neutron probes, which directly measure soil water; Phene cells, which are used to estimate soil water based on the relationship of heat conductance to soil water content; and time domain reflectometers, which can be used to estimate soil water based on the time it takes for an electromagnetic pulse to pass through the soil. The appropriate device for any given situation is a function of the acreage of irrigated land, soils, cost, and other site-specific factors.

Accounting approaches estimate the quantity of soil water remaining in the effective root zone and can be simple or complex. In essence, daily water inputs and outputs are measured or estimated to determine the depletion volume. Irrigation is typically scheduled when the allowable depletion volume is nearly reached.

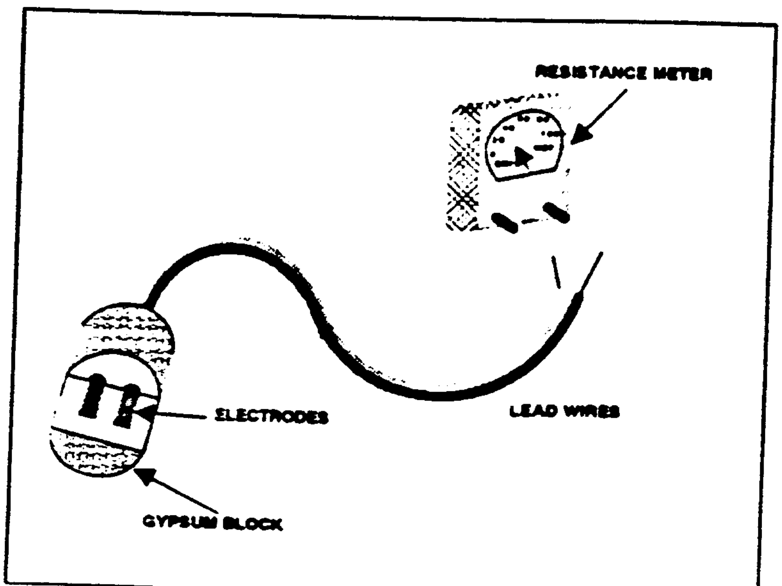

Figure 2-18. Schematic of an electrical resistance block and meter (Evans et al., 1991b).

Once the decision to irrigate has been made, it is important to determine the amount of water to apply. Irrigation needs are a function of the soil water depletion volume in the effective root zone, the rate at which the crop uses water (Figure 2-19), and climatic factors. Accurate measurements of the amount of water applied are essential to maximizing irrigation efficiency. The quantity of water applied

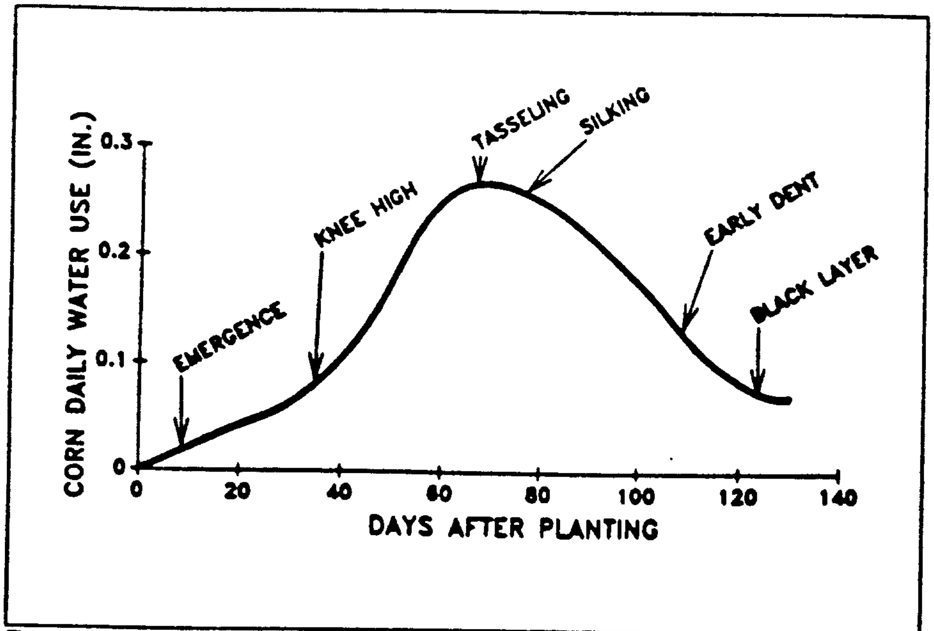

Figure 2-19. Corn daily water use as influenced by stage of development (Evans et al., 1991c).

can be measured by such devices as a totalizing flow meter that is installed in the delivery pipe. If water is supplied by ditch or canal, weirs or flumes in the ditch can be used to measure the rate of flow.

Deep percolation can be greatly reduced by limiting the amount of applied water to the amount that can be stored in the plant root zone. The deep percolation that is necessary for salt management can be accomplished with a sprinkler system by using longer sets or very slow pivot speeds or by applying water during the non-growing season.

Reducing overall water use in irrigation will allow more water for stream flow control and will increase flow for diversion to marshes, wetlands, or other environmental uses. If the source is ground water, reducing overall use will maintain higher ground-water levels, which could be important for maintaining base flow in nearby streams. Reduced water diversion will reduce the salt or pollutant load brought into the irrigation system, thereby reducing the volume of these pollutants that must be managed or discharged from the system.

Although this management measure does not require the replacement of major components of an irrigation system, such changes can sometimes result in greater pollution prevention. Consequently, the following is a broader discussion of the types of design and operational aspects of the overall irrigation system that could be addressed to provide additional control of nonpoint source pollution beyond that which is required by this management measure. Overall, five basic aspects of the irrigation system can be addressed:

(1) Irrigation scheduling;
(2) Efficient application of irrigation water;
(3) Efficient transport of irrigation water;
(4) Use of runoff or tailwater; and
(5) Management of drainage water.

This management measure addresses irrigation scheduling, efficient application, and the control of tailwater when chemigation is used. The efficient transport of irrigation water, the use of runoff or tailwater, and the management of drainage water are additional considerations.

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Although not a required element of this management measure, the seepage losses associated with canals and laterals can be reduced by lining the canals and laterals, or can be eliminated by conversion from open canals and laterals to pipelines. Flow-through losses will not be changed by canal or lateral lining, but can be eliminated or greatly reduced by conversion to pipelines.

Surface irrigation systems are usually designed to have a percentage (up to 30 percent) of the applied water lost as tailwater. This tailwater should be managed with a tailwater recovery system, but such a system is not required as a component of this management measure unless chemigation is practiced. Tailwater recovery systems usually include a system of ditches or berms to direct water from the end of the field to a small storage structure. Tailwater is stored until it can be either pumped back to the head end of the field and reused or delivered to additional irrigated land. In some locations, there may be downstream water rights that are dependent upon tailwater, or tailwater may be used to maintain flow in streams. These requirements may take legal precedence over the reuse of tailwater.

Well-designed and managed irrigation systems remove runoff and leachate efficiently; control deep percolation; and minimize erosion from applied water, thereby reducing adverse impacts on surface water and ground water. If a tailwater recovery system is used, it should be designed to allow storm runoff to flow through the system without damage. Additional surface drainage structures such as filter strips, field drainage ditches, subsurface drains, and water table control may also be used to control runoff and leachate if site conditions warrant their use. Sprinkler systems will usually require design and installation of a system to remove and manage storm runoff.

A properly designed and operated sprinkler irrigation system should have a uniform distribution pattern. The volume of water applied can be changed by changing the total time the sprinkler runs; by changing the pressure at which the sprinkler operates; or, in the case of a center pivot, by adjusting the speed of travel of the system. There should be no irrigation runoff or tailwater from most well-designed and well-operated sprinkler systems.

The type of irrigation system used will dictate which practices can be employed to improve water use efficiency and to obtain the most benefit from scheduling. Flood systems will generally infiltrate more water at the upper end of the field than at the lower end because water is applied to the upper end of the field first and remains on that portion of the field longer. This will cause the upper end of the field to have greater deep percolation losses than the lower end. Although not required as a component of this management measure, this situation can sometimes be improved by changing slope throughout the length of the field. This type of change may not be practical or affordable in many cases. For example, furrow length can be reduced by cutting the field in half and applying water in the middle of the field. This will require more pipe or ditches to distribute the water across the middle of the field.

3. Management Measure Selection

This management measure was selected based on an evaluation of available information that documents the beneficial effects of improved irrigation management (see Section II.F.4 of this chapter). Specifically, the available information shows that irrigation efficiencies can be improved with scheduling that is based on knowledge of water needs and measurement of applied water. Improved irrigation efficiency can result in the reduction or elimination of runoff and return flows, as well as the control of deep percolation. Secondly, backflow preventers can be used to protect wells from chemicals used in chemigation. In addition, tailwater prevention, or tailwater management where necessary, is effective in reducing the discharge of soluble and particulate pollutants to receiving waters.

By reducing the volume of water applied to agricultural lands, pollutant loads are also reduced. Less interaction between irrigation water and agricultural land will generally result in less pollutant transport from the land and less leaching of pollutants to ground water.

The practices that can be used to implement this measure on a given site are commonly used and are recommended by SCS for general use on irrigated lands. By designing the measure using the appropriate mix of structural and management practices for a given site, there is no undue economic impact on the operator. Many of the practices that can be used to implement this measure (e.g., water-measuring devices, tailwater recovery systems, and backflow preventers) may already be required by State or local rules or may otherwise be in use on irrigated fields. Since many irrigators may already be using systems that satisfy or partly satisfy the intent of the management measure, the only action that may be necessary will be to determine the effectiveness of the existing practices and add additional practices, if needed.

4. Effectiveness Information

Following is information on pollution reductions that can be expected from installation of the management practices outlined within this management measure.

In a review of a wide range of agricultural control practices, EPA (1982) determined that increased use of call periods, on-demand water ordering, irrigation scheduling, and flow measurement and control would all result in decreased losses of salts, sediment, and nutrients (Table 2-28). Various alterations to existing furrow irrigation systems were also determined to be beneficial to water quality, as were tailwater management and seepage control.

Logan (1990) reported that chemical backsiphon devices are highly effective at preventing the introduction of pesticides and nitrogen to ground water. The American Society of Agricultural Engineers (ASAE) specifies safety devices for chemigation that will prevent the pollution of a water supply used solely for irrigation (ASAE, 1989).

Properly designed sprinkler irrigation systems will have little runoff (Boyle Engineering Corp., 1986). Furrow irrigation and border check or border strip irrigation systems typically produce tailwater, and tailwater recovery systems may be needed to manage tailwater losses (Boyle Engineering Corp., 1986). Tailwater can be managed by applying the water to additional fields, by treating and releasing the tailwater, or by reapplying the tailwater to upslope cropland.

The Rock Creek Rural Clean Water Program (RCWP) project in Idaho is the source of much information regarding the benefits of irrigation water management (USDA, 1991). All crops in the Rock Creek watershed are irrigated with water diverted from the Snake River and delivered through a network of canals and laterals. The combined implementation of irrigation management practices, sediment control practices, and conservation tillage has resulted in measured reductions in suspended sediment loadings ranging from 61 percent to 95 percent at six stations in Rock Creek (1981-1988). Similarly, 8 of 10 sub-basins showed reductions in suspended sediment loadings over the same time period. The sediment removal efficiencies of selected practices used in the project are given in Table 2-29.

In California it is expected that drip irrigation will have the greatest irrigation efficiency of those irrigation systems evaluated, whereas conventional furrow irrigation will have the lowest irrigation efficiency and greatest runoff fraction (Table 2-30). Tailwater recovery irrigation systems are expected to have the greatest percolation rate. Plot studies in California have shown that in-season irrigation efficiencies for drip irrigation and Low Energy Precision Application (LEPA) are greater than those for improved furrow and conventional furrow systems (Table 2-31). LEPA is a linear move sprinkler system in which the sprinkler heads have been removed and replaced with tubes that supply water to individual furrows (Univ. Calif., 1988). Dikes are placed in the furrows to prevent water flow and reduce soil effects on infiltrated water uniformity.

Mielke et al. (1981) studied the effects of tillage practice and type of center pivot irrigation on herbicide (atrazine and alachlor) losses in runoff and sediment. Study results clearly show that, for each of three tillage practices studied, low-pressure spray nozzles result in much greater herbicide loss in runoff than either high-pressure or low-pressure impact heads.

5. Irrigation Water Management Practices

As discussed more fully at the beginning of this chapter and in Chapter 1, the following practices are described for illustrative purposes only. State programs need not require implementation of these practices. However, as a practical matter, EPA anticipates that the management measure set forth above generally will be implemented by applying one or more management practices appropriate to the source, location, and climate. The practices set forth below have been found by EPA to be representative of the types of practices that can be applied successfully apply to achieve the management measure described above.

Table 2-28. Summary of Pollutant Impacts of Selected Irrigation Practices[a] (USEPA, 1982)

Practice	Description	T-P[b]	NA-P[c]	T-N[d]	NA-N[e]	A-Pes[f]	NA-Pes[g]	Salts[h]	Sed[i]
Call Period	A minimum length of time allowed to place an order.	-	-	-	-	-	-	-	-
On-Demand Water Ordering	Maximizes scheduling flexibility; however, this encourages less planning.	-/0	-/0	-/0	-/0	-/0	-/0	-/0	-/0
Irrigation Scheduling	Uses meteorological information with soil moisture levels to forecast future irrigations.		-	-	-	-	-	-	-
Conveyance Channel Improvements and Maintenance	Keep canals free of silt deposits and vegetation to maintain capacity. Repair damaged canal banks.	-	-	-	-	-	-	-	-
Improved Management of System Storage	System water storage provides flexibility and efficiency, but it should be minimized to reduce seepage and evaporation.	-	-	-	-	-	-	-	-
Improved Management of Return Flows	Canals should not be operated at capacity at all times with unneeded water spilled into return flows.				-			-	
Seepage Control	Lining canals, ditches, laterals, and watercourses that have high seepage losses with some impermeable material.				-			-	
Flow Measurement and Control	Measure and control flow to ensure adequate application of water while preventing unnecessary and wasteful diversions. To control the flow of water in canals and ditches, structures such as checks, drops, culverts, and field inlet devices are used. Notched weirs or small fiberglass flumes are used to measure the flow of water.	-	-	-	-	-	-	-	-
Cutback Irrigation	Flow volume is adjusted by using a head ditch or delivery pipe, which is adjusted so that a flow is quickly introduced to the end of the furrow and then "cut back" to a "soaking" flow rate. Increases uniformity of application and reduces tailwater, but is only applicable if there is sufficient cross slope.	-	-	-	-	-	-	-	-
Gated Pipe System	Combines features of improved furrow and cutback systems, and can be automatically controlled and coupled with on-demand water availability.	-	-	-	-	-	-	-	-

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Table 2-28. (continued)

Practice	Description	T-P[b]	NA-P[c]	T-N[d]	NA-N[e]	A-Pes[f]	NA-Pes[g]	Salts[h]	Sed[i]
Multi-set Irrigation System	Combines features of improved furrow with a shorter length of run by using lateral supply pipes across each field.	-	-	-	-	-	-	-	-
Tailwater Reuse System/Subsurface Drainage	Tile drainage allows collection of surface flows into a water drainage system for control.	-	-	-	-	-	-	-	-
Sprinkler Irrigation	This system includes side-roll, center-pivot, tow-line, and solid-set sprinklers. Sprinkler systems are more efficient than surface irrigation.	-	-	-	-	-	-	-	-
Trickle Irrigation	Water is delivered to individual plants through lines or emitters in order to provide crop plants with nearly optimal soil moisture.	-	-	-	-	-	-	-	-

[a] + = increases in application of control will increase pollutant losses; - = increases in application of control will decrease pollutant losses; 0 = no appreciable effect. Blanks indicate no information presented.
[b] Absorbed phosphorus (total and labile).
[c] Nonabsorbed phosphorus (soluble forms).
[d] Absorbed nitrogen (total N and ammonium).
[e] Nonabsorbed nitrogen (nitrate).
[f] Absorbed pesticide.
[g] Nonabsorbed pesticide.
[h] Salts.
[i] Sediment.

Table 2-29. Sediment Removal Efficiencies and Comments on BMPs Evaluated (USDA, 1991)

Practice	Sediment Removal Efficiency (%)		Comment
	Average	Range	
Sediment basins: field, farm, subbasin	87	75-95	Cleaning costly.
Mini-basins	86[a]	0-95	Controlled outlets essential. Many failed. Careful management required.
Buried pipe systems (incorporating mini-basins with individual outlets into a buried drain)	83	75-95	High installation cost. Potential for increased production to offset costs. Eliminates tailwater ditch. Good control of tailwater.
Vegetative filters	50[a]	35-70	Simple. Proper installation and management needed.
Placing straw in furrows	50	40-80	Labor-intensive without special equipment. Careful management required.

[a] Mean of those that did not fail.

Table 2-30. Expected Irrigation Efficiencies of Selected Irrigation Systems in California (California SWRCB, 1987)

Irrigation System	Irrigation Efficiency (%)	Percolation Fraction (%)	Runoff Fraction (%)
Conventional Furrow	60	17.5	22.5
Gated Pipe	67.5	14.2	18.3
Shorter Run	70	13.3	16.7
Tail Water Recovery	73.2	21.3	5.5
Hand Move Sprinkler	80	8.75	11.3
Lateral Move Sprinkler	87.5	5.5	7.0
Drip	95	4.0	1.0

Table 2-31. Irrigation Efficiencies of Selected Irrigation Systems for Cotton (California SWRCB, 1991)

System	Year	Seasonal Irrigation (in.)	In-Season Distribution Uniformity (%)	In-Season Irrigation Efficiency (%)	In-Season Deep Percolation (in.)
Drip Irrigation	1989	17.82	87	99	2.43
	1990	19.24	81	82	3.98
LEPA (Low Energy Precision Application)	1989	14.21	92	97	2.88
	1990	23.19	92	78.6	6.13
Improved Furrow	1989	20.89	57.5	36	16.9
	1990	16.35	86.5	75.3	6.15
Conventional Furrow	1989	21.26	59.3	36	19.4
	1990	20.00	74	74	9.85

The U.S. Soil Conservation Service practice number and definition are provided for each management practice, where available. Also included in italics are SCS statements describing the effect each practice has on water quality (USDA-SCS, 1988).

Irrigation Scheduling Practices

Proper irrigation scheduling is a key element in irrigation water management. Irrigation scheduling should be based on knowing the daily water use of the crop, the water-holding capacity of the soil, and the lower limit of soil moisture for each crop and soil, and measuring the amount of water applied to the field. Also, natural precipitation should be considered and adjustments made in the scheduled irrigations.

Practices that may be used to accomplish proper irrigation scheduling are:

a. *Irrigation water management (449): Determining and controlling the rate, amount, and timing of irrigation water in a planned and efficient manner.*

Management of the irrigation system should provide the control needed to minimize losses of water, and yields of sediment and sediment attached and dissolved substances, such as plant nutrients and herbicides, from the system. Poor management may allow the loss of dissolved substances from the irrigation system to surface or ground water. Good management may reduce saline percolation from geologic origins. Returns to the surface water system would increase downstream water temperature.

The purpose is to effectively use available irrigation water supply in managing and controlling the moisture environment of crops to promote the desired crop response, to minimize soil erosion and loss of plant nutrients, to control undesirable water loss, and to protect water quality.

To achieve this purpose the irrigator must have knowledge of (1) how to determine when irrigation water should be applied, based on the rate of water used by crops and on the stages of plant growth; (2) how to measure or estimate the amount of water required for each irrigation, including the leaching needs; (3) the normal time needed for the soil to absorb the required amount of water and how to detect changes in intake rate; (4) how to adjust water stream size, application rate, or irrigation time to compensate for changes in such factors as intake rate or the amount of irrigation runoff from an area; (5) how to recognize erosion caused by irrigation; (6) how to estimate the amount of irrigation runoff from an area; and (7) how to evaluate the uniformity of water application.

Tools to assist in achieving proper irrigation scheduling:

b. *Water-measuring device: An irrigation water meter, flume, weir, or other water-measuring device installed in a pipeline or ditch.*

The measuring device must be installed between the point of diversion and water distribution system used on the field. The device should provide a means to measure the rate of flow. Total water volume used may then be calculated using rate of flow and time, or read directly, if a totalizing meter is used.

The purpose is to provide the irrigator the rate of flow and/or application of water, and the total amount of water applied to the field with each irrigation.

c. *Soil and crop water use data: From soils information the available water-holding capacity of the soil can be determined along with the amount of water that the plant can extract from the soil before additional irrigation is needed.*

Water use information for various crops can be obtained from various USDA publications.

The purpose is to allow the water user to estimate the amount of available water remaining in the root zone at any time, thereby indicating when the next irrigation should be scheduled and the amount of water needed. Methods to measure or estimate the soil moisture should be employed, especially for high-value crops or where the water-holding capacity of the soil is low.

Practices for Efficient Irrigation Water Application

Irrigation water should be applied in a manner that ensures efficient use and distribution, minimizes runoff or deep percolation, and eliminates soil erosion.

The method of irrigation employed will vary with the type of crop grown, the topography, and soils. There are several systems that, when properly designed and operated, can be used as follows:

d. *Irrigation system, drip or trickle (441): A planned irrigation system in which all necessary facilities are installed for efficiently applying water directly to the root zone of plants by means of applicators* (orifices, emitters, porous tubing, or perforated pipe) operated under low pressure (Figure 2-20). The applicators can be placed on or below the surface of the ground (Figure 2-21).

Surface water quality may not be significantly affected by transported substances because runoff is largely controlled by the system components (practices). Chemical applications may be applied through the system. Reduction of runoff will result in less sediment and chemical losses from the field during irrigation. If excessive, local, deep percolation should occur, a chemical hazard may exist to shallow ground water or to areas where geologic materials provide easy access to the aquifer.

e. Irrigation system, sprinkler (442): A planned irrigation system in which all necessary facilities are installed for efficiently applying water by means of perforated pipes or nozzles operated under pressure.

Proper irrigation management controls runoff and prevents downstream surface water deterioration from sediment and sediment attached substances. Over irrigation through poor management can produce impaired water quality in runoff as well as ground water through increased percolation. Chemigation with this system allows the operator the opportunity to mange nutrients, wastewater and pesticides. For example, nutrients applied in several incremental applications based on the plant needs may reduce ground water contamination considerably, compared to one application during planting. Poor management may cause pollution of surface and ground water. Pesticide drift from chemigation may also be hazardous to vegetation, animals, and surface water resources. Appropriate safety equipment, operation and maintenance of the system is needed with chemigation to prevent accidental environmental pollution or backflows to water sources.

f. Irrigation system, surface and subsurface (443): A planned irrigation system in which all necessary water control structures have been installed for efficient distribution of irrigation water by surface means, such as furrows, borders, contour levees, or contour ditches, or by subsurface means.

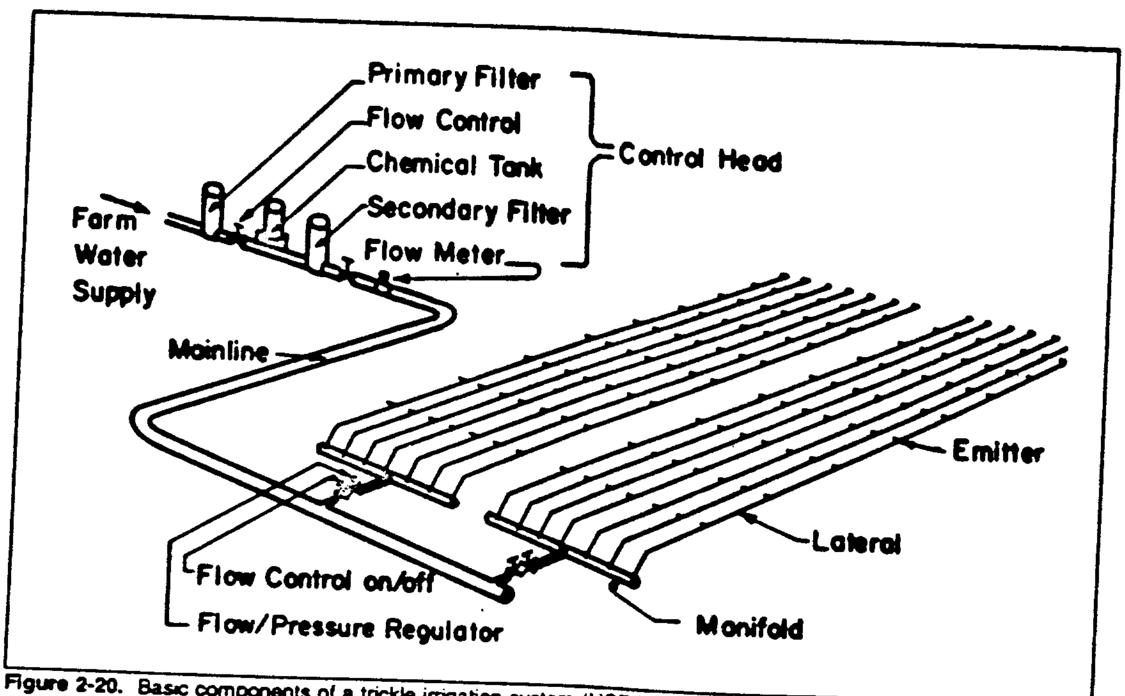

Figure 2-20. Basic components of a trickle irrigation system (USDA-SCS, 1984).

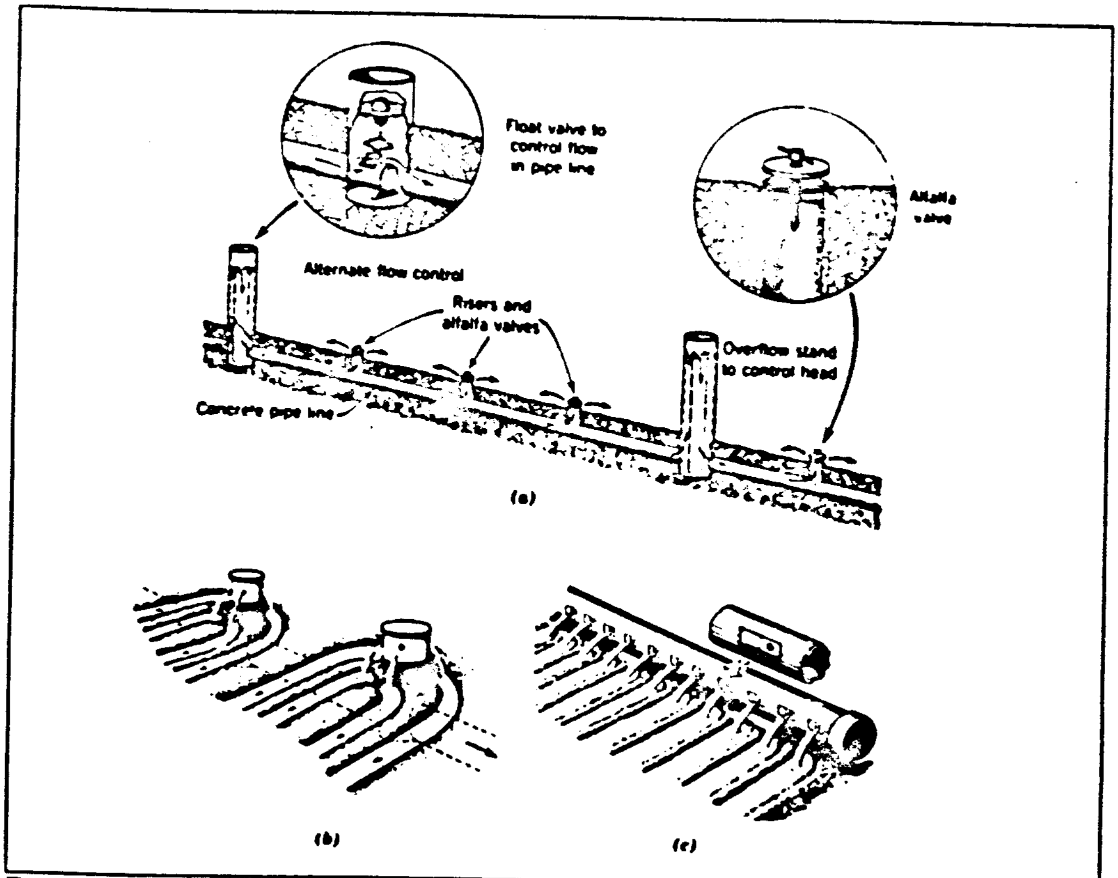

Figure 2-21. Methods of distribution of irrigation water from (a) low-pressure underground pipe, (b) multiple-outlet risers, and (c) portable gated pipe (Schwab et al., 1981).

Operation and management of the irrigation system in a manner which allows little or no runoff may allow small yields of sediment or sediment-attached substances to downstream waters. Pollutants may increase if irrigation water management is not adequate. Ground water quality from mobile, dissolved chemicals may also be a hazard if irrigation water management does not prevent deep percolation. Subsurface irrigation that requires the drainage and removal of excess water from the field may discharge increased amounts of dissolved substances such as nutrients or other salts to surface water. Temperatures of downstream water courses that receive runoff waters may be increased. Temperatures of downstream waters might be decreased with subsurface systems when excess water is being pumped from the field to lower the water table. Downstream temperatures should not be affected by subsurface irrigation during summer months if lowering the water table is not required. Improved aquatic habitat may occur if runoff or seepage occurs from surface systems or from pumping to lower the water table in subsurface systems.

■ g. *Irrigation field ditch (388): A permanent irrigation ditch constructed to convey water from the source of supply to a field or fields in a farm distribution system.*

The standard for this practice applies to open channels and elevated ditches of 25 ft^3/second or less capacity formed in and with earth materials.

Irrigation field ditches typically carry irrigation water from the source of supplying to a field or fields. Salinity changes may occur in both the soil and water. This will depend on the irrigation water quality, the level of water management, and the geologic materials of the area. The quality of ground and surface water may be altered depending on environmental conditions. Water lost from the irrigation system to downstream runoff may contain dissolved substances, sediment, and sediment-attached substances that may degrade water quality and increase water temperature. This practice may make water available for wildlife, but may not significantly increase habitat.

h. *Irrigation land leveling (464): Reshaping the surface of land to be irrigated to planned grades.*

The effects of this practice depend on the level of irrigation water management. If plant root zone soil water is properly managed, then quality decreases of surface and ground water may be avoided. Under poor management, ground and surface water quality may deteriorate. Deep percolation and recharge with poor quality water may lower aquifer quality. Land leveling may minimize erosion and when runoff occurs concurrent sediment yield reduction. Poor management may cause an increase in salinity of soil, ground and surface waters. High efficiency surface irrigation is more probable when earth moving elevations are laser controlled.

Practices for Efficient Irrigation Water Transport

Irrigation water transportation systems that move water from the source of supply to the irrigation system should be designed and managed in a manner that minimizes evaporation, seepage, and flow-through water losses from canals and ditches. Delivery and timing need to be flexible enough to meet varying plant water needs throughout the growing season.

Transporting irrigation water from the source of supply to the field irrigation system can be a significant source of water loss and cause of degradation of both surface water and ground water. Losses during transmission include seepage from canals and ditches, evaporation from canals and ditches, and flow-through water.[9] The primary water quality concern is the development of saline seeps below the canals and ditches and the discharge of saline waters. Another water quality concern is the potential for erosion caused by the discharge of flow-through water. Practices that are used to ensure proper transportation of irrigation water from the source of supply to the field irrigation system *can be found in the USDA-SCS Handbook of Practices, and include: irrigation water conveyance, ditch and canal lining (428); irrigation water conveyance, pipeline (430); and structure for water control (587).*

Practices for Utilization of Runoff Water or Tailwater

The utilization of runoff water to provide additional irrigation or to reduce the amount of water diverted increases the efficiency of use of irrigation water. For surface irrigation systems that require runoff or tailwater as part of the design and operation, a tailwater management practice needs to be installed and used. The practice is described as follows:

i. *Irrigation system, tailwater recovery (447): A facility to collect, store, and transport irrigation tailwater for reuse in the farm irrigation distribution system.*

The reservoir will trap sediment and sediment attached substances from runoff waters. Sediment and chemicals will accumulate in the collection facility by entrapping which would decrease downstream yields of these substances.

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[9] Flow-through water is water that is never applied to the land but is needed to maintain hydraulic head in the ditch. Flow-through water is also water transported in excess of delivery requirements, carried to reduce the level of management necessary to adjust flows in the ditch for changed delivery locations and amounts. Typically this water (10 - 35 percent of delivery requirements) is applied to fields as excess flow above the requested or billed amount, or returned to the supply stream as delivery system tailwater. Often credit is given by the regulatory agency for this returned water.

Salts, soluble nutrients, and soluble pesticides will be collected with the runoff and will not be released to surface waters. Recovered irrigation water with high salt and/or metal content will ultimately have to be disposed of in an environmentally safe manner and location. Disposal of these waters should be part of the overall management plan. Although some ground water recharge may occur, little if any pollution hazard is usually expected.

Practices for Drainage Water Management

Drainage water from an irrigation system should be managed to reduce deep percolation, move tailwater to the reuse system, reduce erosion, and help control adverse impacts on surface water and groundwater. A total drainage system should be an integral part of the planning and design of an efficient irrigation system. This may not be necessary for those soils that have sufficient natural drainage abilities.

There are several practices to accomplish this:

■ j. *Filter strip (393): A strip or area of vegetation for removing sediment, organic matter, and other pollutants from runoff and waste water.*

Filter strips for sediment and related pollutants meeting minimum requirements may trap the coarser grained sediment. They may not filter out soluble or suspended fine-grained materials. When a storm causes runoff in excess of the design runoff, the filter may be flooded and may cause large loads of pollutants to be released to the surface water. This type of filter requires high maintenance and has a relative short service life and is effective only as long as the flow through the filter is shallow sheet flow.

Filter strips for runoff form concentrated livestock areas may trap organic material, solids, materials which become adsorbed to the vegetation or the soil within the filter. Often they will not filter out soluble materials. This type of filter is often wet and is difficult to maintain.

Filter strips for controlled overland flow treatment of liquid wastes may effectively filter out pollutants. The filter must be properly managed and maintained, including the proper resting time. Filter strips on forest land may trap coarse sediment, timbering debris, and other deleterious material being transported by runoff. This may improve the quality of surface water and has little effect on soluble material in runoff or on the quality of ground water.

All types of filters may reduce erosion on the area on which they are constructed. Filter strips trap solids from the runoff flowing in sheet flow through the filter. Coarse-grained and fibrous materials are filtered more efficiently than fine-grained and soluble substances. Filter strips work for design conditions, but when flooded or overloaded they may release a slug load of pollutants into the surface water.

■ k. *Surface drainage field ditch (607): A graded ditch for collecting excess water in a field.*

From erosive fields, this practice may increase the yields of sediment and sediment-attached substances to downstream water courses because of an increase in runoff. In other fields, the location of the ditches may cause a reduction in sheet and rill erosion and ephemeral gully erosion. Drainage of high salinity areas may raise salinity levels temporarily in receiving waters. Areas of soils with high salinity that are drained by the ditches may increase receiving waters. Phosphorus loads, resulting from this practice may increase eutrophication problems in ponded receiving waters. Water temperature changes will probably not be significant. Upland wildlife habitat may be improved or increased although the habitat formed by standing water and wet areas may be decreased.

■ l. *Subsurface drain (606): A conduit, such as corrugated plastic tile, or pipe, installed beneath the ground surface to collect and/or convey drainage water.*

Soil water outletted to surface water courses by this practice may be low in concentrations of sediment and sediment-adsorbed substances and that may improve stream water quality. Sometimes the drained soil water is high in the *concentration of nitrates and other dissolved substances and drinking water standards may be exceeded. If drainage water that is high in dissolved substances is able to recharge ground water, the aquifer quality may become impaired. Stream water temperatures may be reduced by water drainage discharge. Aquatic habitat may be altered or enhanced with the increased cooler water temperatures.*

■ *m. Water table control (641): Water table control through proper use of subsurface drains, water control structures, and water conveyance facilities for the efficient removal of drainage water and distribution of irrigation water.*

The water table control practice reduces runoff, therefore downstream sediment and sediment-attached substances yields will be reduced. When drainage is increased, the dissolved substances in the soil water will be discharged to receiving water and the quality of water reduced. Maintaining a high water table, especially during the nongrowing season, will allow denitrification to occur and reduce the nitrate content of surface and ground by as much as 75 percent. The use of this practice for salinity control can increase the dissolved substance loading of downstream waters while decreasing the salinity of the soil. Installation of this practice may create temporary erosion and sediment yield hazards but the completed practice will lower erosion and sedimentation levels. The effect of the water table control of this practice on downstream wildlife communities may vary with the purpose and management of the water in the system.

■ *n. Controlled drainage (335): Control of surface and subsurface water through use of drainage facilities and water control structures.*

The purpose is to conserve water and maintain optimum soil moisture to (1) store and manage infiltrated rainfall for more efficient crop production; (2) improve surface water quality by increasing infiltration, thereby reducing runoff, which may carry sediment and undesirable chemicals; (3) reduce nitrates in the drainage water by enhancing conditions for denitrification; (4) reduce subsidence and wind erosion of organic soils; (5) hold water in channels in forest areas to act as ground fire breaks; and (6) provide water for wildlife and a resting and feeding place for waterfowl.

Practices for Backflow Prevention

■ *o. The American Society of Agricultural Engineers recommends, in standard EP409, safety devices to prevent backflow when injecting liquid chemicals into irrigation systems (ASAE Standards, 1989).*

The process of supplying fertilizers, herbicides, insecticides, fungicides, nematicides, and other chemicals through irrigation systems is known as chemigation. A backflow prevention system will "prevent chemical backflow to the water source" in cases when the irrigation pump shuts down (ASAE, 1989).

Three factors an operator must take into account when selecting a backflow prevention system are the characteristics of the chemical that can backflow, the water source, and the geometry of the irrigation system. Areas of concern include whether injected material is toxic and whether there can be backpressure or backsiphonage (ASAE, 1989; USEPA, 1989b).

Several different systems used as backflow preventers are:

(1) **Air gap.** A physical separation in the pipeline resulting in a loss of water pressure. Effective at end of line service where reservoirs or storage tanks are desired.

(2) **Check valve with vacuum relief and low pressure drain.** Primarily used as an antisiphon device (Figure 2-22).

(3) **Double check valve.** Consists of two single check valves coupled within one body and can handle both backsiphonage and backpressure.

(4) **Reduced pressure principle backflow preventer.** This device can be used for both backsiphonage and backpressure. It consists of a pressure differential relief valve located between two independently acting check valves.

(5) **Atmospheric vacuum breaker.** Used mainly in lawn and turf irrigation systems that are connected to potable water supplies. This system cannot be installed where backpressure persists and can be used only to prevent backsiphonage.

6. Cost Information

A cost of $10 per irrigated acre is estimated to cover investments in flow meters, tensiometers, and soil moisture probes (USEPA, 1992; Evans, 1992). Information from North Carolina indicates that the cost of devices to measure soil water ranges from $3 to $4,500 (Table 2-32). Gypsum blocks and tensiometers are the two most commonly used devices.

For quarter-section center pivot systems, backflow prevention devices cost about $416 per well (Stolzenburg, 1992). This cost (1992 dollars) is for (1) an 8-inch, 2-foot-long unit with a check valve inside ($386) and (2) a one-way injection point valve ($30). Assuming that each well will provide about 800-1,000 gallons per minute, approximately 130 acres will be served by each well. The cost for backflow prevention for center pivot systems then becomes approximately $3.20 per acre. In South Dakota, the cost for an 8-inch standard check valve is about $300, while an 8-inch check valve with inspection points and vacuum release costs about $800 (Goodman, 1992). The latter are required by State law. For quarter-section center pivot systems, the cost for standard check valves ranges from about $1.88 per acre (corners irrigated, covering 160 acres) to $2.31 per acre (circular pattern, covering about 130 acres).

Tailwater can be prevented in sprinkler irrigation systems through effective irrigation scheduling, but may need to be managed in furrow systems. The reuse of tailwater downslope on adjacent fields is a low-cost alternative to tailwater recovery and upslope reuse (Boyle Engineering Corp., 1986). Tailwater recovery systems require a suitable

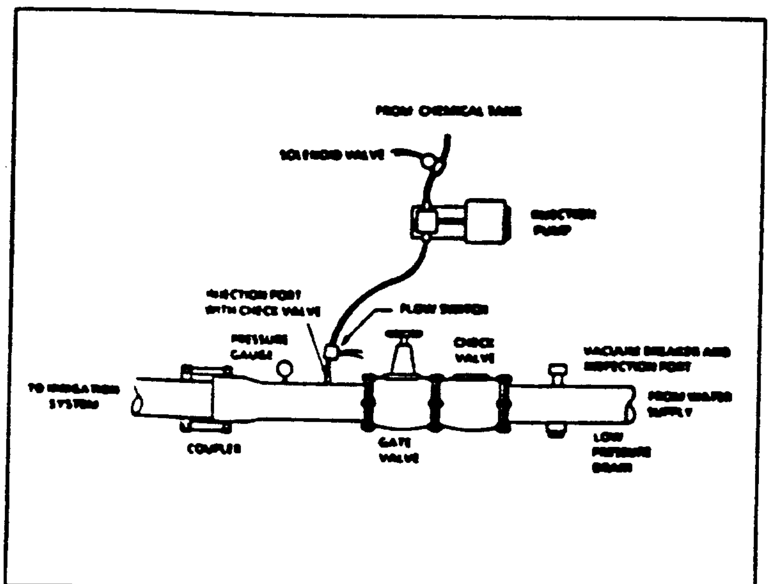

Figure 2-22. Backflow prevention device using check valve with vacuum relief and low pressure drain (ASAE, 1989).

Table 2-32. Cost of Soil Water Measuring Devices

Device	Approximate Cost
Flow meters[a]	$35 to $300, depending on size
Tensiometers[a]	$35 and up, depending on size
Gypsum blocks[a]	$3-4, $200-400 for meter
Neutron Probe[a]	$4,000-4,500
Phene Cell[a]	$4,000-4,500
Flow meters, tensiometers, and soil moisture probes[b]	$10 per irrigated acre

[a] Sneed, 1992.
[b] Evans, 1992.

drainage water receiving facility such as a sump or a holding pond, and a pump and pipelines to return the tailwater for reapplication (Boyle Engineering Corp., 1986). The cost to install a tailwater recovery system was about $125/acre in California (California State Water Resources Control Board, 1987) and $97.00/acre in the Long Pine Creek, Nebraska, RCWP (Hermsmeyer, 1991).

The cost to install irrigation water conservation systems (ASCS practice WC4) for the primary purpose of water conservation in the 33 States that used the practice was about $86.00 per acre served in 1991 (USDA-ASCS, 1992b). Practice WC4 increased the average irrigation system efficiency from 48 percent to 64 percent at an amortized cost of $9.47 per acre foot of water conserved. The components of practice WC4 are critical area planting, canal or lateral, structure for water control, field ditch, sediment basin, grassed waterway or outlet, land leveling, water conveyance ditch and canal lining, water conveyance pipeline, trickle (drip) system, sprinkler system, surface and subsurface system, tailwater recovery, land smoothing, pit or regulation reservoir, subsurface drainage for salinity, and toxic salt reduction. When installed for the primary purpose of water quality, the average installation cost for WC4 was about $52 per acre served. For erosion control, practice WC4 averaged approximately $57 per acre served. Specific cost data for each component of WC4 are not available.

Water management systems for pollution control, practice SP35, cost about $26 per acre served when installed for the primary purpose of water quality (USDA-ASCS, 1992b). When installed for erosion control, SP35 costs about $19 per acre served. The components of SP35 are grass and legumes in rotation, underground outlets, land smoothing, structures for water control, subsurface drains, field ditches, mains or laterals, and toxic salt reduction.

The design lifetimes for a range of salt load reduction measures are presented in Table 2-33 (USDA-ASCS, 1988).

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Table 2-33. Design Lifetime for Selected Salt Load Reduction Measures (USDA-ASCS, 1988)

Practice/Structure	Design Life (years)
Irrigation Land Leveling	10
Irrigation Pipelines - Aluminum Pipe	20
Irrigation Pipelines - Rigid Gated Pipe	15
Irrigation Canal and Ditch Lining	20
Irrigation Field Ditches	1
Water Control Structure	20
Trickle Irrigation System	10
Sprinkler Irrigation System	15
Surface Irrigation System	15
Irrigation Pit or Regulation Reservoir	20
Subsurface Drain	20
Toxic Salt Reduction	1
Irrigation Tailwater Recovery System	20
Irrigation Water Management	1
Underground Outlet	20
Pump Plant for Water Control	15

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III. GLOSSARY

10-year, 24-hour storm: A rainfall event of 24-hour duration and 10-year frequency that is used to calculate the runoff volume and peak discharge rate to a BMP.

25-year, 24-hour storm: A rainfall event of 24-hour duration and 25-year frequency that is used to calculate the runoff volume and peak discharge rate to a BMP.

Acceptable Management System (AMS): A combination of conservation practices and management that meets resource quality criteria established in the FOTG by the State Conservationist that is feasible within the social, cultural, or economic constraints identified for the resource conditions. It is expected that some degradation may continue to occur for the resource after the AMS is applied (Part 506, Glossary, SCS General Manual).

Adsorption: The adhesion of one substance to the surface of another.

Agronomic practices: Soil and crop activities employed in the production of farm crops, such as selecting seed, seedbed preparation, fertilizing, liming, manuring, seeding, cultivation, harvesting, curing, crop sequence, crop rotations, cover crops, strip-cropping, pasture development, and others (Soil Conservation Society of America, 1982).

Aquifer: A geologic formation or structure that transmits water in sufficient quantity to supply the needs for a water development; usually saturated sands, gravel, fractures, and cavernous and vesicular rock (Soil Conservation Society of America, 1982).

ASCS: Agricultural Stabilization and Conservation Service of USDA.

Animal unit: A unit of measurement for any animal feeding operation calculated by adding the following numbers: the number of slaughter and feeder cattle multiplied by 1.0, plus the number of mature dairy cattle multiplied by 1.4, plus the number of swine weighing over 25 kilograms (approximately 55 pounds) multiplied by 0.4, plus the number of sheep multiplied by 0.1, plus the number of horses multiplied by 2.0 (40 CFR Part 122, Appendix B).

AUM: Animal unit month. A measure of average monthly stocking rate that is the tenure of one animal unit for a period of 1 month. With respect to the literature reviewed for the grazing management measure, an animal unit is a mature, 1,000-pound cow or the equivalent based on average daily forage consumption of 26 pounds of dry matter per day (Platts, 1990). Alternatively, an AUM is the amount of forage that is required to maintain a mature, 1,000-pound cow or the equivalent for a one-month period. See *animal unit* for the NPDES definition.

Backflow prevention device: A safety device used to prevent water pollution or contamination by preventing flow of water and/or chemicals in the opposite direction of that intended (ASAE, 1989).

Best Management Practice (BMP): A practice or combination of practices that are determined to be the most effective and practicable (including technological, economic, and institutional considerations) means of controlling point and nonpoint pollutants at levels compatible with environmental quality goals (Soil Conservation Society of America, 1982).

Broiler: Bird that is raised for its meat production; usually produced in a 7-week period.

Center pivot: Automated sprinkler irrigation achieved by automatically rotating the sprinkler pipe or boom, supplying water to the sprinkler head or nozzle, as a radius from the center of the field to be irrigated (Soil Conservation Society of America, 1982).

Chemigation: The addition of one or more chemicals to the irrigation water.

Chemigated water: Water to which fertilizers or pesticides have been added.

Check valve: A device to provide positive closure that effectively prohibits the flow of material in the opposite direction of normal flow when operation of the irrigation system pumping plant or injection unit fails or is shut down (ASAE, 1989).

Composting: A controlled process of degrading organic matter by microorganisms (Soil Conservation Society of America, 1982).

Conservation management system (CMS): A generic term that includes any combination of conservation practices and management that achieves a level of treatment of the five natural resources that satisfies criteria contained in the Field Office Training Guide (FOTG), such as a resource management system or an acceptable management system (Part 506, Glossary, SCS General Manual).

Cover crop: A close-growing crop grown primarily for the purpose of protecting and improving soil between periods of regular crop production or between trees and vines in orchards and vineyards (Soil Conservation Society of America, 1982).

Crop residue: The portion of a plant or crop left in the field after harvest (Soil Conservation Society of America, 1982).

Crop rotation: The growing of different crops in recurring succession on the same land (Soil Conservation Society of America, 1982).

Defoliant: A herbicide that removes leaves from trees and growing plants (USEPA, 1989a).

Denitrification: The chemical or biochemical reduction of nitrate or nitrite to gaseous nitrogen, either as molecular nitrogen or as an oxide of nitrogen (Soil Conservation Society of America, 1982).

Deposition: The accumulation of material dropped because of a slackening movement of the transporting material—water or wind (Soil Conservation Society of America, 1982).

Desiccant: A chemical agent used to remove moisture from a material or object (Soil Conservation Society of America, 1982).

Dike: An embankment to confine or control water, especially one built along the banks of a river to prevent overflow of lowlands; a levee (Soil Conservation Society of America, 1982).

Diversion: A channel, embankment, or other man-made structure constructed to divert water from one area to another (Soil Conservation Society of America, 1982).

Effluent: Solid, liquid, or gaseous wastes that enter the environment as a by-product of man-oriented processes (Soil Conservation Society of America, 1982).

Empirical: Originating in or relying or based on factual information, observation, or direct sense experience.

EPA: United States Environmental Protection Agency.

Erosion: Wearing away of the land surface by running water, glaciers, winds, and waves. The term erosion is usually preceded by a definitive term denoting the type or source of erosion such as gully erosion, sheet erosion, or bank erosion (Brakensiek et al., 1979).

ES: Extension Service of USDA.

Evaporation: The process by which a liquid is changed to a vapor or gas (Soil Conservation Society of America, 1982).

Fallow: Allowing cropland to lie idle, either tilled or untilled, during the whole or greater portion of the growing season (Soil Conservation Society of America, 1982).

Fertilizer: Any organic or inorganic material of natural or synthetic origin that is added to a soil to supply elements essential to plant growth (Soil Conservation Society of America, 1982).

Field capacity: The soil-water content after the force of gravity has drained or removed all the water it can, usually 1 to 3 days after rainfall (Evans et al., 1991c).

Flume: An open conduit on a prepared grade, trestle, or bridge for the purpose of carrying water across creeks, gullies, ravines, or other obstructions; also used in reference to calibrated devices used to measure the flow of water in open conduits (Soil Conservation Society of America, 1982).

Forb: A broad-leaf herbaceous plant that is not a grass, sedge, or rush.

FOTG: USDA-SCS's Field Office Technical Guide.

Grade: (1) The slope of a road, channel, or natural ground. (2) To finish the surface of a canal bed, roadbed, top of embankment, or bottom of excavation (Soil Conservation Society of America).

Grazing unit: An area of public or private pasture, range, grazed woodland, or other land that is grazed as an entity.

Herbaceous: A vascular plant that does not develop woody tissue (Soil Conservation Society of America, 1982).

Herbicide: A chemical substance designed to kill or inhibit the growth of plants, especially weeds (Soil Conservation Society of America, 1982).

Herding: The guiding of a livestock herd to desired areas or density of distribution.

Holding pond: A reservoir, pit, or pond, usually made of earth, used to retain polluted runoff water for disposal on land (Soil Conservation Society of America, 1982).

Hybrid: A plant resulting from a cross between parents of different species, subspecies, or cultivar (Soil Conservation Society of America, 1982).

Hydrophyte: A plant that grows in water or in wet or saturated soils (Soil Conservation Society of America, 1982).

Incineration: The controlled process by which solids, liquid, or gaseous combustible wastes are burned and changed into gases; the residue produced contains little or no combustible material (Soil Conservation Society of America, 1982).

Inert: A substance that does not react with other substances under ordinary conditions.

Infiltration: The penetration of water through the ground surface into subsurface soil or the penetration of water from the soil into sewer or other pipes through defective joints, connections, or manhole walls (USEPA, 1989a).

Insecticide: A pesticide compound specifically used to kill or control the growth of insects (USEPA, 1989a).

Integrated Pest Management (IPM): A pest population management system that anticipates and prevents pests from reaching damaging levels by using all suitable tactics including natural enemies, pest-resistant plants, cultural management, and the judicious use of pesticides, leading to an economically sound and environmentally safe agriculture.

Irrigation: Application of water to lands for agricultural purposes (Soil Conservation Society of America, 1982).

Irrigation scheduling: The time and amount of irrigation water to be applied to an area.

Karst: A type of topography characterized by closed depressions, sinkholes, underground caverns, and solution channels. See *sinkhole* (Soil Conservation Society of America, 1982).

Lagoon: A reservoir or pond built to contain water and animal wastes until they can be decomposed either by aerobic or anaerobic action (Soil Conservation Society of America, 1982).

Lateral: Secondary or side channel, ditch, or conduit (Soil Conservation Society of America, 1982).

Layer: Bird that is used to produce eggs for broilers, new layers, or consumption.

Leachate: Liquids that have percolated through a soil and that contain substances in solution or suspension (Soil Conservation Society of America, 1982).

Leaching: The removal from the soil in solution of the more soluble materials by percolating waters (Soil Conservation Society of America, 1982).

Legume: A member of a large family that includes many valuable food and forage species, such as peas, beans, peanuts, clovers, alfalfas, sweet clovers, lespedezas, vetches, and kudzu (Soil Conservation Society of America, 1982).

Levee: See *dike*.

Limiting nutrient concept: The application of nutrient sources such that no nutrient (e.g., N, P, K) is applied at greater than the recommended rate.

Livestock: Domestic animals.

Load: The quantity (i.e., mass) of a material that enters a waterbody over a given time interval (Soil Conservation Society of America, 1982).

Manure: The fecal and urinary defecations of livestock and poultry; may include spilled feed, bedding litter, or soil (Soil Conservation Society of America, 1982).

Micronutrient: A chemical element necessary in only extremely small amounts (less than 1 part per million) for the growth of plants (Soil Conservation Society of America, 1982).

NOAA: United States Department of Commerce, National Oceanic and Atmospheric Administration.

Nutrients: Elements, or compounds, essential as raw materials for organism growth and development, such as carbon, nitrogen, phosphorus, etc. (Soil Conservation Society of America, 1982).

Parasites: An organism that lives on or in a host organism during all or part of its existence. Nourishment is obtained at the expense of the host (Soil Conservation Society of America, 1982).

Pasture: Grazing lands planted primarily to introduced or domesticated native forage species that receives periodic renovation and/or cultural treatments such as tillage, fertilization, mowing, weed control, and irrigation. Not in rotation with crops.

Percolation: The downward movement of water through the soil (Soil Conservation Society of America, 1982).

Perennial plant: A plant that has a life span of 3 or more years (Soil Conservation Society of America, 1982).

Permanent wilting point: The soil water content at which healthy plants can no longer extract water from the soil at a rate fast enough to recover from wilting. The permanent wilting point is considered the lower limit of plant-available water (Evans et al., 1991c).

Permeability: The quality of a soil horizon that enables water or air to move through it; may be limited by the presence of one nearly impermeable horizon even though the others are permeable (Soil Conservation Society of America, 1982).

Pesticide: Any chemical agent used for control of plant or animal pests. Pesticides include insecticides, herbicides, fungicides, nematocides, and rodenticides.

Pheromone: A substance secreted by an insect or an animal that influences the behavior or morphological development, or both, of other insects or animals of the same species (Soil Conservation Society of America, 1982).

Plant-available water: The amount of water held in the soil that is available to plants; the difference between field capacity and the permanent wilting point (Evans et al., 1991c).

Pollutant: Dredged spoil, solid waste, incinerator residue, sewage, garbage, sewage sludge, munitions, chemical wastes, biological materials, radioactive materials, heat, wrecked or discarded equipment, rock, sand, cellar dirt, and industrial, municipal, and agricultural waste discharged into water (Section 502(6) of The Clean Water Act as amended by the Water Quality Act of 1987, Pub. L. 100-4).

Range: Land on which the native vegetation (climax or natural potential) is predominantly grasses, grass-like plants, forbs, or shrubs. Includes lands revegetated naturally or artificially when routine management of that vegetation is accomplished mainly through manipulation of grazing. Range includes natural grasslands, savannas, shrublands, most deserts, tundra, alpine communities, coastal marshes, wet meadows, and riparian areas.

Reduced-till: A system in which the primary tillage operation is performed in conjunction with special planting procedures to reduce or eliminate secondary tillage operations (Soil Conservation Society of America, 1982).

Residue: See *crop residue*.

Resource Management System (RMS): A combination of conservation practices and management identified by land or water uses that, when installed, will prevent resource degradation and permit sustained use by meeting criteria established in the FOTG for treatment of soil, water, air, plant, and animal resources (Part 506, Glossary, SCS General Manual).

Return flow: That portion of the water diverted from a stream that finds its way back to the stream channel either as surface or underground flow (Soil Conservation Society of America, 1982).

Riparian area: Vegetated ecosystems along a waterbody through which energy, materials, and water pass. Riparian areas characteristically have a high water table and are subject to periodic flooding and influence from the adjacent waterbody.

Root zone: The part of the soil that is, or can be, penetrated by plant roots (Soil Conservation Society of America, 1982).

Runoff: That part of precipitation, snow melt, or irrigation water that runs off the land into streams or other surface water. It can carry pollutants from the air and land into the receiving waters (USEPA, 1989a).

Salinity: The concentration of dissolved solids or salt in water (Soil Conservation Society of America, 1982).

Savannas: A grassland with scattered trees, either as individuals or clumps; often a transitional type between true grasslands and woodland.

SCS: Soil Conservation Service of USDA.

SCS Soils-5 Information: SCS Soil Interpretation Records data base, which contains a wide variety of soil characteristics and interpretations. Available through the Statistical Laboratory, Iowa State University, Ames, Iowa.

Sediment: The product of erosion processes; the solid material, both mineral and organic, that is in suspension, is being transported, or has been moved from its site of origin by air, water, gravity, or ice (USDA-SCS, 1991).

Sedimentation: The process or act of depositing sediment (Soil Conservation Society of America, 1982).

Seepage: Water escaping through or emerging from the ground along an extensive line or surface as contrasted with a spring, where the water emerges from a localized spot (Soil Conservation Society of America, 1982).

Settleable solids: Solids in a liquid that can be removed by stilling a liquid. Settling times of 1 hour (APHA/AWWA/WPFC, 1975) or more are generally used (Soil Conservation Society of America, 1982).

Sheet flow: Water, usually storm runoff, flowing in a thin layer over the ground surface (Soil Conservation Society of America, 1982).

Silage: A fodder crop that has been preserved in a moist, succulent condition by partial fermentation; such crops include corn, sorghums, legumes, and grasses (Soil Conservation Society of America, 1982).

Sinkhole: A depression in the earth's surface caused by dissolving of underlying limestone, salt, or gypsum; drainage is through underground channels; may be enlarged by collapse of a cavern roof (Soil Conservation Society of America, 1982).

Slope: The degree of deviation of a surface from horizontal, measured as a percentage, as a numerical ratio, or in degrees (Soil Conservation Society of America, 1982).

Sludge: The material resulting from chemical treatment of water, coagulation, or sedimentation (Soil Conservation Society of America, 1982).

Soil profile: A vertical section of the soil from the surface through all its horizons, including C horizons (Soil Conservation Society of America, 1982).

Soil survey: A general term for the systematic examination of soils in the field and in laboratories; their description and classification; the mapping of kinds of soil; the interpretation of soils according to their adaptability for various crops, grasses, and trees; their behavior under use or treatment for plant production or for other purposes; and their productivity under different management systems (Soil Conservation Society of America, 1982).

Soil water depletion volume: The amount of plant-available water removed from the soil by plants and evaporation from the soil surface (Evans et al., 1991c).

Surface water: All water whose surface is exposed to the atmosphere (Soil Conservation Society of America, 1982).

Suspended sediment: The very fine soil particles that remain in suspension in water for a considerable period of time (Soil Conservation Society of America, 1982).

Tailwater: Irrigation water that reaches the lower end of a field (Soil Conservation Society of America, 1982).

Tillage: The operation of implements through the soil to prepare seedbeds and rootbeds, control weeds and brush, aerate the soil, and cause faster breakdown of organic matter and minerals to release plant foods (Soil Conservation Society of America, 1982).

Tilth: The physical condition of the soil as related to its ease of tillage, its fitness as a seedbed, and its impedance to seedling emergence and root penetration (Soil Conservation Society of America, 1982).

Topography: The relative positions and elevations of the natural or man-made features of an area that describe the configuration of its surface (Soil Conservation Society of America, 1982).

USDA: United States Department of Agriculture.

Waste: Material that has no original value or no value for the ordinary or main purpose of manufacture or use; damaged or defective articles of manufacture; or superfluous or rejected matter or refuse (Soil Conservation Society of America, 1982).

Watershed: A drainage area or basin in which all land and water areas drain or flow toward a central collector such as a stream, river, or lake at a lower elevation.

Water table: The upper surface of the ground water or that level below which the soil is saturated with water; locus of points in soil water at which the hydraulic pressure is equal to atmospheric pressure (Soil Conservation Society of America, 1982).

Weir: Device for measuring or regulating the flow of water (Soil Conservation Society of America, 1982).

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Appendix 2A

SCS Field Office Technical Guide Policy

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United States Department of Agriculture
Soil Conservation Service
P.O. Box 2890
Washington, D.C.
20013

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February 12, 1990

GENERAL MANUAL
450-TCH
AMENDMENT - 4 (PART 401)

SUBJECT: TCH - SCS TECHNICAL GUIDE POLICY

Purpose. To transmit revised Soil Conservation Service (SCS) Field Office Technical Guide (FOTG) policy.

Effective Date. This policy is effective when received.

Background. SCS Field Office Technical Guide policy was revised by 450-GM, Amendment 3, February 1987. As a result of numerous comments received on that policy, the National Technical Guide Committee (NTGC) prepared a draft revision for review by selected states and by technical guide committees at the National Technical Centers. Amendment 4 is the result of comments on the draft.

Explanation. Policy transmitted by this amendment contains guidance by which FOTG are established, changed and maintained. Following are the more important changes from Amendment 3:

1. State and NTC responsibilities in Section 401.01 for maintaining up-to-date information in technical guides have been amplified.

2. The descriptions of the six resource concerns in Section 401.03(b)(3)(iii) have been replaced with descriptions of the five resources: soil, water, air, plants, and animals.

3. Criteria for treatment required to achieve an RMS for each of the five resources have been clearly stated in Section 401.03(b)(iv).

4. The process for developing criteria for treatment required to achieve an Acceptable Management System (AMS), a new concept, has been stated in section 401.03(b)(3)(v).

5. Explanation of the content of the National Handbook for Conservation Practices (NHCP) in Subpart B has been revised to remove redundant statements and clearly states responsibilities for changes in NHCP and for issuance and review of interim standards.

6. Section V of the FOTG, described in section 401.03(b)(5), has been totally revised and is now named "Conservation Effects." Guidance on effects is provided to aid in conservation planning activities.

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Filing Instructions:

1. Remove and discard existing GM 450, Part 401, dated February 1987. (Amendment 3)

2. Replace with the enclosed GM 450, Part 401, dated January 1990.

Directives Cancelled:

1. Remove and discard National Instruction No. 450-301, dated October 5, 1979.

WILSON SCALING
Chief

Enclosures

PART 401 - TECHNICAL GUIDES

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SUBPART A - POLICY AND RESPONSIBILITIES

401.00 General.

(a) This part states policy for establishing, changing, and maintaining technical guides. It also establishes supporting committees for maintaining those guides.

(b) The Soil Conservation Service (SCS) is responsible for providing national leadership and administration of programs to conserve soil, water, and related resources on the private lands of the Nation. A primary goal is to provide technical assistance to decisionmakers for the planning and implementation of a system of conservation practices and management which achieves a level of natural resource protection that prevents degradation and permits sustainable use. In cases where degradation has already occurred, the goal is to restore the resource to the degree practical to permit sustainable use. Technical guides provide procedures and criteria for the formulation and evaluation of resource management systems which achieve these goals and, when needed, for the formulation and evaluation of acceptable management systems which achieve these goals to the extent feasible.

(c) Technical guides are primary technical references for SCS. They contain technical information about conservation of soil, water, air, and related plant and animal resources. Technical guides used in any office are to be localized so that they apply specifically to the geographic area for which they are prepared. These documents are referred to as Field Office Technical Guides (FOTGs). Appropriate parts of FOTG will be systematically automated as data bases, computer programs, and other electronic-based materials compatible with the Computer Assisted Management and Planning System (CAMPS) are developed.

(d) Technical guides provide:

(1) Soil interpretations and potential productivity within alternative levels of management intensity and conservation treatment;

(2) Technical information for achieving SCS's and the decisionmaker's objectives;

(3) Information for interdisciplinary planning for the conservation of soil, water, and related resources;

(4) A basis for identifying resource management system (RMS) options and, when needed, acceptable management system (AMS) options and components thereof;

(5) Information on effects of resource management systems, acceptable management

systems, and their component practices;

(6) Criteria to evaluate the quality of RMS options, AMS options, and components thereof;

(7) Standards and specifications for conservation practices;

(8) Information for evaluating the economic feasibility of conservation practices and resource management system options;

(9) Information for locating and identifying cultural resources and methods to account for their significance; and

(10) Technical material for training employees.

401.01 Responsibilities.

(a) National Headquarters (NHQ).

(1) The Deputy Chief for Technology has national leadership for policy and procedures for developing and using the FOTG.

(2) The Director, Ecological Sciences Division (ECS), chairs the National Technical Guide Committee (NTGC).

(3) The NTGC makes recommendations to the Deputy Chief for Technology regarding technical guide policy and procedure.

(b) National Technical Centers (NTCs).

(1) NTC directors are responsible for establishing a Technical Guide Committee (TGC) at each NTC.

(2) The TGC provides guidance to states in developing FOTGs.

(3) NTC directors establish procedures to coordinate NTC technical review and concurrence of state developed material that affect either policy or technical aspects in all sections of the FOTG.

(4) The TGC coordinates NTC technical review and concurrence of state developed material as described in (3). The NTC director will inform the state conservationist (STC) of NTC action and comments.

(5) The TGC refers proposed changes in the National Handbook of Conservation Practices (NHCP) to NTGC for action.

(6) NTC provide states with examples of guidance documents for RMS and AMS options, displays of conservation effects, and guidance documents developed to meet specific program requirements. NTC has primary technical oversight.

(7) NTC directors are responsible for coordination and consistency among NTC regions.

(c) State offices.

(1) The state conservationist (STC) is responsible for the development, quality, coordination, use, and maintenance of FOTG in his/her state.

(2) The STC will:

(i) Coordinate FOTG contents across state lines where Major Land Resource Areas are shared to achieve reasonable uniformity between and among states;

(ii) Request appropriate assistance from the NTC director to prepare, revise, and maintain the FOTG and to correlate FOTG contents with adjoining states;

(iii) Submit to the NTC for review and concurrence all state developed materials that affect either policy or technical aspects in all FOTG sections prior to issuance;

(iv) Propose interim standards, variances, or changes in national standards to the NTC director for action;

(v) Establish a state TGC and appoint membership;

(vi) Establish criteria for RMS and AMS with concurrence by the NTC; and

(vii) Establish procedures for maintaining up-to-date data in FOTG. All FOTG material is to be reviewed by the designated state discipline specialist at least once every two years. Material is to be updated as necessary to maintain technical adequacy. Each technical guide subsection described in section 401.03(b) is to contain a table of contents showing the issue date and the date of the last review.

(d) Area offices.

(1) The area conservationist (AC) will:

(i) Coordinate the development, use, and maintenance of FOTG in the field offices supervised;

(ii) Work with the specialists in the state offices to achieve high-quality FOTG; and

(iii) Establish an area-level TGC if necessary.

(e) Field offices.

(1) District conservationists (DC) will:

(i) Take the lead to develop and assemble the FOTG;

(ii) Use and maintain the FOTG in the office(s) they supervise;

(iii) Ensure that all field office technical assistance is based on FOTG contents;

(iv) Identify needed changes and/or additions; and

(v) Request specialist help to make improvements.

(2) All field office employees are responsible for identifying the need for improvements and for informing the DC of those needs.

401.02 National Technical Guide Committee (NTGC).

(a) Membership. The members of the NTGC are:

(1) Director, Ecological Sciences Division (chairperson);
(2) Director, Engineering Division;
(3) Director, Economics and Social Sciences Division;
(4) Director, Soil Survey Division;
(5) Director, Land Treatment Program Division;
(6) Director, Conservation Planning Division;
(7) Director, Watershed Projects Division;
(8) Director, Basin and Area Planning Division;
(9) Director of an NTC (on a 1-year rotation);
(10) Executive Secretary (appointed by the chairperson); and
(11) Chair of National Conservation Practice Standards Subcommittee (NCPSS) (appointed by the NTGC chairperson).
(12) A representative from the Extension Service will be invited to participate in all NTGC meetings.

(b) Responsibilities.

(1) Keep national FOTG policy and procedures current by recommending policy changes to the Deputy Chief for Technology.

(2) Respond to requests for FOTG policy and procedure clarification.
(3) Designate members of the National Conservation Practice Standards Subcommittee.
(4) Act upon recommendations from NCPSS.
(5) Coordinate policy and procedures established to automate FOTG contents and functions in SCS operations.
(6) Create ad hoc subcommittees as necessary.
(7) Receive and act upon requests, recommendations, referrals, and suggestions from the NTC TGC.

(c) NTGC operation.

(1) NTGC will meet quarterly and otherwise as convened by the chairperson.
(2) Materials for consideration by the NTGC will be sent to the chairperson.
(3) Minutes of each meeting will be sent to each member, the Deputy Chiefs for Technology and Programs, and NTC directors.
(4) Matters requiring action will be acted upon within 45 days of receipt.

401.03 Content of technical guides.

(a) Technical guides contain Sections I through V and appropriate subsections. Those sections are:

(1) Section I - General Resource References;

(2) Section II - Soil and Site Information;

(3) Section III - Conservation Management Systems;

(4) Section IV - Practice Standards and Specifications; and

(5) Section V - Conservation Effects.

(b) The following are descriptions of technical guide sections and subsections:

(1) Section I - General Resource References.

This section lists references and other information for use in understanding the field office working area or in making decisions about resource use and management systems. The actual references listed are to be filed to the extent possible in the same location as the FOTG. References kept in other locations will be cross-referenced. The following are subsections of Section I of the FOTG.

(i) Reference lists. These include handbooks, manuals, and reports commonly used in resource conservation planning and implementation activities such as irrigation and drainage guides; the *National List of Scientific Plant Names* (NLSPN); the *National Register of*

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Historic Places; published soil surveys; basic water resources information on ground water quality, surface water quality, and water quantity; recreation potential appraisals; natural resource inventories; reports that identify such items as areas susceptible to flooding; river basin reports; seismic zones; and documentation of useful computer models.

(ii) **Cost data.** General reference data on costs, such as cost lists for practice components.

(iii) **Maps.** The SCS National Planning Manual (NPM), Part 507, Exhibits 507.09, contains a list of resource maps that should be included. Water quality problem areas and areas with a potential water quality problem are to be included here.

(iv) **Erosion prediction.** Guidance, data, and SCS approved techniques for predicting soil erosion are to be included here, or appropriately referenced.

(v) **Climatic data.** This subsection contains local climatic data needed for planning conservation management systems and installing conservation practices, such as record low and high temperatures; averages for such items as rainfall, length of growing season, temperatures, wind velocities, hail incidence, and snowfall; water supply data; probability of receiving selected amounts of precipitation by months; and frost-free periods. References should be made to other climatic data in other field office documents.

(vi) **Cultural (archaeological and historic) resource information.** This subsection contains general locational data and documentation suitable for inventory, checking and recording, and conservation planning. The law states that specific locational information, such as site maps, is not to be available to the general public; therefore they should only be referenced in this subsection.

(vii) **Threatened and endangered species list.** This subsection contains information on species of plants and animals that are threatened and endangered and are to be accounted for in conservation planning.

(viii) **Laws.** List of state and local laws, ordinances, or regulations that impact Conservation Management System development and other technical applications such as conservation practice application.

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(2) Section II - Soil and Site Information.

Information from the State Soil Survey Database (3SD) will be used as the basis of this section. The 3SD contains current information on soils and their basic interpretations as tailored from the Soil Interpretations Records (SCS-SOI-5). Detailed interpretations of soils will be provided in Section II by state and area specialists.

Interpretations are specific to the soils identified and mapped in the area. Map units to which the interpretations apply are clearly identified by name, symbol(s), or both. New map unit names and symbols resulting from reclassification of soils are cross-referenced to old names and symbols and shown on a list.

Soils are to be described and interpreted to help make decisions about use and management of land. Soil characteristics that limit or affect land use and management are to be identified, and soils are to be rated according to limitations, capability, suitability, and/or potential.

This information may be available in published soil surveys or in the State Soil Survey Database (3SD). A copy of the appropriate sections of soil surveys can be included in the applicable subsections, or reference can be made to the source document maintained in the field office.

The following are subsections of Section II of the FOTG.

(i) Soils legend. This list includes the names of the soil map units and, for each unit, the identification of interpretive groups (if any) of importance in the field office. For map units having two or more soils in their name, interpretive groups are identified for each soil. Where appropriate, the map unit is placed in a group that generally controls the use and management of the area.

If soil surveys of more than one vintage are used, the symbols used in each are to be identified along with appropriate interpretive groups. For remapped areas, only the legend for the most recent mapping is to be used.

(ii) Soil descriptions.

(A) Nontechnical soil descriptions for use with individuals, groups, and units of government are included. Brief references to major limitations e.g., erosion or wetness, and soil potential are a part of each description. Basic information needed to develop these descriptions is in the soil map unit descriptions and in the State Soil Survey Database (3SD).

(B) Technical descriptions of each soil series and of each soil map unit are provided in this section or available in the field office. If such descriptions are maintained as separate material, the source document should be listed here as a reference.

(iii) Detailed soil interpretations. These will be supplied by appropriate technical specialists for all land uses in the field office area. Examples follow:

(A) Cropland interpretations. These include soil interpretive information needed for plant adaptations, yield estimates, and the lists of soil map units that meet the soil requirements for prime farmland and highly erodible land. Interpretations are presented by land capability units, erodibility index, and soil map units in narrative or tabular form as appropriate. Where land capability unit or erodibility index is used, a list of all soil map units in each capability unit or erodibility index is included.

(B) Rangeland, grazed forest land, and native pasture interpretations. The required content of range and native pasture interpretive groupings is outlined in the National Range Handbook. All soils used as rangeland are to be placed in appropriate range sites. Range site descriptions and condition guides for rangeland are included. Grazed forest land and native pasture groupings include references to individual soils, grazing groups, or woodland suitability groups. Interpretations may be presented by individual soil map units or by groups of soil map units.

(C) Forest land interpretations. These are presented by individual soils or by woodland suitability groups (WSG). These interpretations include the woodland class symbol that denotes potential productivity for the indicator species in wood per cubic meters per hectare. Site index and annual productivity estimates in cubic feet per acre, board feet per acre, and/or cords per acre may also be provided for important tree species. The subclass indicates the primary soil or physiographic characteristic that contributes to important hazards or limitations in management. Site index information is also provided for important tree species.

(D) Nonagricultural interpretations. Nonagricultural uses include commercial development, subdivision development, industrial related development, roads and other transportation and transmission systems, and other land uses important to the area.

(E) Recreation interpretations. These include the ratings of soils for recreation uses.

(F) Wildlife interpretations. These are presented by wildlife habitat elements with descriptions of each element.

(G) Pastureland and hayland interpretations. These are arranged by pastureland and hayland suitability groups, capability units, other groupings, or soil map units.

(H) Mined land interpretations. These include interpretations which dictate the limitation to reclamation, revegetation, and maintenance for the different types of mined land.

(I) Windbreak interpretations. These interpretations are made by individual soils or by windbreak suitability groups (WISG). Interpretations provided by the WISG include the soil-adapted species recommended, the predicted height growth in 20 years, and the soil-related limitations.

(J) Engineering interpretations. These include engineering properties, indices, and soil interpretations for engineering uses and practices.
(K) Waste disposal interpretations. These are interpretations related to the suitability of soils for disposal of organic and inorganic wastes.

(L) Water quality and quantity interpretations. These are interpretations related to soil properties affecting water quantity and quality problems and treatments. Included are soil-pesticide interactive ratings and soil ratings for nitrates and soluble nutrients.

(M) **Hydric soils interpretations.** These are interpretations related to the identification and use of wetlands.

(3) Section III - Conservation Management Systems.

The function of SCS is to provide technical assistance to decisionmakers to protect, maintain, and improve soil, water, air, and related plant and animal resources. This section provides guidance for developing resource management systems (RMS) and acceptable management systems (AMS) for a resource area to prevent or treat problems and take advantage of opportunities associated with these resources. This section includes a description of considerations important in conservation planning of soil, water, air, and related plant and animal resources.

(i) **An RMS achieves the goal of preventing resource degradation and permitting sustainable use as stated in 401.00 (b).** An RMS is achieved if criteria for soil, water, air, and related plant and animal resources are met as defined in Section 401.03(b)(3)(iv). This section describes either national criteria or considerations that must be addressed in developing state criteria for achieving an RMS that solve identified onsite and offsite resource problems using best available technology. The concept and use of RMS is defined in the SCS National Planning Manual (NPM). RMS are not to be confused with "conservation systems," as defined in 7 CFR Section 12.2 for treatment of highly erodible land. A conservation system for Food Security Act purposes is an erosion reduction component of an RMS for cropland.

(ii) **SCS helps decisionmakers plan and apply conservation management systems to prevent and/or solve identified onsite and offsite resource problems or conditions and to achieve the decisionmaker's and public objectives.** SCS identifies and documents decisionmaker's objectives, consistent with land capability and sound environmental principles, as part of element 3 (Determining objectives) of the planning process (reference: National Planning Manual). SCS identifies and documents resource problems or conditions as part of element 4 (Providing resource inventory data) of the planning process. As part of element 6 (Developing and evaluating conservation alternatives), information on conservation effects is used to provide suitable options for addressing the decisionmaker's and public objectives.

(iii) **The five resources are soil, water, air, plants, and animals.** Each resource has several considerations important in conservation planning. Additional considerations in a specific state may need to be added to account for wide variations in soils, climate, or topography. A description of the main considerations for each resource follows:

(A) Soil. Considerations for the soil resource are erosion, condition, and deposition.

[1] Erosion. This consideration deals with one or more of the following types or locations of erosion: sheet and rill, wind, concentrated flow (ephemeral gully and classic gully), streambank, soil mass movement (land slips or slides), road bank, construction site, and irrigation-induced. All of these forms of erosion that are identi fied on the site to be planned need to be dealt with in developing treatment options.

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[2] Condition. This consideration deals with the chemical and physical characteristics of soil as related to its ease of tillage, fitness as a seedbed, and ability to absorb, store, and release water and nutrients for plants. Aspects of this consideration will improve soil tilth, which reduces soil crusting and compacting; optimize water infiltration; optimize soil organic material; enhance beneficial soil organisms and biological activity; reduce subsidence; and minimize effects of excess natural and applied chemicals and elements such as salt, selenium, boron, and heavy metals. This consideration also deals with the proper and safe land application and utilization of animal wastes, other organics, nutrients, and pesticides.

[3] Deposition. This consideration deals with onsite or offsite deposition of products of erosion, which includes sediment causing damages to land, crops, and property, such as structures and machinery. This consideration also deals with safety hazards and decreased long-term productivity.

(B) Water. Considerations for the water resource are quantity and quality.

[1] Quantity includes:
• proper disposal of water from overland flows or seeps, both natural and man-made;
• management of water accumulations on soil surfaces or in soil profiles and vadose zones;
• optimization of irrigation and precipitation water use;
• dealing with other problems relating to irrigation — water mounding, water supply and distribution, increasing or decreasing water tables;
• management of deep percolation, runoff, and evaporation;
• water storage;
• management of water for wetland protection; and
• sediment deposition in lakes, ponds, streams and reservoirs, and restricted water conveyance capacity.

[2] Quality includes:
• reducing the effects of salinity and sodicity;
• minimizing deep percolation of contaminated water which will lead to unacceptable levels of pollutants in the underlying ground water;
• maintaining acceptable water quality;
• minimizing offsite effects including ground water contamination by pesticides, nutrients, salts, organics, metals and other inorganics, and pathogens; contamination of surface water (streams and lakes) by sediment, pesticides, nutrients, salts, organics, metals and other inorganics; pathogens; fecal coliform; and high temperature;
• reducing the quantity of sediment;
• improving the quality of sediment;
• ensuring that all waters will be free from substances attributable to man-caused nonpoint source discharges in concentrations that:

*settle to form objectionable deposits;
*float as debris, scum, oil or other matter to form nuisances;

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•produce objectionable color, odor, taste, or turbidity;

•injure, are toxic to, or produce adverse physiological or behavior responses in humans, animals, or plants; or

•produce undesirable aquatic life or result in the dominance of nuisance species.

(C) **Air.** This resource deals with onsite and offsite airborne effects of undesirable odors, windblown particulates, chemical drift, temperature, and wind.

(D) **Plants.** The considerations for the plant resource are suitability, condition, and management.

[1] **Suitability includes:**
- plant adaptation to site; and
- plant suitability for intended use.

[2] **Condition includes:**
- productivity, kinds, amounts, and distribution of plants; and
- health and vigor of plants.

[3] **Management includes:**
- establishment, growth, and harvest (including grazing) of plants;
- agricultural chemical management (pesticides and nutrients); and
- pest management (brush, weeds, insects, and diseases).

(E) **Animals.** This includes wild and domestic animals, both terrestrial and aquatic. The considerations for the animal resource are habitat and management.

[1] **Habitat includes:**
- food;
- cover or shelter; and
- water.

[2] **Management includes:**
- population and resource balance; and
- animal health.

(iv) **Criteria for treatment required to achieve an RMS will be established by SCS.** They are to be stated in either qualitative or quantitative terms for each resource consideration. Where national criteria have not been established, the state conservationist will establish criteria with concurrence by the NTC. Where state and/or local regulations establish more restrictive criteria, these must be used in developing criteria for state and local programs. For example, some state and/or local regulations have established criteria for offsite control of water quality.

(A) **Soil.** Following are the criteria for this resource:

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[1] Erosion.

• Estimated sheet and rill or wind erosion rates are reduced to the level that long term soil degradation is prevented and a high level of crop productivity can be sustained economically and indefinitely.

• Erosion from ephemeral or similar gullies is reduced to a level which permits efficient farming operations and sustains long term productivity.

• Irrigation-induced erosion is reduced to a level that sustains long term productivity.

• Other forms of erosion, such as classic gullies, streambank, roadbank, and land-slides, that are identified as needing treatment (and are within the ability of the decisionmaker to treat), are reduced to the degree necessary to protect the resources or threatened man-made improvements.

[2] Condition.

• Soil tilth is maintained or improved;

• Crop production practices return adequate residue within the rotation cycle;

• Soil compaction by machinery, livestock, or other traffic is minimized;

• Water infiltration is optimized so as not to increase sheet and rill erosion;

• Wind forces and soil blowing are controlled below the crop tolerance level of young seedlings;

• Toxic chemicals affecting soil and plants are controlled to levels sufficient to prevent soil degradation and are below the tolerance of adapted crops;

• Application and utilization of animal wastes and other organics are at a rate that the soil, soil microbes and bacteria, and the plant community can assimilate, degrade, or retain the various materials.

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[3] Deposition.

• Where existing or potential onsite or offsite deposition problem(s) are identified, the practices applied to the contributing land resolve the identified deposition problem(s).

• State and/or local governments may establish criteria in response to identified deposition problems. These criteria will be used to determine the adequacy of an RMS with regard to offsite effects. This may require the establishment of more restrictive criteria for one or more of the resources to alleviate the problem. Local public perception of an acceptable level could be used where no standards have been established.

• When disposal of animal wastes and other organics is needed, it shall be done in a manner that maintains or enhances the natural resources.

(B) **Water.** In developing criteria for this resource, the state conservationist is to address:

[1] **Quantity.**

• Overland flows and subsurface water conveyed by conservation practices are safely conducted and disposed of through acceptable outlets.

• Water system discharges going from one ownership to another ownership are not changed from natural flow pathways unless needed land and/or water rights have been obtained consistent with local, state, and Federal regulations.

• Water quality aspects associated with outlets are accounted for.

• Appropriate water storage requirements are in accordance with the needs of the planned use.

• Drainage activities are consistent with SCS policy regarding wetland protection.

• For irrigated land, a minimum percentage level of efficiency is achieved or exceeded for each type of irrigation system and management, as stated in the SCS state irrigation guide.

• For land under supplemental irrigation where adequate water supplies exist, or for land under partial irrigation because of water deficiency or lack of seasonal availability or frequency of availability of water, water is applied in the most effective manner, so that the infiltration rate of the soil, the plant needs, and the soil water-holding capacity are not exceeded.

• Vegetation, cropping sequences, and cultural operations are managed for efficient use of precipitation by minimizing water losses to runoff and evaporation, thereby inducing positive effects on the plant-soil moisture relationship, on ground water recharge, and on water yield downstream.

[2] **Quality.**

• Sediment movement is controlled to minimize contamination of receiving waters.

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• Percolation below the root zone is managed to minimize contamination of the percolating water and to minimize the negative effects on production.

• Water used for salt leaching and plant temperature modification is applied to minimize adverse effects.

• Acceptable water temperature is maintained.

• Irrigation water and natural precipitation are managed to minimize the movement of nutrients, pesticides, sediment, salts, and animal wastes to offsite surface and ground water.

• Water-based uses, such as aquaculture enterprises and water-based recreation facilities maintain or improve environmental quality.

• Where surface or ground water nutrient and/or pesticide problems or potential problems exist, the selection of appropriate nutrients or pesticides and the timing, chemical forms, and rate and method of application reduce adverse effects. The use of pesticides and nutrients with high potential for polluting water are avoided where site limitations, such as slope, depth to ground water, soil, and material in the vadose zone or aquifer could allow that potential to be realized. Soil-pesticide interactive ratings to identify potential problem situations from surface runoff and/or leaching are used according to FOTG guidelines. Alternative practices or other pest control methods (mechanical, cultural, or biological) or integrated methods are recommended where site limitations exist that increase the probability of degrading water supplies, either below the surface or downstream.

• Agricultural chemical containers and chemicals (including waste oil, fuel, and detergents) are used, handled, and disposed of in compliance with Federal, state, and local laws.

(C) Air. Criteria established by the state conservationist are to address the following onsite and offsite considerations:

• Airborne particulates from agricultural sources do not cause safety, health, machinery, vehicular, or structure problems.

• Local and state regulations are followed in minimizing undesirable odors from agricultural sources.

• Air movement and temperatures are modified when necessary using appropriate vegetative or mechanical means.

• Chemical drift from the application of agricultural chemicals is controlled by adherence to local and state application recommendations and product labels.

(D) **Plants.** Criteria established by the state conservationist are to address the following considerations:

- Plants on all land uses are used, maintained and improved to achieve acceptable production levels to meet conservation, environmental, decisionmaker, and public objectives.

- Nutrient applications for any land use are based on plant nutrient requirements, production requirements, soil test recommendations, soil fertility, soil potential limitations, water budget, and the types of practices planned. Nutrients from all sources (animal waste, crop residue, soil residual, commercial fertilizer, atmospheric-fixed) are considered when calculating the amount of nutrients to apply. Timing, method, and rate of application, and chemical forms of nutrients to be applied are taken into consideration in planning practices.

- Pesticide applications for any land use are applied according to the label recommendation and federal, state, and local regulations.

- On Cropland, crops are grown in a planned sequence that meets conservation, production, and decisionmaker objectives; and weeds, insects, other pests, and diseases are adequately treated.

- On Hayland, dominant native or introduced plant species are appropriate for the forage, agronomic, or commercial use; well adapted to the site; and their stand density is maintained or improved.

- On Native Pasture, herbaceous plants are properly grazed, forage value rating is medium or better, vigor is strong and is commensurate with overstory canopy.

- On Pastureland, dominant plant species are appropriate for the use, adapted to the site, and their stand density is adequate and productivity is maintained or improved.

- On Rangeland, the plant community is managed to meet the needs of the plants and animals in a manner to conserve the natural resources and meet the objectives of the decisionmaker. As a general rule, rangeland in poor or fair ecological range condition is managed for an upward range trend, and rangeland in good or excellent ecological range condition will be managed for a static or upward range trend. In some special situations, poor or fair ecological range condition could be managed for a static range trend to meet special objectives of the decisionmaker as long as there is no degradation of the soil resource.

- On Forest Land, trees are well distributed, vigorous, relatively free of insects, disease, and other damage, and the density of the stand is within 25% of forest stand density guide spacing on a stems-per-acre basis for the particular forest types. Forest Land shall be protected from wildfires and erosion. Forest Land that is grazed shall also be managed to meet the needs of the forage plants, the animals, and the objectives of the decisionmaker.

• On Wildlife Land, Recreation Land, and Other Land, adapted or native plants are of sufficient quantity and quality to improve or protect the defined resource.

• On Urban Land uses, soil cover is maintained using suitable plants or other cover to keep soil erosion within acceptable limits, minimize runoff, and manage infiltration.

(E) Animals. Criteria established by the state conservationist are to address the following considerations:

• The adaptation, kinds, amounts, distribution, health, and vigor of livestock and wildlife are appropriate for the site.

• Adequate quality, quantity and distribution of food are provided for the species of concern.

• Adequate quantity, quality and distribution of wildlife cover for the species of concern are provided. Domestic animals are provided adequate shelter as needed.

• Adequate quantity, quality and distribution of water are provided for the species of concern.

• The decisionmaker's enterprise and the balance between forage production and livestock needs are appropriate.

• Domestic livestock are managed in a manner that meets the needs of the ecosystem, the animal, and that accomplishes the goals and objectives of the decisionmaker.

• Animal wastes and other organic wastes are managed according to an animal waste management plan developed according to SCS standards. Minimum quality criteria are met when the animal waste management plan is applied. Where surface and ground water problems exist from organic waste, bacteria, pathogens, microorganisms, or nutrients, special design considerations for each component will be necessary to eliminate further contamination of runoff or leachates.

(v) An AMS will be established for a resource area in the event that social, cultural, or economic characteristics of the area prevent the feasible achievement of an RMS. An AMS is achieved when soil, water, air, and related plant and animal criteria for the related resource use are established at the level which is achievable in view of the social, cultural, and economic characteristics of the resource area involved.

(A) Social, cultural, and economic considerations are used to establish the level of natural resource protection obtainable and may constrain the resource criteria used in formulating an

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RMS. Criteria for treatment required to achieve an AMS will be established by SCS. They are to be stated in either qualitative or quantitative terms for each resource consideration. The state conservationist will establish criteria with concurrence by the NTC. Some of these criteria are prescribed by law or statute; e.g., the National Historic Preservation Act. Others are developed through an onsite assessment of social, cultural, and economic factors which define the reasonable and practical degree to which the resource criteria can be achieved. Where regional, state and/or local regulations establish more restrictive criteria, these must be used.

(B) The following criteria are applied to determine the practical limits of resource protection within a resource area and temper the resource criteria to be used in the formulation of an AMS.

(1) Social
- Public health is maintained or improved.
- Treatment level is compatible with community characteristics.
- Treatment level is compatible with clientele characteristics.

(2) Cultural
- Protection of cultural resources is consistent with GM 420, Part 401.

(3) Economic
- Treatment level reflects the ability to pay that is representative of the area.
- Inputs required for conservation treatment are readily available.
- Conservation treatment is consistent with government program participation.

(vi) Additional considerations useful in the planning process to screen or select suitable conservation treatments for individual decisionmakers may include legal, social, cultural, economic, aesthetic, management, and other factors. These are integral to the planning process and are discussed in the National Planning Manual and are displayed in Section V.

(vii) Applications of RMS and AMS Criteria

(A) Several factors may affect the actual level or degree of treatment achieved at a point in time or that is required to be achieved by the decisionmaker. Without legal constraints, the differing cultural, social or economic situation of a decisionmaker usually determines the degree of treatment planned or attained at any point in time. Where an RMS or AMS is not attainable during the present planning effort, the progressive planning approach in NPM 501.04 (d) may be used to ultimately achieve planning and application of an RMS or AMS. Progressive planning is the incremental process of building a plan on part or all of the planning unit consistent with the decisionmaker's ability to make decisions over a period of time. The progression on individual planning units is always toward the planning and implementation of an RMS.

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(B) Legislated programs usually have varying authorities and qualifying criteria that may require more or less treatment than RMS or AMS criteria. An example is legislated practices for improving water quality. In this case, the related program manual will establish the criteria to be achieved. These applications must be coordinated across county and state lines and should be for the period of time specified in the law or in the related policies and procedures.

(C) The opportunity for establishing an RMS to achieve the non-degradation and sustainable use goal should be evaluated when ownership, land use, or cropping system changes, or when new technology becomes available.

(D) Decisionmakers may desire to plan treatment in addition to that required to meet RMS or AMS criteria to enhance resource conditions or to serve secondary or tertiary uses or objectives. This additional treatment may include conservation practices or management that contribute to further improvement of water quality; increased production, drainage, or irrigation; enhancement of cultural and environmental values, wildlife habitat, or aesthetics; or improved health and safety.

(viii) RMS, AMS, or other guidance documents will be developed by major land use in the field office area and placed in Section III of each FOTG.

(A) Only enough guidance documents to show examples of the RMS and AMS options to treat the most common identified resource problems for each locally applicable major land use will be developed. NTC will provide specific examples of format for guidance to states in the preparation of guidance documents. Guidance documents are to be developed by states for each FOTG using the NTC format. Guidance documents are to have concurrence of the NTC. NTC directors are to coordinate formats across NTC boundaries.

(B) Guidance documents will present a reasonable number of alternative combinations of practices and management that will meet the criteria for solving resource problems common to that land use.

(C) In developing guidance documents, the effects that alternative practices and combinations of practices and management have on the five resources and on the social, economic, and cultural considerations are to be used. For each guidance document developed, a display of effects of the conservation system should be included in Section V. Guidance on the development and display of effects is provided in Section 401.03(b)(5).

(D) Guidance documents may need to be developed to meet specific program requirements, in which case they are to be clearly labeled to show the program(s) or provision(s) of law to which they apply. These guidance documents may describe management actions in addition to conservation practices that can be carried out to achieve these program purposes.

(ix) Conservation practices are to be installed according to SCS practice standards and specifications. Practice standards and specifications are the same for both RMS and AMS.

(4) Section IV - Practice Standards and Specifications

(i) This section of FOTG contains conservation practice standards and specifications.

(ii) The first item of Section IV is an alphabetical list of conservation practices used by the field office, followed by the practice standards and specifications in the same order. This list will include the date of preparation or revision of each standard, supplement, specification, and interim standard in effect. This list will also show the date of the last review. This list will be revised and reissued each time a change is made in a conservation practice standard, supplement, or specification. See section 401.01(c)(2)(vii).

(iii) Practice standards establish the minimum level of acceptable quality for planning, designing, installing, operating, and maintaining conservation practices. Standards from the National Handbook of Conservation Practices (NHCP) and interim standards are to be used, and will be supplemented by states as needed.

(iv) Practice specifications describe requirements necessary to install a conservation practice so that it functions properly. For most practices in the NHCP, it is necessary to prepare state specifications to fit local soil and climatic conditions. Specifications include some or all of the following: major elements of work to be done; kind, quality, and quantity of materials to be used; essential details of installation; and other technical instructions necessary for installing and maintaining the practice.

(v) See **Part 401 - Subpart B** for policy and procedural details for standards and specifications.

(5) Section V - Conservation Effects

(i) The purpose of this section is twofold:

(A) The first purpose is to provide a repository of data on the effects of conservation activities. Such data are an important part of technical reference material used by SCS and decisionmakers in planning conservation actions. SCS determines the effects of conservation treatments in order to help formulate and facilitate the identification of suitable conservation management systems to protect the resource base and to address the decisionmaker's and society's social, cultural, and economic objectives. The concept of using conservation effects in the decisionmaking process (CED) is elaborated in the National Planning Manual.

(B) The second purpose of this section is to serve as a source of appropriate procedures and methods for collecting, analyzing, and displaying conservation effects data.

(ii) Conservation effects information will typically include the resource setting (i.e., soil, slope, etc.), the specific conservation treatments applied, the kinds, amounts, and timing of actions undertaken by decisionmakers in their operations, and the expected outcome in terms of solving resource problems and meeting social, cultural, and economic objectives.

(A) Effects of conservation may be expressed in either narrative or quantitative terms that represent factual data on experienced or expected results of the specified conservation treatment as applied to the resource setting. Effects of conservation will normally be expressed as a condition or stage of the factors associated with a specified conservation action. For example, typical effects could be: a corn yield of 110 bushels per acre; a USLE erosion rate of 4 tons per acre; irrigation efficiency of 60%; or "a significant reduction in ephemeral gully erosion will occur with this treatment." "Impacts" is a closely related term. An impact is a measure of the change between the stage or condition of one treatment alternative to another. Guidance on the use of effects information in the conservation planning process is contained in the National Planning Manual.

(B) To the extent possible, conservation effects information will include conservation treatments on the five resources and their considerations as described in Section III above.

[1] Examples of effects of conservation treatment on the five resources include but are not limited to:

- Expected effect on sheet and rill, wind, or ephemeral gully erosion.
- Indicators or measures of soil conditions, such as tilth, compaction, and infiltration.
- Where applicable, indicators of soil deposition.
- Measures or indicators of effects on quality and quantity of surface or subsurface waters, such as chemical runoff as influenced by the conservation system.
- Effects on plant conditions and management, such as expected status of range conditions with the indicated range conservation actions.
- Measures of conservation effects on wild and domestic animals, including animal waste uses and effects on the resource base.
- Indicators of effects on air, such as airborne particulates, odors, and chemical drift.

[2] Effects information will also include management, social, cultural, and economic information. Factors such as cost, client acceptability, and physical changes to cultural resource sites associated with the specific conservation treatment component are to be identified. Included, for example, would be:

- Tillage requirements, labor inputs, quantity and costs of inputs, net economic returns, experienced yields, risk management requirements, operation and maintenance requirements, time requirements, cultural resources (archaeological and historic properties), length of life of practices, health and safety, aesthetics, and community effects.

(C) Information developed on conservation effects will vary significantly in scope and detail depending on the resource conditions in the local area as well as upon the needs for technical reference materials to carry out conservation activities in that location.

(iii) Section V of the FOTG should contain summaries of effects data relevant to the field office area. As a minimum, Section V should contain a display of the important effects for decisionmaking for each of the RMS and AMS developed and inserted in Section III. The display should be cross referenced with cropping system, soil map units, and other descriptions of the resource setting and conditions (e.g., precipitation, slope, etc.) that the RMS or AMS was formulated to address in that field office. The format of the display should be easily understandable so as to make the information valuable as ready reference material for the conservation planner and decisionmaker to facilitate planning and decisionmaking. The display will show the degree of resource protection achieved.

(A) Options may be evaluated by simply comparing the differences in the effects of the options.

(B) NTC will provide specific examples of format guidance to states for recording and displaying conservation effects data.

(C) Collection of data on conservation effects is a long term effort to be undertaken as part of the followup element in the planning process. Initial efforts may provide effect information for only the most common situations. Over time, additional resource situations and treatment alternatives will be examined to add depth and breadth to the available conservation effect information.

(D) Information on conservation effects may be refined or updated over time as needed in the local area. The data on conservation effects should be useful to field office personnel in identifying suitable conservation treatment applicable to the area, and serves as technical reference materials when working with decisionmakers in the conservation planning process. (See National Planning Manual Section 508.01).

(iv) Data on conservation effects may be developed by following two general approaches:

(A) The observation and documentation of the experiences of cooperators. Typically, conservationists will make observations of conservation treatments applied by one or more decisionmakers in the first or second year following the application and record the effects experienced. This data can be recorded in conservation field notes and be entered into CAMPS databases. Effects information may also be available from conservation field trials, university research plots, or other trials in the area.

(B) Models of processes impacted by conservation actions can be used to simulate the physical, agronomic, or other effects of treatment systems. Actual results or graphs summarizing results could be developed by state staffs and provided to field offices for inclusion in FOTG. Appropriate models or references to the appropriate models may be stored in FOTG Section V to facilitate use in collecting and analyzing conservation effects data.

(v) Data relating effects of conservation practices on the five resources may be displayed in tabular, narrative, or matrix form. This will be useful in developing RMS or AMS for inclusion in FOTG Section III.

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SUBPART B — NATIONAL HANDBOOK OF CONSERVATION PRACTICES

401.10 Purpose.

This subpart sets forth SCS policy for establishing and maintaining a National Handbook of Conservation Practices (NHCP). It also includes directions for variances, changes, interim standards, and adaptations of standards to state and local conditions.

401.11 Content.

(a) The NHCP establishes a national standard for each conservation practice, including:

(1) The official name, definition, code identity, and unit of measurement for the practice;

(2) A concise statement of the scope, purposes (including secondary purposes), conditions where the practice applies, and planning considerations for the practice; and

(3) Criteria for the practice.

(b) For some conservation practices, the NHCP also establishes items for inclusion in state-developed specifications.

(c) The NHCP contains an index of national standards, including:

(1) The practice name and unit.

(2) The SCS technical discipline leader responsible for each practice.

(3) The date of the current standard.

(4) The code number of the standard.

401.12 National Conservation Practice Standards Subcommittee (NCPSS) of National Technical Guide Committee (NTGC).

The National Conservation Practice Standards Subcommittee (NCPSS) of NTGC coordinates and updates the NHCP. The NTGC designates subcommittee members and acts on recommendations from NCPSS.

401.13 Practice standards and specifications.

(a) Practice standards establish the minimum level of acceptable quality of planning, designing, installing, operating and maintaining conservation practices.

(1) NHCP standards are to be used directly within a state, or state supplements can be added as necessary. Because of wide variations in soils, climate, and topography, state conservationists may need to add special provisions or provide more detail in the standards. State laws and local ordinances or regulations may dictate more stringent criteria.

(2) The official practice name, definition, code identity, and unit of measurement are established nationally and are not to be changed. Generally, the statement of scope, purpose, and conditions where a practice applies can be used directly.

(b) Practice specifications establish the technical details and workmanship for the various operations required to install the practice and the quality and extent of the materials to be used.

(1) Specifications enumerate items that apply when adapting the standard to site specific locations, such as considerations of site preparation and protection; instructions for use of materials described in the standard; or guidance for performing installation operations not directly addressed in the standard. Statements in the specifications are not to conflict with the requirements of the standard.

(2) Items to be included in state-developed specifications for a limited number of conservation practices are contained in the NHCP. Specifications for practices are to be developed by states or NTCs and are to consider the wide variations in soils, climate, and topography present in the various states. State developed specifications must be approved by the appropriate discipline specialist and the state conservationist. Specifications are to meet the requirements of state laws and local ordinances or regulations.

(c) National Technical Centers (NTCs) review and concur in supplements to NHCP standards and specifications prepared by a state for use within that state to ensure conformance with NHCP and consistency among states.

401.14 Variances.

Only the directors of the Engineering and/or Ecological Sciences Divisions can approve variances from requirements stated in the NHCP except that approval authority for variations in channel stability requirements has been delegated to the heads of engineering staffs at the NTC (see NEM 210 Section 501.32). Any other request for a variance is to be submitted to the NTGC and is to include recommendations of the appropriate NTC Director. The NTGC will refer the request to the appropriate division for action. Variances, when granted, are for a specific period of time or until the practice standard to which they pertain is revised, whichever is shorter. Variances will include any requirements for monitoring, evaluation, and reporting needed to determine whether or not changes in practice standards are necessary.

401.15 Changes in the National Handbook of Conservation Practices (NHCP).

(a) The NTGC will consider and recommend proposed changes in the NHCP to the Deputy Chief for Technology. Changes will be made by numbered handbook notices issued by the Deputy Chief for Technology.

(b) Each NHCP standard is to be formally reviewed by the NCPSS at least once every five years from the date of issuance or revision to determine if the standard is needed and up-to-date. If revisions are needed, the revised standard will establish the current minimum level of acceptable quality for planning, designing, installing, operating, and maintaining conservation practices.

(c) The NTC reviews all state proposed changes to NHCP and sends recommendations for approval or disapproval to NTGC. Review and approval of technical content of proposed changes is to be made by the Director, Engineering Division, or the Director, Ecological Sciences Division. Review and approval of format with respect to inclusion of items listed in Section 401.11 are to be performed by NTGC.

401.16 Interim standards.

(a) Interim standards are prepared by states or NTC to address problems for which there is no existing standard.

(b) Interim standards are to be approved by the NTC Director.

(c) Interim standards are to be issued for a period not to exceed 3 years. The NTC director can extend the period for further evaluation at the end of this period, and after an analysis of practice performance using the interim standard.

(d) Interim standards will be evaluated by NTC Technical Guide Committees at the end of the 3-year period and, if appropriate, recommendations made to the NTGC for inclusion in the National Handbook of Conservation Practices.

(e) The notice of approval of each interim standard will provide instructions to states regarding evaluation of practice performance.

(f) NTC directors are to send information copies of all interim standards and evaluation reports to NTGC.

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Appendix 2B

List of References for Nonpoint Source Database - Pennsylvania State University

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Articles Entered into NPSDB Listed in Order by SAN

Current as of 05/27/92

SAN	Applic. Class	First Authors	Article Title
2	Confined Livestock	Dickey, E.C.	Performance and Design of Vegetable Filters for Feedlot Runoff Treatment, Livestock Waste, A Renewable Resource
3	Confined Livestock		Livestock in Confinement - Section 10.0
10	Confined Livestock Manure Spreading	Westerman, P.W., et al.	Swine Manure and Lagoon Effluent Applied to a Temperate Forage Mixture: II Rainfall Runoff and Soil Chemical Properties, Journal of Environmental Quality, Vol. 16, No. 2, 1987
13	Conf. Livstk Manure Spreading.	Quisenberry, V.L., et al.	Management Aspects of Applying Poultry or Dairy Manures to Grassland in the Piedmont Region, Livestock Waste, A Renewable Resource
15	Manure Spreading	Doyle, R.C., et al	Effectiveness of Forest Buffer Strip in Improving the Water Quality of Manure Polluted Runoff
16	Manure Spreading	Mueller, D.H., et al.	Phosphorus Losses as Affected by Tillage and Manure Application, Soil Science Society Journal, Vol. 48, 1984
21	Manure Spreading	Gerhart, James M.,	Ground Water Recharge and Its Effects on Nitrate Concentration Beneath a Manured Field Site in Pennsylvania, Ground Water, Vol. 24, No. 4, 1986
22	Manure Spreading	Hubbard, R.K., et al.	Surface Runoff and Shallow Ground Water Quality as Affects by Center Pivot Applied Dairy Cattle Wastes, Transactions of the ASAE, 1987
23	Manure Spreading	Waters, S.P.	Water Quality Impacts on Animal Waste Application in a Northeastern Oklahoma Watershed
25	Manure Spreading	Clausen, John C.	Water Quality Achievable with Agricultural Best Management Practices, Journal of Soil and Water Conservation, 1989
26	Manure Spreading	Deiyman, Marcia M., Saied Mostaghimi	A Model for Evaluating the Impact of Land Application of Organic Wastes on Runoff Water Quality, Research Journal of the Water Pollution Control Federation, 1991
30	Cropland Erosion	Naderman, George C.	Surface Water Management for Crop Production on Highly Erodible Land
32	Cropland Erosion		Impact of Land-Treatment on the Restoration of Skinner Lake Noble County Indiana

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34	Cropland Erosion	McGregor, K.C., et al.	Effects of Tillage with Different Crop Residues on Runoff and Soil Loss
36	Cropland Erosion	Spomer, R.G. (duplicate)	Concentrated Flow Erosion on Conventional and Conservation Tilled Watershed
41	Cropland Erosion	Smith, S.J.	Water Quality Impacts Associated with Wheat Culture in the Southern Plains Journal of Environmental Quality, Vol. 20, No. 1, 1991
42	Cropland Erosion	Rayavian, Daryoush	Hydrologic Responses of an Agricultural Watershed to Various Hydrologic and Management Conditions
45	Cropland Erosion	Baldwin, P.L., et al.	Effects of Tillage on Quality of Runoff Water
46	Cropland Erosion	Mutchler, C.K., et al.	Erosion from Reduced-Till Cotton
51	Cropland Erosion	Unger, P.W.	Conservation Tillage Systems
53	Cropland Erosion	Mostaghimi, S., et al.	Influence of Tillage Systems and Residue Levels on Runoff, Sediment and Phosphorus Losses Transactions of the ASAE, Vol. 31, No. 1, 1988
54	Cropland Erosion	McDowell, L. L.	Nitrogen and Phosphorus Losses in Runoff from No-Till Soybeans
56	Cropland Erosion	Meek, B.D.	Infiltration Rate as Affected by an Alfalfa and No-Till Cotton Cropping System
58	Cropland Erosion	Cogo, N.P.	Soil Loss Reductions from Conservation Tillage Practices
59	Cropland Erosion	Zhu, J.C.	Runoff Soil and Dissolved Nutrients Losses from No-Till Soybeans with Winter Cover Crops
60	Cropland Erosion	Berg, W.A.	Management Effects on Runoff, Soil and Nutrient Losses from Highly Erodible Soils in the Southern Plains
62	Cropland Erosion	Dick, W.A., et al.	Surface Hydrologic Response of Soils to No-Till
63	Cropland Erosion	Beasley, D.B., et al.	Using Simulation to Assess the Impacts of Conservation Tillage on Movement of Sediment and Phosphorus into Lake Erie, Winter Meeting of the ASAE, 1986
64	Cropland Erosion	Baker, J.L.	Water Quality Consequences of Conservation Tillage
67	Confined Livestock	Lorimor, J.C., et al.	Nitrate Concentration in Groundwater Beneath a Beef Cattle Feedlot Water Resource Bulletin, Vol. 8, No. 5, 1972
68	Cropland Erosion	Rousseau, A., et al.	Evaluation of Best Management Practices to Control Phosphorus Nonpoint Source Pollution
69	Cropland Erosion	Scott, R., Alfredo B. Granillo	Sediment and Water Yields from Managed Forests on Flat Coastal Plain Sites

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70	Cropland Erosion	Landale, G.W.	Conservation Practice Effects on Phosphorus Losses from Southern Piedmont Watersheds, Journal of Soil and Water Conservation, 1985
54	Cropland Erosion	Dillaha, T.A., et al.	Vegetative Filter Strips for Agricultural Nonpoint Source Pollution Control, Transactions of the ASAE, Vol. 32, No. 2, 1989
93	Nutrient Management	Gold, Arthur J., et al.	Runoff Water Quality from Conservation and Conventional Tillage
94	Nutrient Management	Staver, K. Set al.	Nitrogen Export from Atlantic Coastal Plain Soils, International Summer Meeting of the ASAE, 1988
96	Nutrient Management	Baker, J.L. et al	Effect of Tillage on Infiltration and Anion Leaching, Winter Meeting of the ASAE, 1986
98	Nutrient Management	Mueller, D.H., et al.	Effect of Conservation Tillage on Runoff Water Quality: Total, Dissolved and Algal-Available Phosphorus Losses, Winter Meeting of the ASAE, 1983
100	Nutrient Management	Alberts, E.E., R.G. Spomer	Dissolved Nitrogen and Phosphorus in Runoff from Watersheds in Conservation and Conventional Tillage, Journal of Soil and Water Conservation, 1985
106	Nutrient Management	Angle, J.S., et al.	Nutrient Losses in Runoff from Conventional and No-Till Corn Watersheds, Journal of Environmental Quality, Vol. 13, No. 3
107	Nutrient Management	Mostaghimi, Saied, et al.	Phosphorus Losses from Cropland as Affected by Tillage System and Fertilizer Application Method, Water Resources Bulletin, Vol. 24, No. 4, 1988
110	Nutrient Management	Kanwar, R.S., et al.	Tillage and N-Fertilizer Management Effects on Groundwater Quality, Summer Meeting of the ASAE, 1987
167	Cropland Erosion	Edwards, W.M., et al.	Contribution of Macroporosity to Infiltration into a Continuous Corn No-Till Watershed: Implications for Contaminant Movement
183	Cropland Erosion	Deizman, M.M., et al.	Size Distribution of Eroded Sediment from Two Tillage Systems
184	Cropland Erosion	Khan, M.J., et al.	Mulch Cover and Canopy Effect of Soil Loss
185	Cropland Erosion	McGregor, K.C., et al.	Effect of Incorporating Straw Residues on Interrill Soil Erosion
212	Cropland Erosion	Mostaghimi, S., T.A. Dillaha, V.O. Shanholtz	Runoff, Sediment and Phosphorus Losses from Agricultural Lands as Affected by Tillage and Residue Levels

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CHAPTER 3: Management Measures for Forestry

I. INTRODUCTION

A. What "Management Measures" Are

This chapter specifies management measures to protect coastal waters from silvicultural sources of nonpoint pollution. "Management measures" are defined in section 6217 of the Coastal Zone Act Reauthorization Amendments of 1990 (CZARA) as economically achievable measures to control the addition of pollutants to our coastal waters, which reflect the greatest degree of pollutant reduction achievable through the application of the best available nonpoint pollution control practices, technologies, processes, siting criteria, operating methods, or other alternatives.

These management measures will be incorporated by States into their coastal nonpoint programs, which under CZARA are to provide for the implementation of management measures that are "in conformity" with this guidance. Under CZARA, States are subject to a number of requirements as they develop and implement their Coastal Nonpoint Pollution Control Programs in conformity with this guidance and will have some flexibility in doing so. The application of these management measures by States to activities causing nonpoint pollution is described more fully in *Coastal Nonpoint Pollution Control Program: Program Development and Approval Guidance*, published jointly by the U.S. Environmental Protection Agency (EPA) and the National Oceanic and Atmospheric Administration (NOAA).

B. What "Management Practices" Are

In addition to specifying management *measures*, this chapter also lists and describes management *practices* for illustrative purposes only. While State programs are required to specify management *measures* in conformity with this guidance, States programs need not specify or require implementation of the particular management *practices* described in this document. However, as a practical matter, EPA anticipates that the management measures generally will be implemented by applying one or more management practices appropriate to the site, location, type of operation, and climate. The practices listed in this document have been found by EPA to be representative of the types of practices that can be applied successfully to achieve the management measures. EPA has also used some of these practices, or appropriate combinations of these practices, as a basis for estimating the effectiveness, costs, and economic impacts of achieving the management measures. (Economic impacts of the management measures are addressed in a separate document entitled *Economic Impacts of EPA Guidance Specifying Management Measures for Sources of Nonpoint Pollution in Coastal Waters.*)

EPA recognizes that there is often site-specific, regional, and national variability in the selection of appropriate practices, as well as in the design constraints and pollution control effectiveness of practices. The list of practices for each management measure is not all-inclusive and does not preclude States or local agencies from using other technically sound practices. In all cases, however, the practice or set of practices chosen by a State needs to achieve the management measure.

C. Scope of This Chapter

This chapter contains 10 management measures that address various phases of forestry operations relevant to the control of sources of silvicultural nonpoint pollution that affect coastal waters. A separate measure for forestry operations in forested wetlands is included. These measures are:

(1) Preharvest planning
(2) Streamside management areas
(3) Road construction/reconstruction
(4) Road management
(5) Timber harvesting
(6) Site preparation and forest regeneration
(7) Fire management
(8) Revegetation of disturbed areas
(9) Forest chemical management
(10) Wetland forest management

Each of these topics is addressed in a separate section of this chapter. Each section contains (1) the management measure; (2) an applicability statement that describes, when appropriate, specific activities and locations for which the measure is suitable; (3) a description of the management measure's purpose; (4) the rationale for the management measure's selection; (5) information on the effectiveness of the management measure and/or of practices to achieve the measure; (6) information on management practices that are suitable, either alone or in combination with other practices, to achieve the management measure; and (7) information on costs of the measure and/or of practices to achieve the measure.

Coordination of Measures

The management measures developed for silviculture are to be used as an overall system of measures to address nonpoint source (NPS) pollution sources on any given site. In most cases, not all the measures will be needed to address the NPS sources of a specific site. For example, many silvicultural systems do not require road construction as part of the operation and would not need to be concerned with the management measure that addresses road construction. By the same token, many silvicultural systems do not use prescribed fire and would not need to use the fire management measure.

Most forestry operations will have more than one phase of operation that needs to be addressed and will need to employ two or more of the measures to address the multiple sources. Where more than one phase exists, the application of the measures needs to be coordinated to produce an overall system that adequately addresses all sources for the site and does not cause unnecessary expenditure of resources on the site.

Since the silvicultural management measures developed for the CZARA are, for the most part, a system of practices that are commonly used and recommended by States and the U.S. Forest Service in guidance or rules for forestry-related nonpoint source pollution, there are many forestry operations for which practices or systems of practices have already been implemented. Many of these operations may already achieve the measures needed for the nonpoint sources on them. For cases where existing source control is inadequate, it may be necessary to add only one or two more practices to achieve the measure. Existing NPS progress must be recognized and appropriate credit given to the accomplishment of our common goal to control NPS pollution. There is no need to spend additional resources for a practice that is already in existence and operational. Existing practices, plans, and systems should be viewed as building blocks for these management measures and may need no additional improvement.

D. Relationship of This Chapter to Other Chapters and to Other EPA Documents

1. Chapter 1 of this document contains detailed information on the legislative background for this guidance, the process used by EPA to develop this guidance, and the technical approach used by EPA in the guidance.

2. Chapter 7 of this document contains management measures to protect wetlands and riparian areas that serve a nonpoint source pollution abatement function. These measures apply to a broad variety of nonpoint sources; however, the measures for wetlands described in Chapter 7 are not intended to address silvicultural sources.

Practices for normal silvicultural operations in forested wetlands are covered in Management Measure J of Chapter 3.

3. Chapter 8 of this document contains information on recommended monitoring techniques to (1) ensure proper implementation, operation, and maintenance of the management measures and (2) assess over time the success of the measures in reducing pollution loads and improving water quality.

4. EPA has separately published a document entitled *Economic Impacts of EPA Guidance Specifying Management Measures for Sources of Nonpoint Pollution in Coastal Waters.*

5. NOAA and EPA have jointly published guidance entitled *Coastal Nonpoint Pollution Control Program: Program Development and Approval Guidance.* This guidance contains details on how State coastal nonpoint pollution control programs are to be developed by States and approved by NOAA and EPA. It includes guidance on:

   - The basis and process for EPA/NOAA approval of State Coastal Nonpoint Pollution Control Programs;
   - How NOAA and EPA expect State programs to specify management measures "in conformity" with this management measures guidance;
   - How States may target sources in implementing their Coastal Nonpoint Pollution Control Programs;
   - Changes in State coastal boundaries; and
   - Requirements concerning how States are to implement Coastal Nonpoint Pollution Control Programs.

E. Background

The effects of forestry activities on water quality have been widely studied, and the need for management measures and practices to prevent silvicultural contributions to water pollution has been recognized by all States with significant forestry activities. Silvicultural activities have been identified as nonpoint sources in coastal area water quality assessments and control programs. Water quality concerns related to forestry were addressed in the 1972 Federal Water Pollution Control Act Amendments and later, more comprehensively, as nonpoint sources under section 208 of the 1977 Clean Water Act and section 319 of the 1987 Water Quality Act. On a national level, silviculture contributes approximately 3 to 9 percent of nonpoint source pollution to the Nation's waters (Neary et al., 1989; USEPA, 1992a). Local impacts of timber harvesting and road construction on water quality can be severe, especially in smaller headwater streams (Brown, 1985; Coats and Miller, 1981; Pardo, 1980). Megahan (1986) reviewed several studies on forest land erosion and concluded that surface erosion rates on roads often equaled or exceeded erosion reported for severely eroding agricultural lands. These effects are of greatest concern where silvicultural activity occurs in high-quality watershed areas that provide municipal water supplies or support cold-water fisheries (Whitman, 1989; Neary et al., 1989; USEPA, 1984; Coats and Miller, 1981).

Twenty-four States have identified silviculture as a problem source contributing to NPS pollution in their 1990 section 305(b) assessments (USEPA, 1992b). Silviculture was the pollution source for 9 percent of NPS pollution to rivers in the 42 States reporting NPS pollution figures in section 305(b) assessments (USEPA, 1992b). States have reported up to 19 percent of their river miles to be impacted by silviculture. On Federal lands, such as national forests, many water quality problems can be attributed to the effects of timber harvesting and related activities (Whitman, 1989). In response to these impacts, many States have developed programs to address NPS pollution from forestry activities.

1. Pollutant Types and Impacts

Without adequate controls, forestry operations may degrade several water quality characteristics in waterbodies receiving drainage from forest lands. Sediment concentrations can increase due to accelerated erosion; water temperatures can increase due to removal of overstory riparian shade; slash and other organic debris can accumulate in waterbodies, depleting dissolved oxygen; and organic and inorganic chemical concentrations can increase due to harvesting and fertilizer and pesticide applications (Brown, 1985). These potential increases in water quality contaminants are usually proportional to the severity of site disturbance (Riekerk, 1983, 1985; Riekerk et al., 1989). Silvicultural NPS pollution impacts depend on site characteristics, climatic conditions, and the forest practices employed. Figure 3-1 presents a model of forest biogeochemistry, hydrology, and stormflow interactions.

Sediment. Sediment is often the primary pollutant associated with forestry activities (Pardo, 1980). Sediment is often defined as mineral or organic solid material that is eroded from the land surface by water, ice, wind, or other processes and is then transported or deposited away from its original location.

Sediment transported from forest lands into waterbodies can be particularly detrimental to benthic organisms and many fish species. When it settles, sediment fills interstitial spaces in lake bottoms or streambeds. This can eliminate essential habitat, covering food sources and spawning sites and smothering bottom-dwelling organisms and periphyton. Sediment deposition also reduces the capacity of stream channels to carry water and of reservoirs to hold water. This decreased flow and storage capacity can lead to increased flooding and decreased water supplies (Golden, et al., 1984).

Suspended sediments increase water turbidity, thereby limiting the depth to which light can penetrate and adversely affecting aquatic vegetation photosynthesis. Suspended sediments can also damage the gills of some fish species, causing them to suffocate, and can limit the ability of sight-feeding fish to find and obtain food.

Turbid waters tend to have higher temperatures and lower dissolved oxygen concentrations. A decrease in dissolved oxygen levels can kill aquatic vegetation, fish, and benthic invertebrates. Increases (or decreases) in water temperature outside the tolerance limits of aquatic organisms, especially cold-water fish such as trout and salmon, can also be lethal (Brown, 1974).

Nutrients. Nutrients from forest fertilizers, such as nitrogen and phosphorus adsorbed to sediments, in solution, or transported by aerial deposition, can cause harmful effects in receiving waters. Sudden removal of large quantities of vegetation through harvesting can also increase leaching of nutrients from the soil system into surface waters and ground waters by disrupting the nitrogen cycle (Likens et al., 1970). Excessive amounts of nutrients may cause enrichment of waterbodies, stimulating algal blooms. Large blooms limit light penetration into the water column, increase turbidity, and increase biological oxygen demand, resulting in reduced dissolved oxygen levels. This process, termed eutrophication, drastically affects aquatic organisms by depleting the dissolved oxygen these organisms need to survive.

Forest Chemicals. Herbicides, insecticides, and fungicides (collectively termed pesticides) used to control forest pests and undesirable plant species, can be toxic to aquatic organisms. Pesticides that are applied to foliage or soils, or are applied by aerial means, are most readily transported to surface waters and ground waters (Norris and Moore, 1971). Some pesticides with high solubilities can be extremely harmful, causing either acute or chronic effects in aquatic organisms, including reduced growth or reproduction, cancer, and organ malfunction or failure (Brown, 1974). Persistent pesticides that tend to sorb onto particulates are also of environmental concern since these relatively nonpolar compounds have the tendency to bioaccumulate. Other "chemicals" that may be released during forestry operations include fuel, oil, and coolants used in equipment for harvesting and road-building operations.

Organic Debris Resulting from Forestry Activities. Organic debris includes residual logs, slash, litter, and soil organic matter generated by forestry activities. Organic debris can adversely affect water quality by causing increased biochemical oxygen demand, resulting in decreased dissolved oxygen levels in watercourses. Logging slash and debris deposited in streams can alter streamflows by forming debris dams or rerouting streams, and can also

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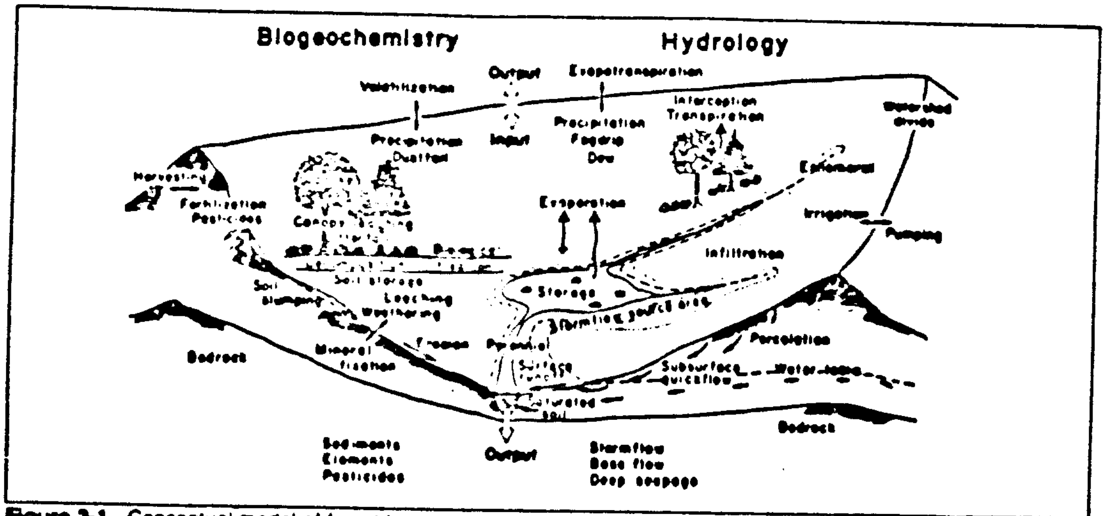

Figure 3-1. Conceptual model of forest biogeochemistry, hydrology and stormflow (Riekerk et al., 1989).

redirect flow in the channel, increasing bank cutting and resulting sedimentation (Dunford, 1962; Everest and Meehan, 1981). In some ecosystems, small amounts of naturally occurring organic material can be beneficial to fish production. Small streams in the Pacific Northwest may be largely dependent on the external energy source provided by organic materials such as leaves and small twigs. Naturally occurring large woody debris in streams can also create physical habitat diversity for rearing salmonids and can stabilize streambeds and banks (Everest and Meehan, 1981; Murphy et al., 1986).

Temperature. Increased temperatures in streams and waterbodies can result from vegetation removal in the riparian zone from either harvesting or herbicide use. These temperature increases can be dramatic in smaller (lower order) streams, adversely affecting aquatic species and habitat (Brown, 1972; Megahan, 1980; Curtis et al., 1990). Increased water temperatures can also decrease the dissolved oxygen holding capacity of a waterbody, increasing biological oxygen demand levels and accelerating chemical processes (Curtis et al., 1990).

Streamflow. Increased streamflow often results from vegetation removal (Likens et al., 1970; Eschner and Larmoyeux, 1963; Blackburn et al., 1982). Tree removal reduces evapotranspiration, which increases water availability to stream systems. The amount of streamflow increase is related to the total area harvested, topography, soil type, and harvesting practices (Curtis et al., 1990). Increased streamflows can scour channels, erode streambanks, increase sedimentation, and increase peak flows.

2. Forestry Activities Affecting Water Quality

The types of forestry activities affecting NPS pollution include road construction and use, timber harvesting, mechanical equipment operation, burning, and fertilizer and pesticide application (Neary et al., 1989).

Road Construction and Use. Roads are considered to be the major source of erosion from forested lands, contributing up to 90 percent of the total sediment production from forestry operations (Rothwell, 1983; Megahan, 1980; Patric, 1976). (See Figure 3-2.) Erosion potential from roads is accelerated by increasing slope gradients on cut-and-fill slopes, intercepting subsurface water flow, and concentrating overland flow on the road surface and in channels (Megahan, 1980). Roads with steep gradients, deep cut-and-fill sections, poor drainage, erodible soils, and road-stream crossings contribute to most of this sediment load, with road-stream crossings being the most frequent

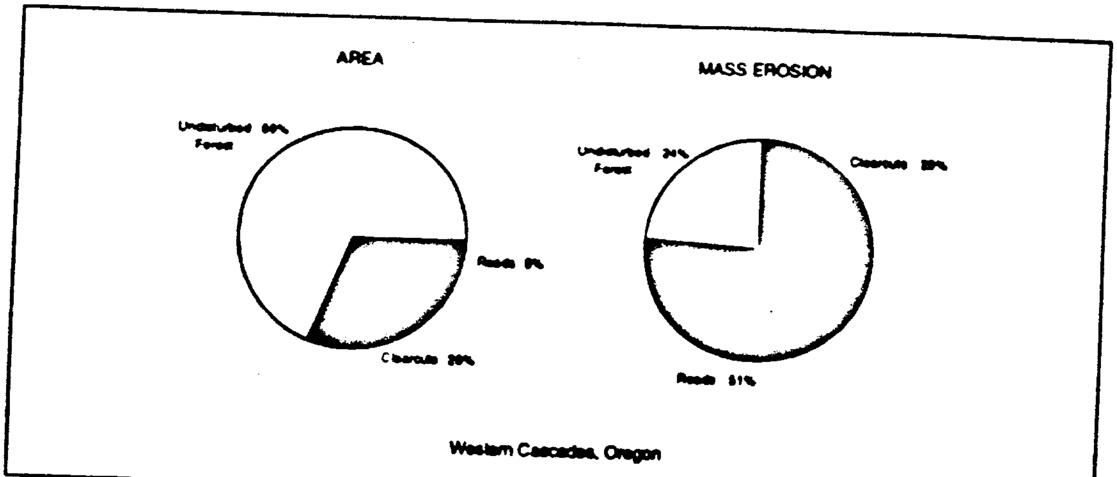

Figure 3-2. Comparison of forest land areas and mass erosion under various land uses (adapted from Sidle, 1989).

sources of erosion and sediment (Rothwell, 1983). Soil loss tends to be greatest during and immediately after road construction because of the unstabilized road prism and disturbance by passage of heavy trucks and equipment (Swift, 1984).

Brown and Krygier (1971) found that sediment production doubled after road construction on three small watersheds in the Oregon Coast Range. Dyrness (1967) observed the loss of 680 cubic yards of soil per acre from the H.J. Andrews Experimental Forest in Oregon due to soil erosion from roads on steep topography. Landslides were observed on all slopes and were most pronounced where forest roads crossed stream channels on steep drainage headwalls. Another example of severe erosion resulting from forestry practices occurred in the South Fork of the Salmon River in Idaho in the winter of 1965, following 15 years of intensive logging and road construction. Heavy rains triggered a series of landslides that deposited sediment on spawning beds in the river channel, destroying salmon spawning grounds (Megahan, 1981). Careful planning and proper road layout and design, however, can minimize erosion and prevent stream sedimentation (Larse, 1971).

Timber Harvesting. Most detrimental effects of harvesting are related to the access and movement of vehicles and machinery, and the skidding and loading of trees or logs. These effects include soil disturbance, soil compaction, and direct disturbance of stream channels. Logging operation planning, soil and cover type, and slope are the most important factors influencing harvesting impacts on water quality (Yobo, 1980). The construction and use of haul roads, skid trails, and landings for access to and movement of logs are the harvesting activities that have the greatest erosion potential.

Surveys of soil disturbance from logging were performed by Hornbeck and others (1986) in Maine, New Hampshire, and Connecticut. They found 18 percent of the mineral soil exposed by logging practices in Maine, 11 percent in New Hampshire, and 8 percent in Connecticut. Megahan (1986) reviewed several studies on forest land erosion and concluded that surface erosion rates on roads often equaled or exceeded erosion reported for severely eroding agricultural lands. Megahan (1986) found that in some cases erosion rates from harvest operations may approach erosion rates from roads and that prescribed burning can accelerate erosion beyond that from logging alone.

Another adverse impact of harvesting is the increase in stream water temperatures resulting from removal of streamside vegetation, with the greatest potential impacts occurring in small streams. However, streamside buffer strips have been shown to minimize the increase in stream temperatures (Brazier and Brown, 1973; Brown and Krygier, 1970).

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Regeneration Methods. Regeneration methods can be divided into two general types: (1) regeneration from seedlings, either planted seedlings or existing seedlings released by harvesting, and (2) regeneration from seed, which can be seed from existing trees on or near the site or the broadcast application of seeds of the desired species. In some areas, regeneration with seedlings by mechanical tree planting is often conducted because it is faster and more consistent. Planting approaches relying on seeding generally require a certain amount of mineral soil to be exposed for seed establishment. For this reason, a site preparation technique is usually needed for regeneration by seeding.

Site Preparation. Mechanical site preparation by large tractors that shear, disk, drum-chop, or root-rake a site may result in considerable soil disturbance over large areas and has a high potential to deteriorate water quality (Beasley, 1979). Site preparation techniques that result in the removal of vegetation and litter cover, soil compaction, exposure or disturbance of the mineral soil, and increased stormflows due to decreased infiltration and percolation, all can contribute to increases in stream sediment loads (Golden et al., 1984). However, erosion rates decrease over time as vegetative cover grows back.

Prescribed burning and herbicides are other methods used to prepare sites that may also have potential negative effects on water quality. These activities are discussed below.

Prescribed Burning. Prescribed burning of slash can increase erosion by eliminating protective cover and altering soil properties (Megahan, 1980). The degree of erosion following a prescribed burn depends on soil erodibility, slope, precipitation timing, volume and intensity, fire severity, cover remaining on the soil, and speed of revegetation. Burning may also increase stormflow in areas where all vegetation is killed. Such increases are partially attributable to decreased evapotranspiration rates and reduced canopy interception of precipitation. Erosion resulting from prescribed burning is generally less than that resulting from roads and skid trails and from site preparation that causes intense soil disturbance (Golden et al., 1984). However, significant erosion can occur during prescribed burning if the slash being burned is collected or piled, causing soil to be moved and incorporated into the slash.

Application of Forest Chemicals. Adverse effects on water quality due to forest chemical application typically result from improper chemical application, such as failure to establish buffers around watercourses (Norris and Moore, 1971). Aerial application of forest chemicals has a greater potential to adversely affect water quality, especially if chemicals are applied under improper conditions, such as high winds (Riekerk et al., 1989), or are applied directly to watercourses.

F. Other Federal, State, and Local Silviculture Programs

1. Federal Programs

Forestry activities on Federal lands are predominantly controlled by the U.S. Department of Agriculture (USDA) Forest Service and Department of the Interior (DOI) Bureau of Land Management (BLM). Private entities operating on Federal lands are regulated by timber sales contracts. The Forest Service has developed preventive land management practices and project performance standards (USEPA, 1991). The Agricultural Stabilization and Conservation Service (ASCS) administers the Forestry Incentives Program (FIP) and Stewardship Incentives Program (SIP). Under FIP, ASCS provides cost-share funds to develop, manage, and protect eligible forest land, with emphasis on enhancing water quality, wildlife habitat, and recreational resources, and producing softwood timber. In addition, the Clean Water Act section 404 regulatory program may be applicable to some forestry activities (such as stream crossings) that involve the discharge of dredged or fill material into waters of the United States. However, section 404(f) of the Act exempts most forestry activities from permitting requirements. Regulations describing 404(f) exemptions, as well as applicable best management practices for section 404, have been published by EPA and the U.S. Army Corps of Engineers (40 CFR 232.3). The management measures in this guidance apply only to nonpoint source silvicultural activities. Clean Water Act section 402 regulations for point source permits exempt these nonpoint silvicultural activities (40 CFR 122.27) except for the section 404 requirements discussed above.

2. State Forestry NPS Programs

Most States with significant forestry activities have developed Best Management Practices (BMPs) to control silviculturally-related NPS water quality problems. Often, water quality problems are not due to ineffectiveness of the practices themselves, but to the failure to implement them appropriately (Whitman, 1989; Pardo, 1980).

There are currently two basic types of State forestry NPS programs, voluntary and regulatory. Thirty-five States currently implement voluntary programs, with 6 of these States having the authority to make the voluntary programs regulatory and 10 States backing the voluntary program with a regulatory program for non-compliers (see Table 3-1 for more specific types of programs). Nine States have developed regulatory programs (Essig, 1991).

Voluntary programs rely on a set of BMPs as guidelines to operators (Cubbage et al., 1989). Operator education and technology transfer are also a responsibility of State Forestry Departments. Workshops, brochures, and field tours are used to educate and to demonstrate to operators the latest water quality management techniques. Landowners are encouraged to hire operators who have a working knowledge of State forestry BMPs (Dissmeyer and Miller, 1991). Transfer of information on State NPS controls to landowners is also an important element of these programs.

Regulatory programs involve mandatory controls and enforcement strategies defined in Forest Practice Rules based on a State's Forest Practices Act or local government regulations. These programs usually require the implementation of BMPs based on site-specific conditions and water quality goals, and they have enforceable requirements (Ice, 1985). Often streams are classified based on their most sensitive designated use, such as importance for municipal water supply or propagation of aquatic life. Many water quality BMPs also improve harvesting operation efficiency and therefore can be applied in the normal course of forest harvest operations with few significant added costs (Ontario Ministry of Natural Resources, 1988; Dissmeyer and Miller, 1991). Harvest operation plans or applications to perform a timber harvest are frequently reviewed by the responsible State agency. Erosion and sedimentation control BMPs are also used in these programs to minimize erosion from road construction and harvesting activities.

Present State Coastal Zone Management (CZM) and section 319 programs may already include specific BMP regulations or guidelines for forestry activities. In some States, CZM programs have adopted State forestry regulations and BMPs through reference or as part of a linked program.

3. Local Governments

Counties, municipalities, and local soil and water conservation management districts may also impose additional requirements on landowners and operators conducting forestry activities. In urbanizing areas, these requirements often relate to concerns regarding the conversion of forested lands to urban uses or changes in private property values due to aesthetic changes resulting from forestry practices. In rural areas additional requirements for forestry activities may be implemented to protect public property (roads and municipal water supplies). Local forestry regulations tend to be stricter in response to residents' complaints (Salazar and Cubbage, 1990).

Table 3-1. State Programs by Region and Frequency (Henly and Ellefson, 1987)

Major Forestry Activity and Program Type	Frequency of States in Region Having Program Type									
	New England	Middle Atlantic	Lake States	Central States	South Atlantic	Southern States	Pacific States	N. Rocky Mountain	S. Rocky Mountain	Total
Water Quality Protection										
Tax Incentives	0	0	1	0	0	0	0	0	0	1
Financial Incentives	0	1	1	0	1	1	1	0	0	5
Educational Programs	5	2	3	5	3	8	3	3	3	35
Technical Assistance	6	5	3	6	3	6	2	4	5	40
Voluntary Guidelines	3	4	1	3	3	9	2	3	2	30
Legal Regulations	5	4	3	1	0	0	5	3	3	24
Reforestation and Timber Management										
Tax Incentives	1	2	3	5	1	2	0	2	0	16
Financial Incentives	1	3	3	4	3	4	2	1	1	22
Educational Programs	5	4	3	6	3	8	3	3	2	37
Technical Assistance	6	5	3	7	3	8	4	5	5	46
Voluntary Guidelines	0	2	2	2	3	3	1	1	2	16
Legal Regulations	1	3	1	1	0	0	4	1	3	14
Forest Protection										
Tax Incentives	0	1	0	0	0	0	0	0	0	1
Financial Programs	0	1	1	0	0	1	1	0	0	4
Educational Programs	5	5	3	6	3	9	1	3	3	38
Technical Assistance	6	5	3	7	3	9	4	4	5	46
Voluntary Guidelines	1	1	1	2	3	3	1	3	2	17
Legal Regulations	6	4	2	6	3	8	5	4	4	42
Wildlife and Aesthetic Management										
Tax Incentives	0	1	1	1	0	0	0	0	0	3
Financial Incentives	0	1	1	3	0	0	1	0	0	6
Educational Programs	4	3	3	5	3	7	1	4	2	32
Technical Assistance	5	5	3	8	3	7	4	4	4	41
Voluntary Guidelines	1	1	1	2	2	3	1	1	1	13
Legal Regulations	2	2	1	2	0	1	5	1	0	14

NOTE: Water Quality Protection focuses on nonpoint silvicultural sources of pollutants, vegetative buffer strips along waters, road and skid trail design and construction. Reforestation and Timber Management focuses on seed trees and other reforestation forms, timber harvesting system, clearcut size and design. Forest Protection focuses on slash treatment, other wildfire-related treatments, prescribed burn smoke management, herbicide and pesticide application, disease and insect management. Wildlife and Aesthetic Management focuses on wildlife habitat, scenic buffers along roadways, coastal zone management requirements.

Regional Groupings of States: New England-Connecticut, Maine, Massachusetts, New Hampshire, Rhode Island and Vermont; Middle Atlantic-Delaware, Maryland, New Jersey, New York, Pennsylvania and West Virginia; Lake States-Michigan, Minnesota, and Wisconsin; Central States-Illinois, Indiana, Iowa, Kansas, Kentucky, Missouri, Nebraska and Ohio; South Atlantic-North Carolina, South Carolina and Virginia; Southern States-Florida, Georgia, Alabama, Mississippi, Tennessee, Arkansas, Louisiana, Oklahoma and Texas; Pacific States-Alaska, California, Hawaii, Oregon and Washington; N. Rocky Mountain-Idaho, Montana, North Dakota, South Dakota and Wyoming; S. Rocky Mountain-Arizona, Colorado, Nevada, New Mexico and Utah.

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II. FORESTRY MANAGEMENT MEASURES

[illegible] Planning

Perform advance planning for forest harvesting that includes the following elements where appropriate:

(1) Identify the area to be harvested including location of waterbodies and sensitive areas such as wetlands, threatened or endangered aquatic species habitat areas, or high- erosion-hazard areas (landslide-prone areas) within the harvest unit.
(2) Time the activity for the season or moisture conditions when the least impact occurs.
(3) Consider potential water quality impacts and erosion and sedimentation control in the selection of silvicultural and regeneration systems, especially for harvesting and site preparation.
(4) Reduce the risk of occurrence of landslides and severe erosion by identifying high-erosion-hazard areas and avoiding harvesting in such areas to the extent practicable.
(5) Consider additional contributions from harvesting or roads to any known existing water quality impairments or problems in watersheds of concern.

Perform advance planning for forest road systems that includes the following elements where appropriate:

(1) Locate and design road systems to minimize, to the extent practicable, potential sediment generation and delivery to surface waters. Key components are:
- **locate roads, landings, and skid trails to avoid to the extent practicable steep grades and steep hillslope areas, and to decrease the number of stream crossings;**
- **avoid to the extent practicable locating new roads and landings in Streamside Management Areas (SMAs); and**
- **determine road usage and select the appropriate road standard.**

(2) Locate and design temporary and permanent stream crossings to prevent failure and control impacts from the road system. Key components are:
- **size and site crossing structures to prevent failure;**
- **for fish-bearing streams, design crossings to facilitate fish passage.**

(3) Ensure that the design of road prism and the road surface drainage are appropriate to the terrain and that road surface design is consistent with the road drainage structures.
(4) Use suitable materials to surface roads planned for all-weather use to support truck traffic.
(5) Design road systems to avoid high erosion or landslide hazard areas. Identify these areas and consult a qualified specialist for design of any roads that must be constructed through these areas.

Each State should develop a process (or utilize an existing process) that ensures that the management measures in this chapter are implemented. Such a process should include appropriate notification, compliance audits, or other mechanisms for forestry activities with the potential for significant adverse nonpoint source effects based on the type and size of operation and the presence of stream crossings or SMAs.

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1. Applicability

This management measure pertains to lands where silvicultural or forestry operations are planned or conducted. The planning process components of this management measure are intended to apply to commercial harvesting on areas greater than 5 acres and any associated road system construction or reconstruction conducted as part of normal silvicultural activities. The component for ensuring implementation of this management measure applies to harvesting and road construction activities that are determined by the State agency to be of a sufficient size to potentially impact the receiving water or that involve SMAs or stream crossings. On Federal lands, where notification of forestry activities is provided to the Federal land management agency, the provisions of the final paragraph of this measure may be implemented through a formal agreement between the State agency and the Federal land management agency. This measure does not apply to harvesting conducted for precommercial thinning or noncommercial firewood cutting.

Under the Coastal Zone Act Reauthorization Amendments of 1990, States are subject to a number of requirements as they develop coastal nonpoint source programs in conformity with this measure and will have some flexibility in doing so. The application of this management measure by States is described more fully in *Coastal Nonpoint Pollution Control Program: Program Development and Approval Guidance*, published jointly by the U.S. Environmental Protection Agency (EPA) and the National Oceanic and Atmospheric Administration (NOAA) of the U.S. Department of Commerce.

2. Description

The objective of this management measure is to ensure that silvicultural activities, including timber harvesting, site preparation, and associated road construction, are conducted without significant nonpoint source pollutant delivery to streams and coastal areas. Road system planning is an essential part of this management measure since roads have consistently been shown to be the largest cause of sedimentation resulting from forestry activities. Good road location and design can greatly reduce the sources and transport of sediment. Road systems should generally be designed to minimize the number of road miles/acres, the size and number of landings, the number of skid trail miles, and the number of watercourse crossings, especially in sensitive watersheds. Timing operations to take advantage of favorable seasons or conditions, avoiding wet seasons prone to severe erosion or spawning periods for fish, is effective in reducing impacts to water quality and aquatic organisms (Hynson et al., 1982). For example, timber harvesting might be timed to avoid periods of runoff, saturated soil conditions, and fish migration and spawning periods.

Preharvest planning should include provisions to identify unsuitable areas, which may have merchantable trees but pose unacceptable risks for landslides or high erosion hazard. These concerns are greatest for steep slopes in areas with high rainfall or snowpack or sensitive rock types. Decomposed granite, highly weathered sedimentary rocks, and fault zones in metamorphic rocks are potential rock types of concern for landslides. Deep soils derived from these rocks, colluvial hollows, and fine-textured clay soils are soil conditions that may also cause potential problems. Such areas usually have a history of landslides, either occurring naturally or related to earlier land-disturbing activities.

Potential water quality and habitat impacts should also be considered when planning silvicultural harvest systems as even-aged (e.g., clearcut, seedtree, shelterwood) or uneven-aged (e.g., group selection or individual tree selection) and planning the type of yarding system. While it may appear to be more beneficial to water quality to use uneven-aged silvicultural stand management because less ground disturbance and loss of canopy cover occur, these factors should also be weighed against the possible effects of harvesting more acres selectively to yield equivalent timber volumes. Such harvesting may require more miles of road construction, which can increase sediment generation and increase levels of road management.

In addition, for uneven-aged systems, yarding in moderately sloping areas is usually done with groundskidding equipment, which can cause much more soil disturbance than cable yarding. For even-aged systems, cable yarding may be used in sloping areas; cable yarding is not widely used for uneven-aged harvesting. Whichever silvicultural system is selected, planning will be required to minimize erosion and sediment delivery to waterbodies. Preharvest planning should address how harvested areas will be replanted or regenerated to prevent erosion and potential impact to waterbodies.

Cumulative effects to water quality from forest practices are related to several processes within a watershed (onsite mass erosion, onsite surface erosion, pollutant transport and routing, and receiving water effects) (Sidle, 1989). Cumulative effects are influenced by forest management activities, natural ecosystem processes, and the distribution of other land uses. Forestry operations such as timber harvesting, road construction, and chemical use may directly affect onsite delivery of nonpoint source pollutants as well as contribute to existing cumulative impairments of water quality.

In areas where existing cumulative effects problems *have already been assessed* for a watershed of concern, the potential for additional contributions to known water quality impairments or problems should be taken into account during preharvest planning. This does not imply that a separate cumulative effects assessment will be needed for each planned forestry activity. Instead, it points to the need to consider the potential for additional contributions to known water quality impairments based on information from previously conducted watershed or cumulative effects assessments. These types of water quality assessments, generally conducted by State or Federal agencies, may indicate water quality impairments in watersheds of concern caused by types of pollutants unrelated to forestry activities. In this case, there would be no potential for additional contributions of those pollutants from the planned forestry activity. However, if existing assessments attribute a water quality problem to the types of pollutants potentially generated by the planned forestry activity, then it is appropriate to consider this during the planning process. If additional contributions to this impairment are likely to occur as a result of the planned activity, this may necessitate adjustments in planned activities or implementation of additional measures. This may include selection of harvest units with low sedimentation risk, such as flat ridges or broad valleys; postponement of harvesting until existing erosion sources are stabilized; and selection of limited harvest areas using existing roads. The need for additional measures, as well as the appropriate type and extent, is best considered and addressed during the preharvest planning process.

Some important sediment sources related to roads are stream crossings, road fills on steep slopes, poorly designed road drainage structures, and road locations in close proximity to streams. Roads through high-erosion-hazard areas can also lead to serious water quality degradation. Some geographical areas have a high potential for serious erosion problems (landslides, major gullies, etc.) after road construction. Factors such as slope steepness, soil and rock characteristics, and local hydrology influence this potential. High-erosion-hazard areas may include badlands, loess deposits, steep and dissected terrain, and areas with existing landslides and are generally recognizable on the ground by trained personnel. Indications of hazard locations may include landslides, gullies, weak soils, unusually high ground water levels, very steep slopes, unvegetated shorelines and streambanks, and major geomorphic changes. Road system planning should identify and avoid these areas.

In most States, high-erosion-hazard areas are limited in extent. In the Pacific Coast States, however, road-related landslides are often the major source of sediment associated with forest management. Erosion hazard areas are often mapped, and these maps are one tool to use in identifying high-erosion-hazard sites. The U.S. Geological Survey has produced geologic hazard maps for some areas. The USDA Soil Conservation Service (SCS) and Agricultural Stabilization and Conservation Service (ASCS), as well as State and local agencies, may also have erosion-hazard-area maps.

Preplanning the timber harvest operation to ensure water quality protection will minimize NPS pollution generation and increase operation efficiency (Maine Forest Service, 1991; Connecticut RC&D Forestry Committee, 1990; Golden et al., 1984). The planning of streamside management area width and extent is also crucial because of SMAs' potential to reduce pollutant delivery. Identification and avoidance of high-hazard areas can greatly reduce the risk of landslides and mass erosion (Golden et al., 1984). Careful planning of road and skid trail system locations will reduce the amount of land disturbance by minimizing the area in roads and trails, thereby reducing erosion and sedimentation (Rothwell, 1978). Studies at Fernow Experimental Forest, West Virginia, demonstrated that good planning reduced skid road area by as much as 40 percent (Kochenderfer, 1970).

Designing road systems prior to construction to minimize road widths, slopes, and slope lengths will also significantly reduce erosion and sedimentation (Larse, 1971). The most effective road system results from planning conducted to serve an entire basin, rather than arbitrarily constructing individual road projects to serve short-term needs (Swift, 1985). The key environmental factors involved in road design and location are soil texture, slope, aspect, climate, vegetation, and geology (Gardner, 1967).

Proper design of drainage systems and stream crossings can prevent system destruction by storms, thereby preventing severe erosion, sedimentation, and channel scouring (Swift, 1984). Removal of excess water from roads will also reduce the potential for grade weakening, surface erosion, and landslides. Drainage problems can be minimized when locating roads by avoiding clay beds, seeps, springs, concave slopes, muskegs, ravines, draws, and stream bottoms (Rothwell, 1978).

Developing a process, or utilizing an existing process, to ensure that the management measures in this chapter are implemented is an important component for forestry nonpoint source control programs. While silvicultural management of forests may extend over long stand rotation periods of 20 to 120 years and cover extensive areas of forestland, the forestry operations that generate nonpoint source pollution, like harvesting and road building, are of relatively short duration and occur in dispersed, often isolated locations in forested areas. Forest harvesting or road building operations are usually operational on a given site only for a period of weeks or months. These operational phases are then followed by the much longer period of regrowth of the stand or the rotation period. Since forestry operations are relatively dispersed and move from site to site within forested areas, it is essential to have some process to ensure implementation of management measures. For example, it is not possible to track the implementation of management measures or determine their effectiveness if there is no way of knowing where or when they might be applied. In the case of monitoring or water quality assessments, correlation of water quality conditions to forestry activities is not possible absent some ability to determine where and to what extent forestry operations are being conducted and whether management measures are being implemented. Because of the dispersed and episodic nature of forestry operations, many States have implemented programs that currently incorporate a process such as notification to ensure implementation and to facilitate evaluation of program implementation and assessment of water quality conditions.

This process has been shown to be a beneficial device for ensuring the implementation of water quality best management practices, particularly for forestry activities. In contrast to the typical forestry situation, nonpoint pollution from urban and agricultural sources is generated from areas and activities that are relatively stationary and repetitive. Because of this, these sources of nonpoint pollution are more apparent and readily addressed than more isolated and episodic forestry operations. Given the unique nature of forestry operations, it is necessary for States to have some mechanism for being apprised of forestry activities in order to uniformly address sources of nonpoint pollution.

This Forestry Management Measure component allows considerable flexibility to States for determining how this provision should be carried out in the coastal zone. For the purposes of this management measure, such a process should include appropriate notification mechanisms for forestry activities with the potential for nonpoint source impacts. It is important to point out that for the purposes of this management measure such a notification process might be either verbal or written and does *not* necessarily require submittal and approval of written preharvest plans (although those States that currently require submittal of a preharvest plan would also fulfill this management measure component for the coastal zone program). States also have flexibility in determining what information should be provided and how this should occur for notification mechanisms. Timing and location of the planned forestry operation are common elements of existing notification requirements and may serve as an acceptable minimum. Existing programs for forestry have found some type of notification of the planned activity to the appropriate State agency to be a very beneficial device for ensuring the implementation of water quality best management practices for silvicultural activities. At least 12 Coastal Zone Management Program States currently require some type of notification, associated with Forest Practices Acts, CWA section 404 requirements, tax incentive or cost share programs, State Forester technical assistance, severance tax filings, stream crossing permits, labor permits, erosion control permits, or land management agency agreements.

3. Management Measure Selection

The rationale for this measure is based on information on the effects of various harvesting practices and the effectiveness and costs of planning, design, and location components addressed in this measure. This measure is also based in part on the experience of some States in using preharvest planning as part of implementation of best management practices.

a. Effectiveness Information

Preharvest planning has been demonstrated to play an important role in the control of nonpoint source pollution and efficient forest management operations. A fundamental component to be considered in timber harvest planning is the selection of the silvicultural system. Research conducted by Beasley and Granillo (1985) demonstrated that selective cutting generated lower water yields and sediment yields than did clearcutting. This is important not only because of the sediment loss, but also because higher stormflows can undercut streambanks and scour channels, reducing channel stability. The data in Table 3-2 show that selective cutting results in sediment yields 2.5 to 20 times less and water yields 1.3 to 2.6 times less than those resulting from clearcutting. As stated previously, the amount and potential water quality impacts of roads needed for each system must also be taken into account.

Methods used for harvesting are closely related to the silvicultural system. Four harvesting methods combined with varying types of management practices to protect water quality, including road location, were compared in a study conducted by Eschner and Larmoyeux (1963) (Table 3-3). Harvesting effects on water quality, as measured by turbidity, were shown to be clearly related to the care taken in logging and planning skid roads. The extensive

Table 3-2. Clearcutting Versus Selected Harvesting Methods (AR) (Beasley and Granillo, 1985)

Water Year	Treatment	Mean Annual Water Yield (cm)	Mean Annual Sediment Losses (kg/ha)
1981	Clearcut	6.4	41
(Preharvest)	Selection	7.4	52
	Control	6.8	52
1982	Clearcut	13.2	264
	Selection	5.1	13
	Control	1.0	4
1983	Clearcut	44.7	63
	Selection	33.8	26
	Control	31.0	19
1984	Clearcut	32.8	83
	Selection	14.5	15
	Control	17.5	46
1985	Clearcut	27.9	73
	Selection	12.3	12
	Control	15.9	17

selection method, combined with some NPS controls (20 percent road grade limits, no skidding in streams, water bars on skid roads), produced higher maximum levels of turbidity than did intensive selection with additional control practices (10 percent road grade limits; skid trails located away from streams). Harvesting by the diameter limit practice without any restrictions on road grades or stream restrictions increased maximum turbidity by 200 times over intensive selection, and commercial clearcutting with no controls increased maximum turbidity by over three orders of magnitude. This study concluded that care taken in preharvest planning of skid roads and logging operations can prevent most potential impairment to water quality.

McMinn (1984) compared a skidder logging system and a cable yarder for their relative effects on soil disturbance (Table 3-4). With the cable yarder, 99 percent of the soil remained undisturbed (the original litter still covered the mineral soil), while the amount of soil remaining undisturbed after logging by skidder was only 63 percent. Beasley, Miller, and Gough (1984) related sediment loss associated with forest roads to the average slope gradient of road segments (Table 3-5). The greater the average slope gradient, the greater the soil loss, ranging from a total of 6.8 tons/acre lost when the slope gradient was 1 percent, to 19.4 tons/acre at 4 percent, to 32.3 tons/acre at 6 percent, to 33.7 tons/acre at 7 percent.

Sidle (1980) found that the impacts of tractor skidding can be lessened through the use of preplanned skid roads and landings designed so that the area disturbed by road construction and the overall extent of sediment compaction at the site are minimized. Sidle (1980) described a study in North Carolina that showed that preplanning roads could result in a threefold decrease in soil compaction at the logging area.

Table 3-3. Effect of Four Harvesting and Road Design Methods on Water Quality (WV, PA) (Eschner and Larmoyeux, 1963)

Watershed Number	Practice	Maximum Turbidity (Turbidity units)	Frequency Distribution of Samples Turbidity Unit Classes: 0 to 10	11 to 99	100 to 999	1000+	Total
			(Number of samples)				
1	Commercial clearcut[a]	56,000	126	40	24	13	203
2	Diameter limit[b]	5,200	171	17	8	7	203
5	Extensive selection[d]	210[c]	195	8	0	0	203
3	Intensive selection[e]	25	201	2	0	0	203
4	Control	15	202	1	0	0	203

Note: Includes regularly scheduled samples and special samples in storm periods.
[a] Skid roads were not planned but were "logger's choice."
[b] Trees over 17 inches DBH were cut. Water bars placed at 2-chain intervals along skid roads.
[c] Not included in frequency distribution. This sample was taken at a time when the other watersheds were not sampled.
[d] Trees over 11 inches DBH were cut. Maximum skid road grade was 20 percent, with water bars installed as needed. Skidding was prohibited in streams.
[e] With intensive selection, trees over 5 inches DBH were cut. Maximum skid road grade was 10 percent. Skidding was prohibited in streams, and roads were located away from streams. Water bars were used as needed, and disturbed areas were stabilized with grass seeding.

Table 3-4. Comparison of the Effect of Conventional Logging System and Cable Miniyarder on Soil (GA) (McMinn, 1984)

Disturbance Class[a]	Cable Skidder (percent)	Miniyarder (percent)
Undisturbed	63	99
Soil exposed	12	1
Soil disturbed	25	0

[a] Undisturbed = original duff or litter still covering the mineral soil.
Exposed = litter and duff scraped away, exposing mineral soil, but no scarification.
Disturbed = Mineral soil exposed and scarified or dislocated.

Table 3-5. Relationship Between Slope Gradient and Annual Sediment Loss on an Established Forest Road[a] (AR) (Beasley, Miller, and Gough, 1984)

Average Slope Gradient of Road Segment (percent)	Soil Deposited[b]		Suspended Solids		Total	
	tons per acre	tons per mile	tons per acre	tons per mile	tons per acre	tons per mile
7	21.6	54.0	12.0	30.0	33.7	84.0
6	10.2	26.7	22.1	57.8	32.3	84.5
4	5.0	11.3	14.4	32.6	19.4	43.8
1	0.2	0.3	6.6	12.4	6.8	12.7

[a] The length of the road segments averaged 330 feet, ranging from 308 to 357 feet. Most of the other physical characteristics of the road were consistent, except the variation in the proportion of backslope to total area. Fill slopes below the road segments were well vegetated. Cut slopes were steep, bare, and actively eroding.
[b] Measured in upslope, inside ditches.

Several researchers have emphasized that prevention is the most effective approach to erosion control for road activities (Megahan, 1980; Golden et al., 1984). Because roads are the greatest source of surface erosion from forestry operations, reducing road surface area while maintaining efficient access is a primary component of proper road design. Careful planning of road layout and design can minimize erosion by as much as 50 percent (Yoho, 1980; Weitzman and Trimble, 1952). This practice has the added benefits of reducing construction, maintenance, and transport costs and increasing forested area for production. Rice et al. (1972) found no increase in sedimentation from a well-designed logging road on gently sloping, stable soils in Oregon except for during the construction period.

Locating roads on low gradients is another planning component that can reduce the impacts of sedimentation. Trimble and Weitzman (1953) presented data showing that lower gradients and shorter road lengths reduce erosion. The same authors, in a 1952 journal article, also presented data showing that reduced gradients in conjunction with water bars can significantly reduce erosion from roads. The data from these two studies are presented in Table 3-6.

b. Cost Information

A cost-benefit analysis by Dissmeyer and others (USDA, 1987) reveals the dramatic, immediate savings from considering water quality during the design phase of a road reconstruction project (Table 3-7). Expertise on soil and water protection provided by a hydrologist resulted in 50 percent of the savings alone. Other long-term economic benefits of careful planning such as longer road life and reduced maintenance costs were not quantified in this analysis.

Table 3-6. The Effect of Skid Road Grade and Length on Road Surface Erosion (WV, PA) (Trimble and Weitzman, 1953)

Skid Road Type (Grade and Length of Slope)	Erosion from Skid Road Surface After Logging		
	Erosion (in)	Average Grade (%)	Average Length (ft)
0-20% grade/0-132 feet	0.4	10	46
21-40% grade/0-132 feet	0.7	29	55
133-264 feet	1.0	35	211

Table 3-7. Costs and Benefits of Proper Road Design (With Water Quality Considerations) Versus Reconstruction (Without Water Quality Considerations) (USDA Forest Service, 1987)

	Without Soil/ Water Input[a]	With Soil/Water Input[a]
Miles of road	3.0	3.0
Reconstruction costs	$796,000	$372,044
Soil/water input costs	--	$800
Immediate benefit (savings) of soil/water input	--	$211,978

[a] Soil/water inputs are design adjustments made by a hydrologist and include narrower road width and steeper road bank cuts in soils of low erodibility and low revegetation potential.

Kochenderfer, Wendel, and Smith (1984) determined the costs for locating four minimum standard roads in the Central Appalachians (Table 3-8). Road location costs increased as the terrain became more difficult (e.g., had a large number of rock outcrops or steep slopes) or required several location changes. Typically, road location costs accounted for approximately 8 percent of total costs.

Ellefson and Miles (1984) performed an economic evaluation of forest practices to curb nonpoint source water pollutants. They presented the cumulative decline in net revenue of 1.2 percent for the practices of skid trail and landing design for a sale with initial net revenue of $124,340.

4. Practices

As discussed more fully at the beginning of this chapter and in Chapter 1, the following practices are described for illustrative purposes only. State programs need not require implementation of these practices. However, as a practical matter, EPA anticipates that the management measure set forth above generally will be implemented by applying one or more management practices appropriate to the source, location, and climate. The practices set forth below have been found by EPA to be representative of the types of practices that can be applied successfully to achieve the management measure discussed above.

a. Harvesting Practices

■ *Consider potential water quality and habitat impacts when selecting the silvicultural system as even-aged (clearcut, seedtree, or shelterwood) or uneven-aged (group or individual selection). The yarding system, site preparation method, and any pesticides that will be used should also be addressed in*

Table 3-8. Characteristics and Road Location[a] Costs of Four "Minimum-Standard" Forest Truck Roads Constructed in the Central Appalachians (Kochenderfer, Wendel, and Smith, 1984)

Road Number	Road Length (miles)	Road Grade (%)	Number of Dips[b]	Culvert Number	Culvert Size (in)	Culvert Length (ft)	Location Costs ($/miles)
1	0.81	6.9	22	1	18	39	585
6	0.78	2.7	15	5	15	135	615
7	0.34	3.7	5	2	15	64	720
8	1.25	2.6	30	0			585

[a] Road location includes the cost to plan, reconnoiter, and lay out 1 mile of road.
[b] Includes natural grade breaks where dozer work is required for outsloping.

preharvest planning. As part of this practice the potential impacts from and extent of roads needed for each silvicultural system should be considered.

- *In warmer regions, schedule harvest and construction operations during dry periods/seasons. In temperate regions, harvest and construction operations may be scheduled during the winter to take advantage of snow cover and frozen ground conditions.*

- *To minimize soil disturbance and road damage, limit operations to periods when soils are not highly saturated (Rothwell, 1978). Damage to forested slopes can also be minimized by not operating logging equipment when soils are saturated, during wet weather, or in periods of ground thawing.*

- *Planned harvest activities or chemical use should not contribute to problems of cumulative effects in watersheds of concern.*

- *Use topographic maps, aerial photography, soil surveys, geologic maps, and rainfall intensity charts to augment site reconnaissance to lay out and map harvest unit; identify and mark, as needed:*
  - *Any sensitive habitat areas needing special protection such as threatened and endangered species nesting areas,*
  - *Streamside management areas,*
  - *Steep slopes, high-erosion-hazard areas, or landslide prone areas,*
  - *Wetlands.*

- *In high-erosion-hazard areas, trained specialists (geologist, soil scientist, geotechnical engineer, wildland hydrologist) should identify sites that have high risk of landslides or that may become unstable after harvest and should recommend specific practices to control harvesting and protect water quality.*

- *Lay out harvest units to minimize the number of stream crossings.*

- *States are encouraged to adopt notification mechanisms that integrate and avoid duplicating existing requirements for notification including severance taxes, stream crossing permits, erosion control permits, labor permits, forest practice acts plans, etc. For example, States may require one preharvest* *plan that the landowner could submit to just one State or local office. The appropriate State agency might encourage forest landowners to develop a preharvest plan. The plan would address the components of this management measure including the area to be harvested, any forest roads to be constructed, and the timing of the activity.*

b. Road System Practices

■ *Preplan skid trail and landing location on stable soils and avoid steep gradients, landslide-prone areas, high-erosion-hazard areas, and poor-drainage areas.*

- Landings should not be located in SMAs.
- New roads and skid trails should not be located in SMAs, except at crossings. Existing roads and landings in the SMA will be closed unless the construction of new roads and landings to access an area will cause greater water quality impacts than the use of existing roads.
- Roads should not be located along stream channels where road fill extends within 50-100 horizontal feet of the *annual* high water level. (Bankfull stage is also used as reference point for this.)

■ *Systematically design transportation systems to minimize total mileage.*

- Weigh skid trail length and number against haul road length and number.
- Locate landings to minimize skid trail and haul road mileage (Rothwell, 1978).

■ *Utilize natural log landing areas to reduce the potential for soil disturbance (Larse, 1971; Yee and Roelofs, 1980).*

■ *Plot feasible routes and locations on an aerial photograph or topographic map to assist in the final determination of road locations.*

Proper design will reduce the area of soil exposed by construction activities. Figure 3-3 presents a comparison of road systems.

■ *In moderately sloping terrain, plan for road grades of less than 10 percent, with an optimal grade between 3 percent and 5 percent. In steep terrain, short sections of road at steeper grades may be used if the grade is broken at regular intervals. Vary road grades frequently to reduce culvert and road drainage ditch flows, road surface erosion, and concentrated culvert discharges (Larse, 1971).*

Gentle grades are desirable for proper drainage and economical construction (Ontario Ministry of Natural Resources, 1988). Steeper grades are acceptable for short distances (200-300 feet), but an increased number of drainage structures may be needed above, on, and below the steeper grade to reduce runoff potential and minimize erosion. In sloping terrain, no-grade road sections are difficult to drain properly and should be avoided when possible.

■ *Design skid trail grades to be 15 percent or less, with steeper grades only for short distances.*

■ *Design roads and skid trails to follow the natural topography and contour, minimizing alteration of natural features.*

This practice will reduce the amount of cut and fill required and will consequently reduce road failure potential. Ridge routes and hillside routes are good locations for ensuring stream protection because they are removed from stream channels and the intervening undisturbed vegetation acts as a sediment barrier. Wide valley bottoms are good routes if stream crossings are few and roads are located outside of SMAs (Rothwell, 1978).

Permanent Haul Road
Temporary Haul Road
Skid Road (or trail)
Bridge (water crossing)
Landing

Plans A, B, and C show three ways to place truck and skid roads on a cutting unit. The comments next to each plan indicate why Plan C is best.

Plan A layout: 2 bridges
4 landings
3 miles of haul road

Comment: Road and bridge construction costs too high. Skid distance too short. Too much steep downhill skidding. Too many landings on too steep land. Two bridges are unnecessary.

Plan B layout: 1 bridge
3 landings
3.5 miles of haul road

Comment: Loop road unnecessary. Skid distances too short. Erosion minimized up hill skidding.

Plan C layout: 1 bridge
2 landings
2 miles of haul road

Comment: Haul road follows high ground. Minimal road construction. Ideal skidding distances. Erosion minimized by uphill skidding. Least number of landings. Only one bridge required.

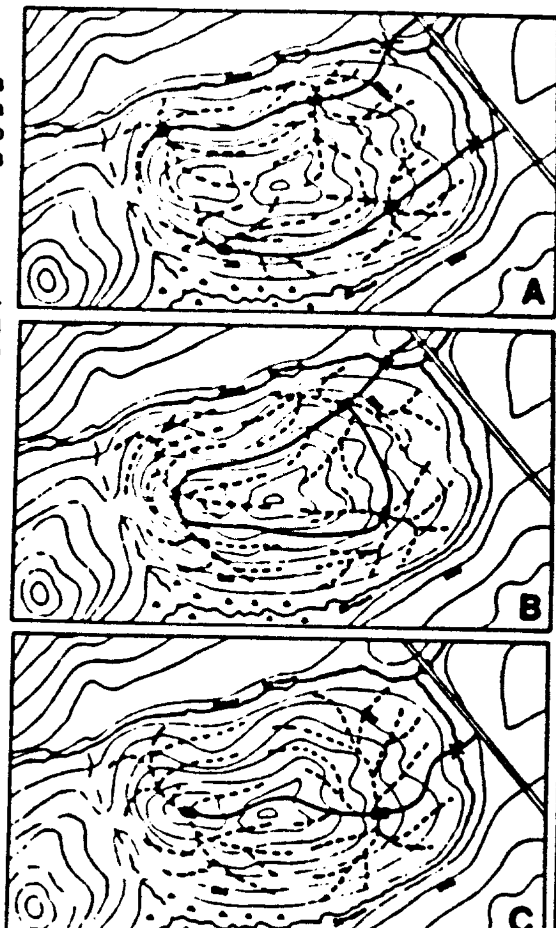

Figure 3-3. How to select the best road layout (Hynson et al., 1982).

■ *Roads in steep terrain should avoid the use of switchbacks through the use of more favorable locations. Avoid stacking roads above one another in steep terrain by using longer span cable harvest techniques.*

■ *Design roads crossing low-lying areas so that water does not pond on the upslope side of the road.*

- Use overlay construction techniques with suitable nonhazardous materials for roads crossing muskegs.
- Provide cross drains to allow free drainage and avoid ponding, especially in sloping areas.

- *Do not locate and construct roads with fills on slopes greater than 60 percent. When necessary to construct roads across slopes that exceed the angle of repose, use full-bench construction and/or engineered bin walls or other stabilizing techniques.*

- *Use full-bench construction and removal of fill material to a suitable location when constructing road prisms on sideslopes greater than 60 percent.*

- *Design cut-and-fill slopes to be at stable angles, or less than the normal angle of repose, to minimize erosion and slope failure potential.*

The degree of steepness that can be obtained is determined by the stability of the soil (Rothwell, 1978). Figure 3-4 depicts proper cut-and-fill construction. Table 3-9 presents an example of stable backslope and fill slope angles for different soil materials.

- Use retaining walls, with properly designed drainage, to reduce and contain excavation and embankment quantities (Larse, 1971). Vertical banks may be used without retaining walls if the soil is stable and water control structures are adequate.
- Balance excavation and embankments to minimize the need for supplemental building material and to maximize road stability.
- Do not use road fills at drainage crossings as water impoundments unless they have been designed as an earthfill dam that may be subject to section 404 requirements. These earthfill embankments should have outlet controls to allow draining prior to runoff periods and should be designed to pass flood flows.

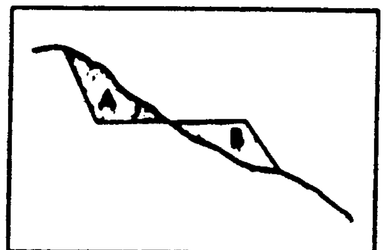

Figure 3-4. Typical side-hill cross section illustrating how cut material, A, equals fill material, B (Rothwell, 1978).

- *Allow time after construction for disturbed soil and fill material to stabilize prior to use (Huff and Deal, 1982). Roads should be compacted and stabilized prior to use. This will reduce the amount of maintenance needed during and after harvesting activities (Kochenderfer, 1970).*

Table 3-9. Stable Back Slope and Fill Slope Angles for Different Soil Materials (Rothwell, 1978)

Back Slopes		Fill Slopes	
Flat ground cuts under 0.9 m	2:1	Common for most soil types	1½:1
Most soil types with ground slopes <55%	1:1	Alluvial soils	2:1
Most soil types with ground slopes >55%	¾:1	Ballast	1:1
Hardpan of soft rock	½:1	Clay	4-1:1
Solid rock	¼:1	Rock, crushed	1-¾:1
		Gravel	1:1
		Sand, moist	1½-1:1
		Sand, saturated	2:1
		Shale	1½:1

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■ *Use existing roads, whenever practical, to minimize the total amount of construction necessary.*

Do not plan and construct a road when access to an existing road is available on the opposite side of the drainage. This practice will minimize the amount of new road construction disturbance. However, avoid using existing or past road locations if they do not meet needed road standards (Swift, 1985).

■ *Minimize the number of stream crossings for roads and skid trails. Stream crossings should be designed and sited to cross drainages at 90° to the streamflow.*

■ *Locate stream crossings to minimize channel changes and the amount of excavation or fill needed at the crossing (Furniss et al., 1991). Apply the following criteria to determine the locations of stream crossings (Hynson et al., 1982):*

- Use a streambed with a straight and uniform profile above, at, and below the crossing;
- Locate crossing so the stream and road alignment are straight in all four directions;
- Cross where the stream is relatively narrow with low banks and firm, rocky soil; and
- Avoid deeply cut streambanks and soft, muddy soil.

■ *Choose stream-crossing structures (bridges, culverts, or fords) with the structural capacity to safely handle expected vehicle loads with the least disturbance to the watercourse. Consider stream size, storm frequency and flow rates, intensity of use (permanent or temporary), water quality, and habitat value, and provide for fish passage.*

■ *Select the waterway opening size to minimize the risk of washout during the expected life of the structure.*

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Bridges or arch culverts, which retain the natural stream bottom and slope, are preferred over pipe culverts for streams that are used for fish migrating or spawning areas (Figures 3-5 and 3-6). Fish passage may be provided in streams that have wide ranges of flow by providing multiple culverts (Figure 3-7).

■ *Design culverts and bridges for minimal impact on water quality. Size small culverts to pass the 25-year flood, and size major culverts to pass the 50-year flood. Design major bridges to pass the 100-year flood.*

■ *The use of fords should be limited to areas where the streambed has a firm rock or gravel bottom (or where the bottom has been armored with stable material), where the approaches are both low and stable enough to support traffic, where fish are not present during low flow, and where the water depth is no more than 3 feet (Ontario Ministry of Natural Resources, 1988; Hynson et al., 1982).*

■ *For small stream crossings on temporary roads, the use of temporary bridges is recommended.*

Temporary bridges usually consist of logs bound together and suspended above the stream, with no part in contact with the stream itself. This prevents streambank erosion, disturbance of stream bottoms, and excessive turbidity (Hynson et al., 1982). Provide additional capacity to accommodate debris loading that may lodge in the structure opening and reduce its capacity.

■ *When temporary stream crossings are used, remove culverts and log crossings upon completion of operations.*

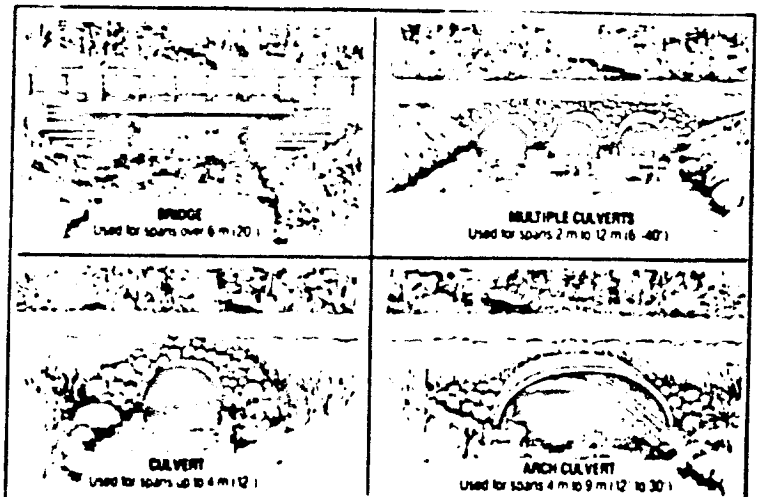

Figure 3-5. Alternative water crossing structures (Ontario Ministry of Natural Resources, 1988).

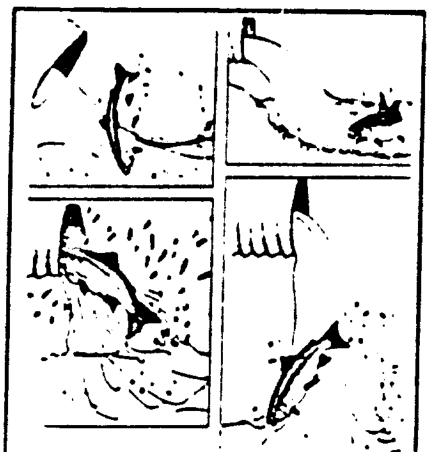

Figure 3-6. Culvert conditions that block fish passage (Yee and Roelofs, 1980).

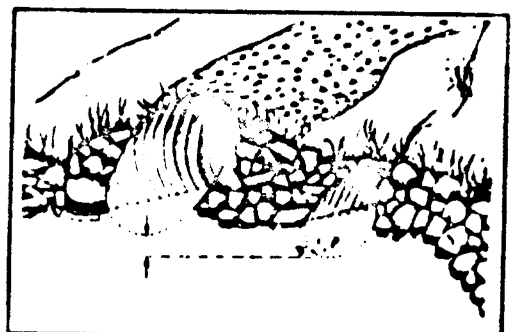

Figure 3-7. Multiple culverts for fish passage in streams that have wide ranges of flows (Hynson et al., 1982).

- *Springs flowing continuously for more than 1 month should have drainage structures rather than allowing road ditches to carry the flow to a drainage culvert.*

- *Most forest roads should be surfaced, and the type of road surface will usually be determined by the volume and composition of traffic, the maintenance objectives, the desired service life, and the stability and strength of the road foundation (subgrade) material (Larse, 1971).*

Figure 3-8 compares roadbed erosion rates for different surfacing materials.

- *Surface roads (with gravel, grass, wood chips, or crushed rocks) where grades increase the potential for surface erosion.*

- *Use appropriately sized aggregate, appropriate percent fines, and suitable particle hardness to protect road surfaces from rutting and erosion under heavy truck traffic during wet periods. Ditch runoff should not be visibly turbid during these conditions. Do not use aggregate containing hazardous materials or high sulfide ores.*

- *Plan water source developments, used for wetting and compacting roadbeds and surfaces, to prevent channel bank and streambed impacts. Access roads should not provide sediment to the water source.*

- *Many States currently utilize some process to ensure implementation of management practices. These processes are typically related to the planning phase of forestry operations and commonly involve some type of notification process. Some States have one or more processes in place which serve as notification mechanisms used to ensure implementation. These State processes are usually associated with either Forest Practices Acts, Erosion Control Acts, State Dredge and Fill or CWA Section 404 requirements, timber tax requirements, or State and Federal incentive and cost share programs. The examples of existing State processes below illustrate some of these which might also be used as mechanisms to ensure implementation of management measures.*

Florida Water Management Districts require notification prior to conducting forestry operations that involve stream crossings. This is required in order to meet the requirements of a State Dredge and Fill general permit, comparable to a CWA section 404 requirement. This notification is usually done by mail, but at least one water management district also allows verbal notification for some types of operations by telephoning an answering machine. In Florida, notification is required for any crossing of "Waters of the State," including wetlands, intermittent streams and creeks, lakes, and ponds. If any of these waters in the State are to be crossed during forestry operations, either by haul roads or by groundskidding, then notification is needed and State BMPs are required by reference in the general permit. Notification is usually provided by mailing in a notification sheet, which says who will conduct the operation and where it will be conducted (see Appendix 3A, Example 3A-1). In addition, information on what type of operation will be conducted, the name of a contact person, and a sketch of the site are included. Use of pesticides for forestry applications in Florida also requires licensing by the State Bureau of Pesticides.

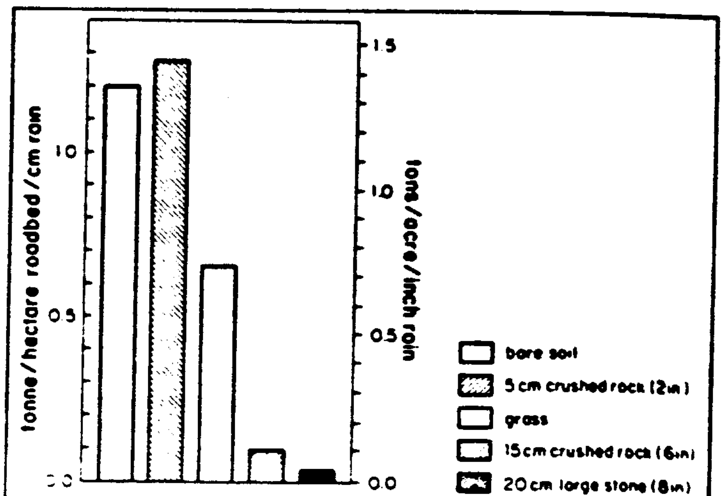

Figure 3-8. Soil loss rates for roadbeds with five surfacing treatments. Roads constructed of sandy loam saprolite (Swift, 1988).

The Oregon Forest Practice Rules require that the landowner or operator notify the State Forester at least 15 days prior to commencement of the following activities: (1) harvesting of forest tree species; (2) construction, reconstruction and improvement of roads; (3) application of pesticides and fertilizers; (4) site preparation for reforestation involving clearing or use of heavy machinery; (5) clearing forest land for conversion to any non-forest use; (6) disposal or treatment of slash; (7) pre-commercial thinning; and (8) cutting of firewood, when the firewood will be sold or used for barrier. The State must approve the activity within 15 days and may require the submittal of a written plan. In addition, the preparation and submittal of a written plan is required for all operations within 100 feet of Class I waters, which are waters that support game fish or domestic uses, or within 300 feet of wetlands and sensitive wildlife habitat areas. Appendix 3A, Example 3A-2 contains a copy of Oregon's Notification of Operation/Application for Permit form. Oregon has developed a system of prioritization for the review and approval of these written plans. In Oregon, notification of intent to harvest is provided to the Department of Revenue through the Department of Forestry for purposes of tax collection. Additional permits for operation of power-driven machinery and to clear rights-of-way for road systems are also required.

New Hampshire does not have a Forest Practices Act, but does have a number of other State processes that serve as notification mechanisms for forestry activities. Prior to conducting forest harvesting, an Intent to Cut Application must be submitted to the Department of Revenue Administration (see Appendix 3A, Example 3A-3). This is required for the timber yield tax, and is filed in order to get a certificate for intent to cut. The Intent to Cut Application must be accompanied by an application for Filling, Dredging or Construction of Structures for those operations that involve the crossing of any freshwater wetland, intermittent or perennial stream, or other surface water. If the activity is not considered a minimum impact, a written plan must be submitted and approved before work may begin. Signature of these applications by the owner or operator adopts by reference the provisions of the State Best Management Practice Handbook. The State Erosion Control Act also requires notification for obtaining a permit for ground-disturbing activities greater than 100,000 square feet. This permit is required prior to commencement of operations. Another State process that entails notification is the provisions for the prevention of pollution from terrain alteration. These provisions require the submission of a plan 30 days before conducting the transport of forest products in or on the border of the surface waters of the State or before significantly altering the characteristics of the terrain in such a manner as to impede the natural runoff or create an unnatural runoff. The State must grant written permission before operations of this type may take place. Each of these existing State mechanisms entails the notification of the State prior to conducting forestry operations. Pesticides licensing is also necessary if the forestry operation involves the application of herbicides or insecticides.

Streamside Management Areas (SMAs)

Establish and maintain a streamside management area along surface waters, which is sufficiently wide and which includes a sufficient number of canopy species to buffer against detrimental changes in the temperature regime of the waterbody, to provide bank stability, and to withstand wind damage. Manage the SMA in such a way as to protect against soil disturbance in the SMA and delivery to the stream of sediments and nutrients generated by forestry activities, including harvesting. Manage the SMA canopy species to provide a sustainable source of large woody debris needed for instream channel structure and aquatic species habitat.

1. Applicability

This management measure pertains to lands where silvicultural or forestry operations are planned or conducted. It is intended to apply to surface waters bordering or within the area of operations. SMAs should be established for perennial waterbodies as well as for intermittent streams that are flowing during the time of operation. For winter logging, SMAs are also needed for intermittent streams since spring breakup is both the time of maximum transport of sediments from the harvest unit and the time when highest flows are present in intermittent streams.

Under the Coastal Zone Act Reauthorization Amendments of 1990, States are subject to a number of requirements as they develop coastal nonpoint source programs in conformity with this measure and will have some flexibility in doing so. The application of this management measure by States is described more fully in *Coastal Nonpoint Pollution Control Program: Program Development and Approval Guidance*, published jointly by the U.S. Environmental Protection Agency (EPA) and the National Oceanic and Atmospheric Administration (NOAA) of the U.S. Department of Commerce.

2. Description

The streamside management area (SMA) is also commonly referred to as a streamside management zone (SMZ) or as a riparian management area or zone. SMAs are widely recognized to be highly beneficial to water quality and aquatic habitat. Vegetation in SMAs reduces runoff and traps sediments generated from upslope activities, and reduces nutrients in runoff before it reaches surface waters (Figure 3-9, Kundt and Hall, 1988). Canopy species provide shading to surface waters, which moderates water temperature and provides the detritus that serves as an energy source for stream ecosystems. Trees in the SMA also provide a source of large woody debris to surface waters. SMAs provide important habitat for aquatic organisms (and terrestrial species) while preventing excessive logging-generated slash and debris from reaching waterbodies (Corbett and Lynch, 1985).

SMAs need to be of sufficient width to prevent delivery of sediments and nutrients generated from forestry activities (harvest, site preparation, or roads) in upland areas to the waterbody being protected. Widths for SMAs are established by considering the slope, soil type, precipitation, canopy, and waterbody characteristics. To avoid failure of SMAs, zones of preferential drainage such as intermittent channels, ephemeral channels and depressions need to be addressed when determining widths and laying out SMAs. SMAs should be designed to withstand wind damage or blowdown. For example, a single rank of canopy trees is not likely to withstand blowdown and maintain the functions of the SMA.

SMAs should be managed to maintain a sufficient number of large trees to provide for bank stability and a sustainable source of large woody debris. Large woody debris is naturally occurring dead and down woody materials and should not be confused with logging slash or debris. Trees to be maintained or managed in the SMA should provide for large woody debris recruitment to the stream at a rate that maintains beneficial uses associated with fish habitat and stream structure at the site and downstream. This should be sustainable over a time period that is equivalent to that needed for the tree species in the SMA to grow to the size needed to provide large woody debris.

A sufficient number of canopy species should also be maintained to provide shading to the stream water surface needed to prevent changes in temperature regime for the waterbody and to prevent deleterious temperature- or sunlight-related impacts on the aquatic biota. If the existing shading conditions for the waterbody prior to activity are known to be less than optimal for the stream, then SMAs should be managed to increase shading of the waterbody.

To preserve SMA integrity for water quality protection, some States limit the type of harvesting, timing of operations, amount harvested, or reforestation methods used. SMAs are managed to use only harvest and silvicultural methods that will prevent soil disturbance within the SMA. Additional operational considerations for SMAs are addressed in subsequent management measures. Practices for SMA applications to wetlands are described in Management Measure J.

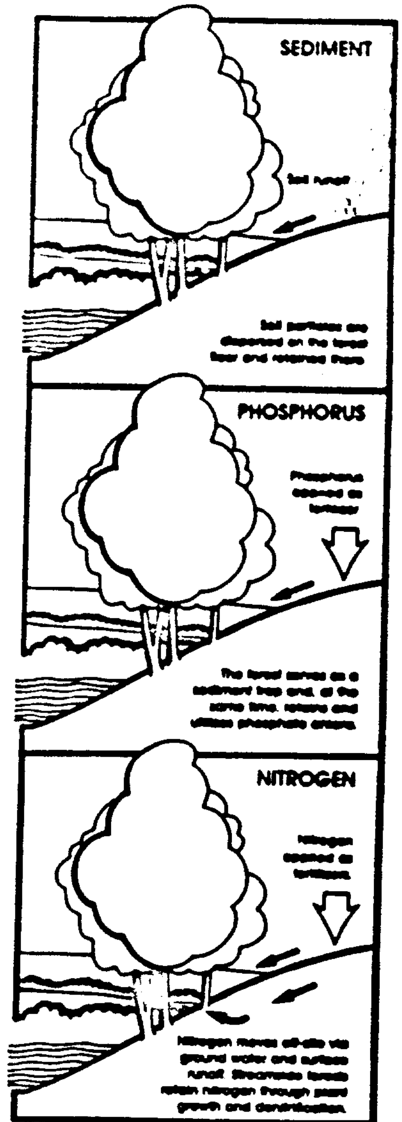

Figure 3-9. SMA pollutant removal processes (Kundt and Hall, 1988).

3. Management Measure Selection

a. Effectiveness Information

The effectiveness of SMAs in protecting streams from temperature increases, large increases in sediment load, and reduced dissolved oxygen was demonstrated by Hall and others (1987) (Table 3-10). Lantz (1971) (Table 3-11) also showed the protection that streamside vegetation and selective cutting gave to both water quality and the cutthroat trout population. A comparison of physical changes associated with logging using three streamside treatments was made by Hartman and others (1987) (Table 3-12). This study was performed to observe the impact of these SMAs on the supply of woody debris essential to the fish population and channel structure. The volume and stability of large woody debris decreased immediately in the most intensive treatment area, decreased a few years after logging in the careful treatment area, and remained stable where streamside trees and other vegetation remained.

Other experimental forest studies have found that average monthly maximum water temperature increases from 3.3 to 10.5 °C following clearcutting (Lynch et. al., 1985). Increases in stream temperature result from increased direct solar radiation to the water surface from the removal of vegetative cover or shading in the streamside area. Stream temperature change depends on the height and density of trees, the width of the waterbody, and the volume of water (stream discharge), with small streams heating up faster than large streams per unit of increased solar radiation (Megahan, 1980). Increased direct solar radiation also shifts the energy sources for stream ecosystems from outside the stream sources, allochthonous organic matter, to instream producers, autochthonous aquatic plants such as algae.

Table 3-10. Comparison of Effects of Two Methods of Harvesting on Water Quality (OR) (Hall et al., 1987)

Watershed	Method	Streamflow	Water Temp.	Sediment	Dissolved Oxygen
Deer Creek	Patch cut with buffer strips (750 acres)	No increase in peak flow	No change	Increases for one year due to periodic road failure	No change
Needle Branch	Clearcut with no stream protection (175 acres)	Small increases	Large changes, daily maximum increase by 30°F, returning to pre-log temp. within 7 years	Five-fold increase during first winter, returning to near normal the fourth year after harvest	Reduced by logging slash to near zero in some reaches; returned to normal when slash removed

Brown and Krygier (1970) report the greatest long-term average temperature response following clearcutting and slash disposal on a small watershed in Oregon. The average monthly temperature increased 14 °F compared to no increase on an adjacent, larger watershed that was clearcut in patches with 50- to 100-foot-wide buffer strips between the logging units and the perennial streams. Lynch and Corbett (1990) report less than a 3 °F mean temperature increase following harvesting, with 100-foot buffer strips along perennial streams. They attribute the increase to an intermittent stream with no protective vegetation that became perennial after harvesting due to increased flow. As a result of this BMP evaluation study, Pennsylvania modified its BMPs to require SMAs along both perennial and intermittent streams.

Another benefit of streamside management areas is control of suspended sediment and turbidity levels. Lynch and others (1985) documented the effectiveness of SMAs in controlling these pollutants (Table 3-13). A combination of practices was applied, including buffer strips and prohibitions for skidding, slash disposal, and road layout in or near streams. Average stormwater-suspended sediment and turbidity levels for the treatment without these practices increased significantly compared to the control and SMA/BMP sites.

Table 3-11. Water Quality Effects from Two Types of Logging Operations in the Alsea Watershed (OR) (Lantz, 1971)

Watershed and Logging Method	Acreage	Oxygen Content	Temperature	Suspended Sediment	Cutthroat Trout Population
Needle Branch; clearcut, streamside vegetation removed	175	Decrease during summer due to debris in water	Increase of maximum from 61°F to 85°F	Increase (largest contribution from roads)	Decrease from 265 to 65 fish in stream ½ mile
Deer Creek; selection cut, streamside vegetation retained	750 30% harvested	Only minor changes, if any			
Flynn Creek; control	500	No changes			

Table 3-12. Summary of Major Physical Changes Within Streamside Treatment Areas (BC) (Hartman et al., 1987)

	Streamside Treatment						
	Leave Strip[a]			Careful[b]	Intensive[c]		
	II	III	IV	VIII	V	VI	VII
Large Debris							
Mean volume (m³/30 m)							
Prelogging	29.6	34.2	37.4	14.3	25.4	26.0	78.2
Postlogging	29.5	50.4	36.4	14.7	23.2	20.0	19.5
Mean number of pieces							
Prelogging	34.0	27.3	32.0	14.2	25.0	25.3	19.8
Postlogging	36.5	27.0	30.0	20.9	27.5	36.2	23.0
Means of stability indices							
Prelogging	54.7	53.0	84.4	82.0	80.2	93.1	98.9
Postlogging	63.3	61.7	61.2	39.0	35.7	43.9	56.2
Small Debris							
Volume							
Prelogging	--	--	--	--	Volume not measured but low. Volume increased after logging and reduced by 90% after 1978 freshet.		--
Postlogging	--	--	--	--			--

Sources: All results except those on substrate change are from Schultz International (1981) and Toews and Moore (1982). The results on substrate change are from Scrivener and Brownlee (1986).

[a] Leave strip treatment included leaving a variable-width strip of vegetation along the stream.

[b] Careful treatment involved clearcutting to the margin of the stream and felling of streambank alder, with virtually no in-channel activity.

[c] Intensive treatment involved clearcutting to the streambank, felling of streambank alder, some yarding of felled trees, and merchantable blowdown from the stream.

Table 3-13. Storm Water Suspended Sediment Delivery for Different Treatments (PA) (Lynch, Corbett, and Mussallem, 1985)

Water Year and Treatment	Annual Average Suspended Sediment in mg/l (Range)
1977	
Forested control	1.7(0.2 - 8.6)
Clearcut-herbicide	10.4(2.3 - 30.5)
Commercial clearcut with BMPs[a]	5.9(0.3 - 20.9)
1978	
Forested control	5.1(0.3 - 33.5)
Clearcut-herbicide	--[b] (1.8 - 38.0)
Commercial clearcut with BMPs[a]	9.3(0.2 - 76.0)

[a] Buffer strips, skidding in streams prohibited, slash disposal away from streams, skid trail and road layout away from streams.

[b] Data not available.

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Table 3-14. Average Changes in Total Coarse and Fine Debris of a Stream Channel After Harvesting (OR) (Froehlich, 1973)

Cutting Practice	Natural Debris (tons per hundred feet of channel)	Material Added in Felling (tons per hundred feet of channel)	% Increase
Conventional tree-felling	8.1	47	570
Cable-assisted directional felling	16	14	112
Conventional tree-felling with buffer strip[a]	12	1.3	14

[a] Buffer strips ranged from 20 to 130 feet wide for different channel segments.

Practices such as directional felling are designed to minimize stream and streambank damage associated with increased logging debris in SMAs. Froehlich (1973) provides data on how effective different cutting practices and buffer strips are in preventing debris from entering the stream channel (Table 3-14). Buffer strips were the most effective debris barriers. Narver (1971) investigated the impacts of logging debris in streams on salmonid production and describes threats to fish embryo survival from low dissolved oxygen concentrations and decreased flow velocities in intragravel waters. Erman and others (1977) studied the effectiveness of buffer strips in protecting aquatic organisms and found significant differences in benthic invertebrate communities when logging occurred with buffer strips less than 30 meters wide.

b. Cost Information

In 4 of the 10 areas in Oregon studied by Dykstra and Froelich (1976a), the 55-foot buffer strip was the least costly alternative, yet these researchers concluded that no single alternative is preferable for all sites in terms of costs and that cost analysis alone cannot resolve the question of best stream protection method (Table 3-15).

Dykstra and Froehlich (1976b) also found that increased cable-assisted directional felling costs (68 to 108 percent increase) were offset by savings in channel clean-up costs (only 27 percent as much large debris and 39 percent small debris accumulated in the stream for cable-assisted felling), increased yield from reduced breakage, and reduced yarding costs. They also estimated costs for debris removal from streams to be $300 to clean 5 tons of debris from a 100-foot segment, or about $60 per ton of residue removed.

Table 3-15. Average Estimated Logging and Stream Protection Costs per MBF[a] (OR) (Dykstra and Froehlich, 1976a)

Cutting Practice	Total Cost: Average	Total Cost: Range	Volume Foregone
Conventional felling	$24.78	$21.90 - 29.93	None
Cable-assisted directional felling (1.43% breakage saved within 200-foot stream)	$26.05	$21.36 - 31.24	--
Cable-assisted felling (10% breakage saved)	$24.64	$19.55 - 29.82	--
Buffer strip (55 feet wide)	$23.34	$19.84 - 27.77	0 to 6 percent
Buffer strip (150 feet wide)	$27.15	$24.33 - 30.28	6 to 17 percent

[a] Cost estimates for each of 10 areas studied by Dykstra and Froehlich were averaged for this table.

Lickwar (1989) examined the costs of SMAs as determined by varying slope steepness (Table 3-16) in different regions in the Southeast and compared them to road construction and revegetation practice costs. He found SMAs to be the least expensive practice, in general, and to cost roughly the same independent of slope.

The costs associated with use of alternative buffer and filter strips were also analyzed in an Oregon case study (Olsen, 1987) (Table 3-17) and by Ellefson and Weible (1980). In the Oregon case study, increasing the buffer width from 35 feet on each side of a stream to 50 feet was shown to reduce the value per acre by $103 undiscounted and $75 discounted costs, approximately a 2 percent increase on a harvesting cost per acre of $5,163 undiscounted and $3,237 discounted. Doubling the buffer width from 35 to 70 feet on each side reduced the dollar value per acre by approximately 3 times more, adding approximately 8 percent to the discounted harvesting costs. Ellefson and Weible also analyzed the added cost and rate of return associated with various filter and buffer strip widths. Doubling the width of a filter strip from 30 to 60 feet increases the cost from $12 to $44 per sale and reduces the rate of return by 0.4 percent. Doubling the width of the buffer strip from 30 to 60 feet doubles the cost and reduces the rate of return by 1 percent. Increasing the width of the buffer strip from 30 to 100 feet triples the cost and reduces the rate of return by 2.3 percent.

4. Practices

As discussed more fully at the beginning of this chapter and in Chapter 1, the following practices are described for illustrative purposes only. State programs need not require implementation of these practices. However, as a practical matter, EPA anticipates that the management measure set forth above generally will be implemented by applying one or more management practices appropriate to the source, location, and climate. The practices set forth below have been found by EPA to be representative of the types of practices that can be applied successfully to achieve the management measure discussed above.

■ ***Generally, SMAs should have a minimum width of 35 to 50 feet. SMA width should also increase according to site-specific factors. The primary factors that determine the extension of SMA width are slope, class of watercourse, depth to water table, soil type, type of vegetation, and intensity of management.***

Many States use SMAs. Examples of SMA designation strategies from Florida, North Carolina, Maine, and Washington are presented. Figure 3-10 depicts Florida's streamside management zone (SMZ) designations. Florida's SMZs are divided into a fixed-width primary zone and a variable secondary zone, each of which has its own special management criteria. Table 3-18 presents North Carolina's recommendations for SMZ widths for various types of waterbodies dependent on adjacent upland slope. Maine's recommended filter strip widths are dependent on the land

Table 3-16. Cost Estimates (and Cost as a Percent of Gross Revenues) for Streamside Management Areas (1987 Dollars) (Lickwar, 1989)

Practice Component	Steep Sites[a]		Moderate Sites[b]		Flat Sites[c]	
Streamside Management Zones	$2,061.77	(0.52%)	$2,397.80	(0.51%)	$2,344.08	(0.26%)

[a] Based on a 1,148-acre forest and gross harvest revenues of $399,68. Slopes average over 9 percent.
[b] Based on a 1,104-acre forest and gross harvest revenues of $473,18. Slopes ranged from 4 percent to 8 percent.
[c] Based on a 1,832-acre forest and gross harvest revenues of $899,49. Slopes ranged from 0 percent to 3 percent.

Table 3-17. Cost Impacts of Three Alternative Buffer Strips (OR)[a]: Case Study Results with 640-Acre Base (36 mbf/acre) (Olsen, 1987)

	Scenario I	Scenario II	Scenario III
Average buffer width (feet on each side)	35	50	70
Percent conifers removed	100	60	25
Percent reclassified Class II streams[b]	0	20	80
Harvesting restrictions	Current	New	New
Road Construction			
New miles	2.09	2.14	3.06
Road and landing acres	10.9	11.1	15.9
Cost total (1000's)	$96.00	$102.00	$197.00
Cost/acre	$149.00	$160.00	$307.00
Harvesting Activities[c]			
mmbf harvested	22.681	22.265	20.277
Acres harvested	638.3	635.5	633.1
Cost total (1000's)	$3,104.00	$3,101.00	$2,842.00
Cost/acre	$4,841.00	$4,835.00	$4,432.00
Cost/mbf	$136.87	$139.26	$140.17
Inaccessible Area and Volume			
Percent area in buffers	1.3	3.9	14.0
mmbf left in buffers	0.000	0.313	2.214
Acres unloggable	1.44	4.32	6.72
mmbf lost to roads and landings	0.202	0.205	0.295
Undiscounted Costs (1000's)			
Road cost	$96.00	$102.00	$197.00
Harvesting cost	$3,104.00	$3,101.00	$2,842.00
Value of volume foregone[d]	$38.00	$101.00	$413.00
Total	$3,238.00	$3,304.00	$3,451.00
Cost/acre	$5,060.00	$5,163.00	$5,393.00
Reduced dollar value/acre	—	$103.00	$323.00
Discounted Costs			
Cost with 4% discount rate (1000's)	$2,023.00	$2,071.00	$2,195.00
Cost/acre	$3,162.00	$3,237.00	$3,431.00
Reduced value/acre	—	$75.00	$269.00

mmbf = million board feet; mbf = thousand board feet

[a] 1986 dollars.

[b] Generally, only Class I streams are buffered.

[c] Includes felling, landing construction and setup, yarding, loading, and hauling.

[d] Volume foregone x net revenue ($150/mbf).

slope between the road and waterbody (Table 3-19). Washington State requires a riparian management zone (RMZ) around all Type 1, 2, and 3 waters where the adjacent harvest cutting is a regeneration cut or a clearcut. A guide for calculating the average width of the RMZ is provided in the Forest Practices Board manual (Washington State Forest Practices Board, 1988)(Figure 3-11).

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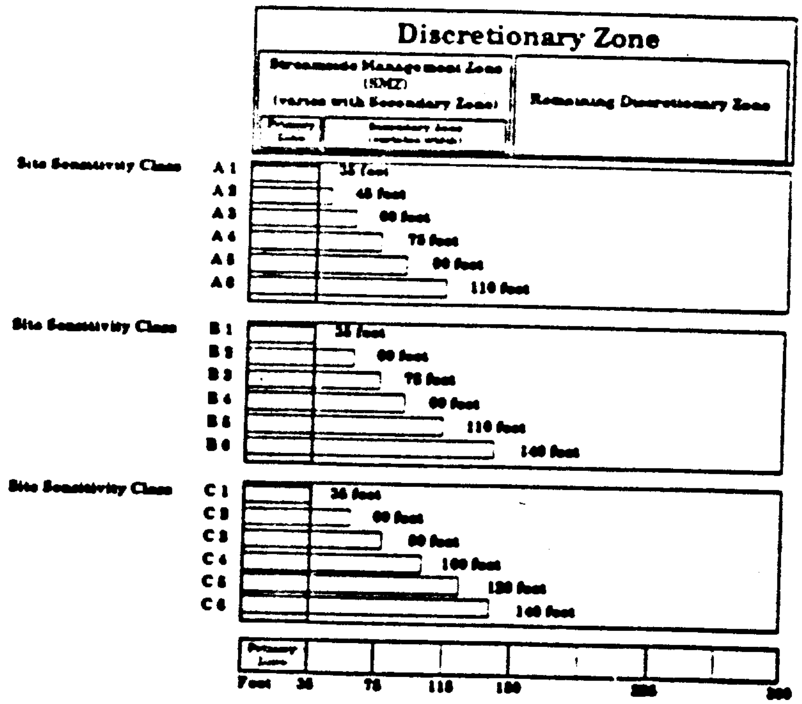

Site Sensitivity Classification

Soil Erodibility	K Factor	Slope					
		0 to 2%	2% to 7%	8% to 12%	13% to 17%	18% to 22%	22% +
Low	Less than 0.20	A 1	A 2	A 3	A 4	A 5	A 6
Moderate	0.21 thru 0.27	B 1	B 2	B 3	B 4	B 5	B 6
High	Greater than 0.28	C 1	C 2	C 3	C 4	C 5	C 6

Figure 3-10. Florida's streamside management zone widths as defined by the Site Sensitivity Classification (Florida Department of Agriculture and Consumer Services, Division of Forestry, 1991).

- *Minimize disturbances that would expose the mineral soil of the SMA forest floor. Do not operate skidders or other heavy machinery in the SMA.*
- *Locate all landings, portable sawmills, and roads outside the SMA.*
- *Restrict mechanical site preparation in the SMA, and encourage natural revegetation, seeding, and handplanting.*
- *Limit pesticide and fertilizer usage in the SMA. Buffers for pesticide application should be established for all flowing streams.*

Table 3-18. Recommended Minimum SMZ Widths (North Carolina Division of Forest Resources, 1989)

Type of Stream or Waterbody	Percent Slope of Adjacent Lands: 0-5	6-10	11-20	21-45	46+
	SMZ Width Each Side (feet)				
Intermittent	50	50	50	50	50
Perennial	50	50	50	50	50
Perennial Trout Waters	50	66	75	100	125
Public Water Supplies (Streams and Reservoirs)	50	100	150	150	200

■ *Directionally fell trees away from streams to prevent logging slash and organic debris from entering the waterbody.*

■ *Apply harvesting restrictions in the SMA to maintain its integrity.*

Enough trees should be left to maintain shading and bank stability and to provide woody debris. This provision for leaving residual trees can be accomplished in a variety of ways. For example, the Maine Forestry Service (1991) specifies that no more than 40 percent of the total volume of timber 6 inches DBH and greater should be removed in a 10-year period, and the trees removed should be reasonably distributed within the SMA. Florida (1991) recommends leaving a volume equal to or exceeding one-half the volume of a fully stocked stand. The number of residual trees varies inversely with their average diameter (Table 3-20). A shading requirement independent of the volume of timber may be necessary for streams where temperature changes could alter aquatic habitat.

Studies by Brazier and Brown (1973) demonstrated that the effectiveness of the SMA in controlling temperature changes is independent of timber volume; it is a complex interrelationship between canopy density, canopy height, stream width, and stream discharge. The Washington State Forest Practices Board (1988) incorporates leave tree and shade requirements in its regulations (Figure 3-12). Shade requirements within the SMA are to leave all nonmerchantable timber that provides midsummer and midday shade to the water surface, and to leave sufficient merchantable timber necessary to retain 50 percent of the summer midday shade. Shade cover is preferably left distributed evenly within the SMA (Figure 3-13). If a threat of blowdown exists, then clumping and clustering of leave trees may be used as long as the shade requirement is met (Figure 3-14).

Table 3-19. Recommendations for Filter Strip Widths (Maine Forest Service, 1991)

Slope of Land (%)	Width of Strip (ft along ground)
0	25
10	45
20	65
30	85
40	105
50	125
60	145
70	165

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Guidelines for Calculating Average Width of Riparian Management Zones (RMZ)

Use the following procedures to calculate average width of Eastern Washington riparian management zone (RMZ) when the adjacent harvest cutting is a regeneration cut or clearcut. Average RMZ width is also used to calculate the acreage and number of trees/acre. (See WAC 222-16-010(33) Partial Cut.)

Procedures

1. RMZs are measured separately on each side of streams. Begin at the ordinary high water mark of Type 1, 2 and 3 Waters and measure the horizontal distance to the line where vegetation changes from wetland to upland type, EXCEPT where the distance is less than the minimum or greater than the maximum widths in the rules. (See 7 below and Figure 14.)
2. Width measurements (horizontal distance) are taken at right angles to the stream reach. See WAC 222-30-020(6) for description of Eastern Washington RMZ. Western Washington RMZ is described in WAC 222-30-020(5).
3. Measure width of RMZ at 5 or more similarly spaced intervals.
4. Use 50 feet or greater distance between width measurements. Sample the entire stream reach within the harvest unit.
5. On each end of the stream reach being measured, begin and end width measurements at one-half the interval used for the other measurements. This helps to reduce sampling errors.
6. If the RMZ width varies more than 30 feet in a set of measurements, increase the number of measurements. Try for uniform sampling. Use enough measurements to adequately sample natural variations in width. (See Figure 14.)
7. On Eastern Washington PARTIAL CUTS, a width of less than 30 feet is treated as 30 feet and a width of more than 50 feet is treated as 50 feet when calculating the average RMZ width for leave trees/acre because these distances are specified in the rules. The natural riparian area may be wider or narrower than stated in the rules.

   For other types of cuts, minimum width is measured in the same way as for partial cuts. But the actual width of more than 30 feet is treated up to a maximum of 300 feet. If the riparian area is wider than 300 feet, it is treated as 300 feet.
8. Calculate average width by totaling the widths in feet and dividing by the number of measurements.
9. In Eastern Washington where the adjacent harvest is a regeneration cut or clearcut, RMZs must AVERAGE 50 feet in width.
10. Multiply average RMZ width by its length within the cutting unit to calculate square feet of RMZ. Measure length approximately parallel to stream reach and near outer edge of RMZ.
11. Multiply square feet by 0.000023 to calculate acres or use Acreage Table 6. (Figure 15 describes leave trees and snags for Eastern Washington RMZ.)

Figure 14. Eastern Washington Riparian Management Zone (RMZ)

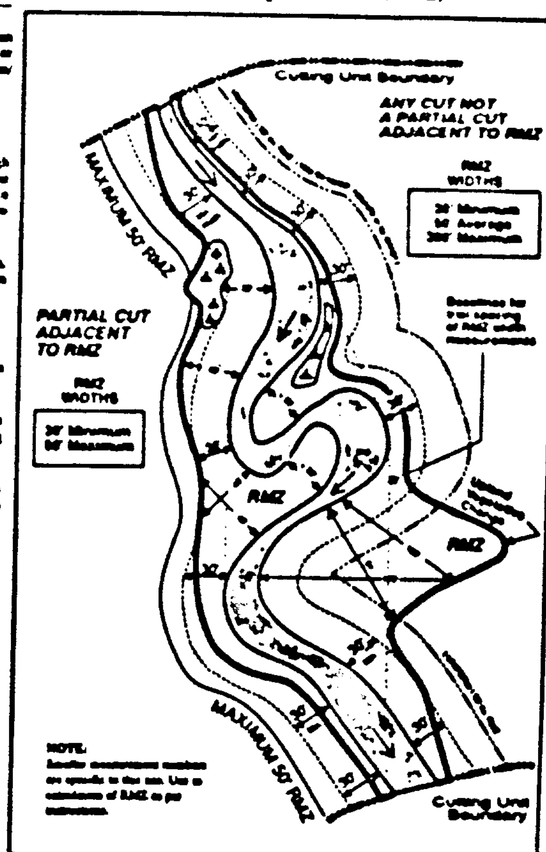

Figure 3-11. Guide for calculating the average width of the RMZ (Washington State Forest Practices Board, 1988).

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Table 3-20. Stand Stocking in the Primary SMZ (Florida Department of Agriculture and Consumer Services, Division of Forestry, 1991)

Average Tree Size (DBH)	Minimum Number of Trees per 100 feet	Average Tree Spacing (feet)
Small (2" to 6")	18	14
Medium (8" to 12")	7	23
Large (14"+)	3	34

Design for Leave Trees and Snags/Acre - Type 1, 2 and 3 Water
(50 percent of ALL leave trees are to be live at completion of harvest.)

#/Ac.	Cond.	Species	Size by dbh	Other Design Criteria
All	Live	Trees	12" or less,	AND
All*	Dead	Snags	All, *(exc. those in viol. L & I Rules)	
			AND	
16	Live	Conifers	12 - 20" diam. a size repr. of stand,	
			AND	
3	Live	Conifers	20" or larger,	AND
[2	Live	Deciduous	Largest trees 16" & larger,	EXCEPT]
[Where 2 Live Deciduous Trees 16" dbh & larger do NOT exist,				AND]
		2 Dead Snags 20" dbh & larger do not exist,		
			SUBSTITUTE	
[2	Live	Conifers	20" or larger, IF these do NOT exist,	]
			SUBSTITUTE	
[5	Live	Conifers	Largest available,	]
			AND	
3	Live	Deciduous	12 - 16", IF they exist in the RMZ, AND	

ADDITIONAL Trees to Total the Minimum Number of Leave Trees:

Minimum Total Number of Leave Trees/Acre
(includes Design Trees)

Adjacent Type of Cut*	Measured 1 Side Width of RMZ			Number of Trees/Acre by Type of Bed	
	Min.	Max.	AV.	Gravel-Cobble (<10" diameter)	Boulder/Bedrock (& lake & pond)
Partial	30'	50'	DNA**	135, 4" dbh & >	75, 4" dbh & >
Other	30'	300'	50'	135, 4" dbh & >	75, 4" dbh & >

*(See definition, regeneration cuts of any type are NOT Partial.)
**Does not apply.

Figure 3-12. Washington State Forest Practices Board (1988) requirements for leave trees in the RMZ.

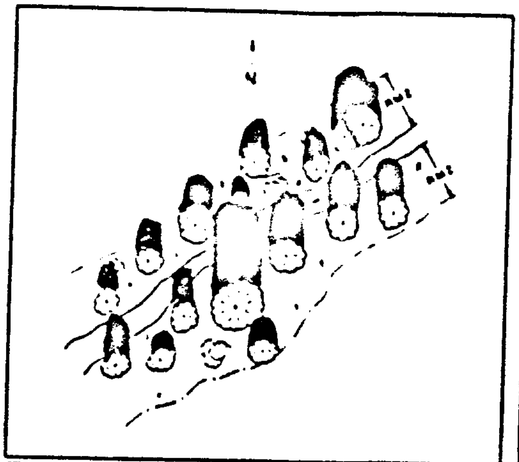

Figure 3-13. Uniform harvesting in the riparian zone (Washington State Forest Practices Board, 1988).

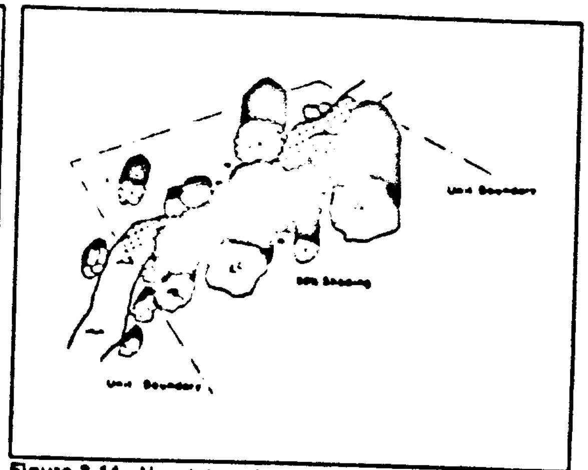

Figure 3-14. Vegetative shading along a stream course (Washington State Forest Practices Board, 1988).

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(1) Follow preharvest planning (as described under Management Measure A) when constructing or reconstructing the roadway.
(2) Follow designs planned under Management Measure A for road surfacing and shaping.
(3) Install road drainage structures according to designs planned under Management Measure A and regional storm return period and installation specifications. Match these drainage structures with terrain features and with road surface and prism designs.
(4) Guard against the production of sediment when installing stream crossings.
(5) Protect surface waters from slash and debris material from roadway clearing.
(6) Use straw bales, silt fences, mulching, or other favorable practices on disturbed soils on unstable cuts, fills, etc.
(7) Avoid constructing new roads in SMAs to the extent practicable.

1. Applicability

This management measure is intended for application by States on lands where silvicultural or forestry operations are planned or conducted. It is intended to apply to road construction/reconstruction operations for silvicultural purposes, including:

- The clearing phase: clearing to remove trees and woody vegetation from the road right-of-way;
- The pioneering phase: excavating and filling the slope to establish the road centerline and approximate grade;
- The construction phase: final grade and road prism construction and bridge, culvert, and road drainage installation; and
- The surfacing phase: placement and compaction of the roadbed, road fill compaction, and surface placement and compaction (if applicable).

Under the Coastal Zone Act Reauthorization Amendments of 1990, States are subject to a number of requirements as they develop coastal nonpoint source programs in conformity with this measure and will have some flexibility in doing so. The application of this management measure by States is described more fully in *Coastal Nonpoint Pollution Control Program: Program Development and Approval Guidance*, published jointly by the U.S. Environmental Protection Agency (EPA) and the National Oceanic and Atmospheric Administration (NOAA) of the U.S. Department of Commerce.

2. Description

The goal of this management measure is to minimize delivery of sediment to surface waters during road construction/reconstruction projects. Figure 3-15 depicts various road structures addressed by this management measure. Disturbance of soil and rock during road construction/reconstruction creates a significant potential for erosion and sedimentation of nearby streams and coastal waters. Some roads are temporary or seasonal-use roads,

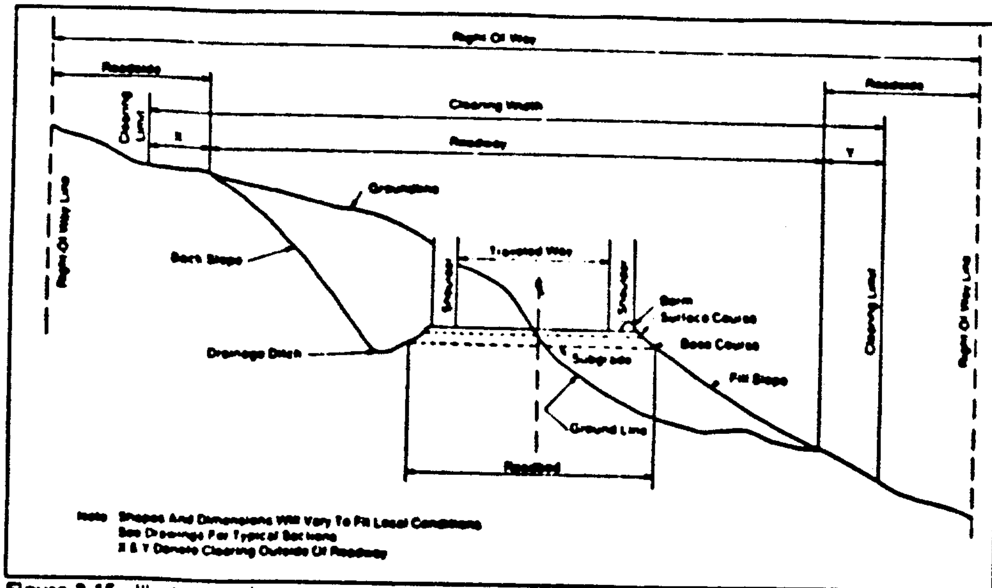

Figure 3-15. Illustration of road structure terms (Hynson et al., 1982).

and their construction does not involve the high level of disturbance generated by permanent, high-standard roads. However, temporary or low-standard roads still need to be constructed in such a way as to prevent disturbance and sedimentation. Brown (1972) stated that road construction is the largest source of silviculture-produced sediment in the Pacific Northwest. It is also a significant source in other regions of the country. Therefore, proper road and drainage crossing construction practices are necessary to minimize sediment delivery to surface waters. Proper road design and construction can prevent road fill and road backslope failure, which can result in mass movements and severe sedimentation. Proper road drainage prevents concentration of water on road surfaces, thereby preventing road saturation that can lead to rutting, road slumping, and channel washout (Dyrness, 1967; Golden et al., 1984). Proper road drainage during logging operations is especially important because that is the time when erosion is greatly accelerated by continuous road use (Kochenderfer, 1970). Figure 3-16 presents various erosion and sediment control practices.

Surface protection of the roadbed and cut-and-fill slopes can:

- Minimize soil losses during storms;
- Reduce frost heave erosion production;
- Restrain downslope movement of soil slumps; and
- Minimize erosion from softened roadbeds (Swift, 1984).

Although there are many commonly practiced techniques to minimize erosion during the construction process, the most meaningful are related to how well the work is planned, scheduled, and controlled by the road builder and those responsible for determining that work satisfies design requirements and land management resource objectives (Larse, 1971).

3. Management Measure Selection

Most erosion from road construction occurs within a few years of disturbance (Megahan, 1980). Therefore, erosion control practices that provide immediate results (such as mulching or hay bales) should be applied as soon as possible to minimize potential erosion (Megahan, 1980). King (1984) found that the amount of sediment produced by road construction was directly related to the percent of the area taken by roads, the amount of protection given to the seeded slopes, and whether the road is given a protective surface (Table 3-21).

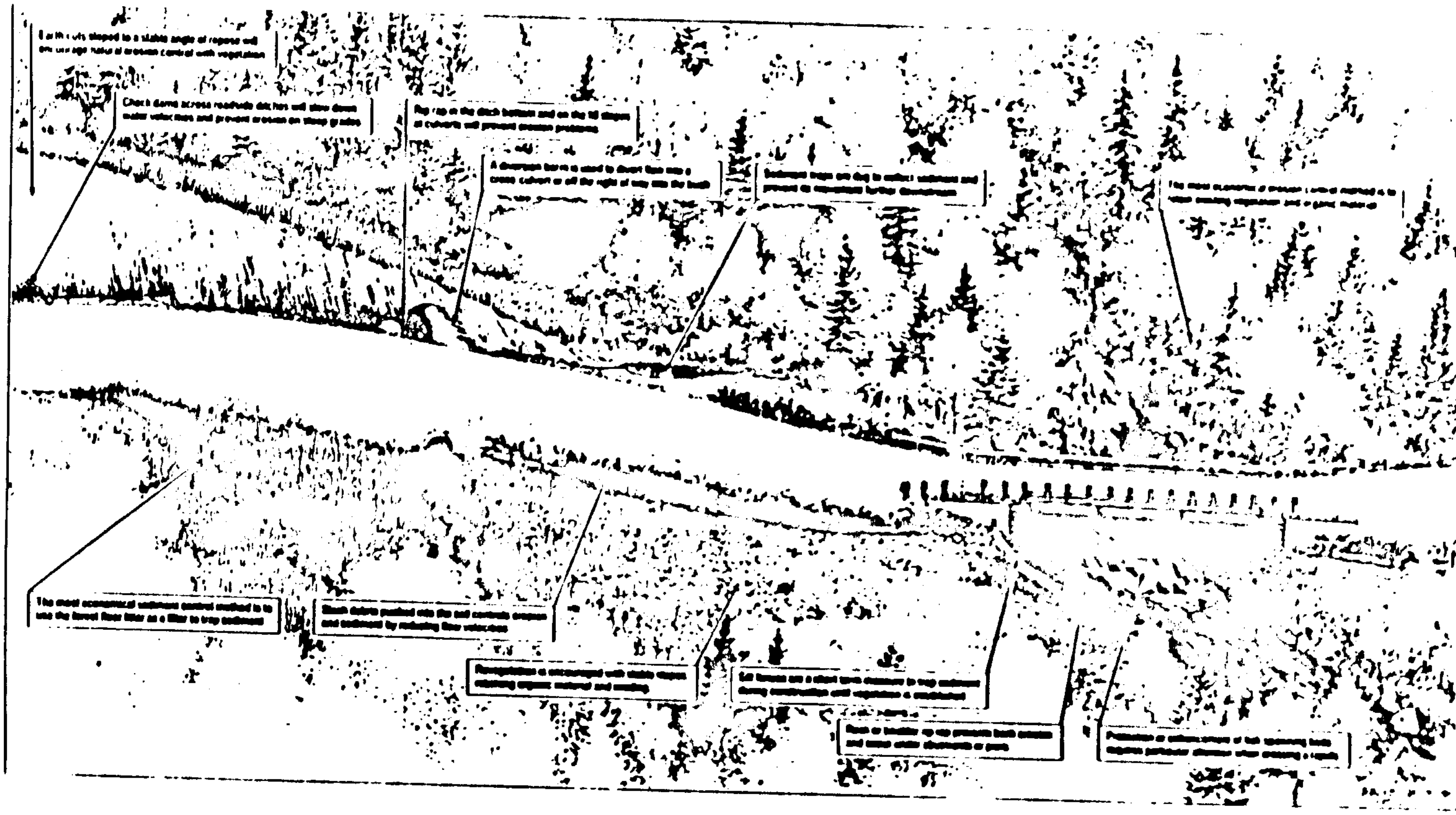

Figure 3-16. Mitigation techniques used for controlling erosion and sediment to protect water quality and fish habitat (Ontario Ministry of Natural Resources, 1988).

Table 3-21. Effects of Several Road Construction Treatments on Sediment Yield (ID) King (1984)

Watershed Area (acres)	Area in Roads (percent)	Treatment	Increase of Annual Sediment Yield* (percent)
207	3.9	Unsurfaced roads; Untreated cut slope; Untreated fill slope	156
161	2.6	Unsurfaced roads; Untreated cut slope dry seeded	130
364	3.7	Surfaced roads; Cut and fill slopes straw mulched and seeded	93
154	1.8	Surfaced roads; Filter windrowed; Cut and fill slopes straw mulched and seeded	53
70	3.0	Surfaced roads; Filter windrowed; Cut and fill slopes hydro-mulched and seeded	25
213	4.3	Surfaced roads; Filter windrowed; Cut and fill slopes hydro-mulched and seeded	19

* Measured in debris basins.

a. Effectiveness Information

The effectiveness of road surfacing in controlling erosion was demonstrated by Kochenderfer and Helvey (1984)(Table 3-22). The data show that using 1-inch crusher-run gravel or 3-inch clean gravel can reduce erosion to less than one-half that of using 3-inch crusher run gravel and to 12 percent that of an ungraveled road surface.

According to Swift (1984b), road cuts and fills are the largest source of sediment once a logging road is constructed. His research showed that planting grass on cut-and-fill slopes of new roads effectively reduced erosion in the southern Appalachians. The combined effectiveness of grass establishment and roadbed graveling was a 97-99 percent reduction in soil loss.

Swift (1986) measured the extent of downslope soil movement for various categories of roadway and slope conditions (Tables 3-23 and 3-24). He found that grassed fill was more effective than mulched fill or bare fill in reducing the downslope movement of soil from newly constructed roads. The author determined grass, forest floor litter, and brush barriers to be effective management practices for reducing downslope sediment.

Megahan (1980, 1987) summarized the results of several studies that echo Swift's conclusions (Table 3-25). The combination of straw mulch with some type of netting to hold it in place reduces erosion by more than 90 percent and has the added benefits of providing immediate erosion control and promoting revegetation. Treating the road surface reduced erosion 70 to 99 percent. Grass seeding alone can control erosion in moist climates, as confirmed by Swift (1984b).

Table 3-22. Effectiveness of Road Surface Treatments in Controlling Soil Losses (WV) (Kochenderfer and Helvey, 1984)

Surface Treatment	Average Annual Soil Losses (tons/acre)*
3-inch clean gravel	5.4
Ungraveled	44.4
3-inch crusher-run gravel	11.4
1-inch crusher-run gravel	5.5

* Six measurements taken over a 2-year time period.

b. Cost Information

The costs associated with construction of rolling dips on roads were estimated by Dubensky (1991) as $19.75 each, with more dips needed as the slope of the road increases.

Ellefson and Miles (1984) determined the decline in net revenue associated with culvert construction, water bar construction, and construction of broad-based dips to be 3.8 percent, 2.3 percent, and 2.4 percent, respectively, for a timber sale with net revenue of $124,340 without these practices. Kochenderfer and Wendel (1980) examined road costs, including bulldozing, construction of drainage dips, culvert installation, and graveling. They concluded that:

(1) Cost to reconstruct a road (including 600 tons of 3-inch clean stone surfacing at $5.74/ton) = *$5,855 per mile*. Cost also included 20.5 hours (25 hours/mile) of D-6 tractor time (for road construction and construction of broad-based drainage dips), 23 hours (28 hours/mile) of JD 450 tractor time to spread gravel and do final dip shaping, and installation of two culverts. Road construction without the stone would have cost *$1,061/mile*.

(2) Cost for a newly constructed road was *$3,673 per mile*, including 200 tons of gravel. Costs included 46.5 hours (57 hours/mile) of D-6 tractor time to bulldoze the road and construct 22 drainage dips. Spreading gravel and final dip shaping required 7.5 hours of JD tractor time. This road, constructed without stone, would have cost *$2,078 per mile*.

The study concluded that road construction costs in terrain similar to the West Virginia mountain area would range from about $2,000/mile with no gravel and few culverts to about $10,000/mile with complete graveling and more frequent use of culverts.

Kochenderfer, Wendel, and Smith (1984) examined the costs associated with road construction of four minimum standard roads in the Appalachians (Table 3-8 gives road characteristics). Excavation costs varied according to site-specific factors (soil type, rock outcrop extent, topography) and increased as the amount of rock needing blasting and the number of large trees to be removed increased. Culvert costs varied according to the size and type of culvert used (Tables 3-26 and 3-27).

Lickwar (1989) studied the costs of various forestry practices in the Southeast. He determined that practices associated with road construction were generally the most expensive, regardless of terrain. The costs for broad-based dips and water bars increased as the terrain steepened, indicating increased implementation of erosion and runoff control practices as slopes increased (Table 3-28). Steeper areas also required additional (nonspecified) road costs that were not necessary in moderate to flat areas.

Table 3-23. Reduction in the Number of Sediment Deposits More Than 20 Feet Long by Grass and Forest Debris (Swift, 1986)

Degree of Soil Protection	Number of Deposits Per 1,000 Feet of Road
Grassed fill, litter and brush burned	13.9
Bare fill, forest litter	9.9
Mulched fill, forest litter	8.1
Grassed fill, forest litter, no brush barrier	6.9
Grassed fill, forest litter, brush barrier	4.5

Table 3-24. Comparison of Downslope Movement of Sediment from Roads for Various Roadway and Slope Conditions (Swift, 1986)

Comparisons	Sites (no.)	Mean Slope (%)	Distance (feet)		
			Mean	Max	Min
All sites	88	46	71	314	2
Barrier[a]					
Brush barriers	26	46	47	156	3
No brush barrier	62	47	81	314	2
Drainage[b]					
Culvert	21	40	80	314	30
Outsloped without culvert	56	47	63	287	2
Unfinished roadbed with berm	11	57	95	310	25
Grass fill and forest litter[c]	46	40	45	148	2
With brush barrier	16	39	34	78	3
With culvert	4	20	37	43	30
Without culvert	12	45	32	78	3
Without brush barrier	30	41	51	148	2
With culvert	7	37	58	87	30
Without culvert	23	42	49	148	2

[a] Examined the effectiveness of leaving brush barriers in place below road fills, rather than removing brush barriers.
[b] Compared roads where storm water was concentrated at a culvert pipe to outsloped roads without a culvert. The berm was constructed on an unfinished roadbed to prevent downslope drainage.
[c] Compared effectiveness of brush barriers versus drainage (i.e., culvert) systems.

Table 3-25. Effectiveness of Surface Erosion Control on Forest Roads (Megahan, 1987, 1980)

Stabilization Measure	Portion of Road Treated	Percent Decrease in Erosion[a]	Reference
Tree planting	Fill slope	50	Megahan, 1974b
Hydromulch, straw mulch, and dry seeding[b]	Fill slope	24 to 58	King, 1984
Grass and legume seeding	Road cuts	71	Dyrness, 1970
Straw mulch	Fill slope	72	Bethlahmy and Kidd, 1966
Straw mulch	Road fills	72	Ohlander, 1964
Wood chip mulch	Road fills	61	Bethlahmy and Kidd, 1966
Wood chip mulch	Fill slope	61	Ohlander, 1964
Excelsior mulch	Fill slope	92	Burroughs and King, 1985
Paper netting	Fill slope	93	Ohlander, 1964
Asphalt-straw mulch	Fill slope	97	Ohlander, 1964
Straw mulch, netting, and planted trees	Fill slope	98	Megahan, 1974b
Straw mulch and netting	Fill slope	99	Bethlahmy and Kidd, 1966
Gravel surface	Road tread	70	Burroughs and King, 1985
Dust oil	Road tread	85	Burroughs and King, 1985
Bituminous surfacing	Road treated	99	Burroughs and King, 1985
Terracing	Cut slope	86	Unpublished data[c]
Straw mulch	Cut slope	32 to 47	King, 1984
Straw mulch	Cut slope	97	Dyrness, 1970

[a] Percent decrease in erosion compared to similar, untreated sites.
[b] No difference in erosion reduction between these three treatments.
[c] Intermountain Forest and Range Experiment Station, Forestry Sciences Laboratory, Boise, ID.

Unit cost comparisons for surfacing practices (Swift, 1984a) reveal that grass is the least expensive alternative, at $174 per kilometer of road (Table 3-29). Five-centimeter crushed rock cost almost $2000 per kilometer, 15-centimeter gravel cost about $6000, and 20-centimeter gravel cost almost $9000. The author cautions, however, that material costs alone are misleading because an adequate road surface might endure several years of use, whereas a grassed or thinly-graveled surface would need replenishing. Even so, multiple grass plantings may be cheaper and more effective than gravel spread thinly over the roadbed, depending on climate, growing conditions, soil type, and road use (Swift, 1984b). Megahan (1987) found that dry seeding alone cost significantly less than seeding in conjunction with plastic netting (Table 3-30).

Table 3-26. Cost Summary for Four "Minimum-Standard" Forest Truck Roads Constructed in the Central Appalachians[a] (1984 Dollars) (Kochenderfer, Wendel, and Smith, 1984)

Road No.	Costs (dollars/mile)			
	Excavation	Culvert	Labor & Vehicle	Total
1	2,900	371	1,092	5,048
6	4,200	1,043	1,947	7,805
7	5,650	1,143	2,116	9,629
8	3,950	0	722	5,457

[a] Costs and time rounded to nearest whole number.

Table 3-27. Unit Cost Data for Culverts (Kochenderfer, Wendel, and Smith, 1984)

Culvert Type	Cost
15-inch gasline pipe (30-foot sections)	$7.50/ft
15-inch galvanized	$6.00/ft
18-inch galvanized	$7.75/ft
36-inch galvanized	$19.00/ft

Table 3-28. Cost Estimates (and Cost as a Percent of Gross Revenues) for Road Construction (1987 Dollars) (Lickwar, 1989)

Practice Component	Location					
	Steep Sites[a]		Moderate Sites[b]		Flat Sites[c]	
Stream crossings	$31.74	(0.01%)	$128.74	(0.03%)	$2,998.74	(0.33%)
Broad-based dips	$11,520	(2.88%)	$7,040.00	(1.49%)	$3,240.00	(0.36%)
Water bars	$8,520	(2.13%)	$4,440.00	(0.94%)	$2,160	(0.24%)
Added road costs	$3,990	(1.00%)	Not Provided		Not Provided	

[a] Based on a 1,148-acre forest and gross harvest revenues of $399,685. Slopes average over 9 percent.
[b] Based on a 1,104-acre forest and gross harvest revenues of $473,182. Slopes ranged from 4 percent to 8 percent.
[c] Based on a 1,832-acre forest and gross harvest revenues of $899,491. Slopes ranged from 0 percent to 3 percent.

Table 3-29. Cost of Gravel and Grass Road Surfaces (NC, WV) (Swift, 1984a)

Surface	Requirements/km	Unit Cost	Total Cost/km
Grass	28 kg Ky-31	$0.840/kg	$23.52
	14 kg rye	$0.660/kg	$9.24
	405 kg 10-10-10	$0.121/kg	$49.01
	900 kg lime	$0.033/kg	$29.70
	Labor and equipment	$62.14/km	$62.14
Crushed rock (5 cm)*	425 ton	$4.680/ton	$1,989
Crushed rock (15 cm)*	1,275 ton	$4.680/ton	$5,967
Large stone (20 cm)*	1,690 ton	$5.240/ton	$8,856

* Values in parentheses are thickness or depth of surfacing material.

Table 3-30. Costs of Erosion Control Measures (ID) (Megahan, 1987)

Measure	Cost ($/acre)
Dry seeding	124
Plastic netting placed over seeded area	5,662

Source: Haber, D.F., and T. Kadoch, 1982. Costs of Erosion Control Measures Used on a Forest Road in the Silver Creek watershed in Idaho, University of Idaho, Dept. of Civil Engineering.

4. Practices

As discussed more fully at the beginning of this chapter and in Chapter 1, the following practices are described for illustrative purposes only. State programs need not require implementation of these practices. However, as a practical matter, EPA anticipates that the management measure set forth above generally will be implemented by applying one or more management practices appropriate to the source, location, and climate. The practices set forth below have been found by EPA to be representative of the types of practices that can be applied successfully to achieve the management measure described above.

- *Follow the design developed during preharvest planning to minimize erosion by properly timing and limiting ground disturbance operations.*

- *Construct bridges and install culverts during periods when streamflow is low.*

- *Avoid construction during egg incubation periods on streams with important spawning areas.*

- *Practice careful equipment operation during road construction to minimize the movement of excavated material downslope as unintentional sidecast.*

- *Compact the road base at the proper moisture content, surfacing, and grading to give the designed road surface drainage shaping.*

■ *Use straw bales, straw mulch, grass-seeding, hydromulch, and other erosion control and revegetation techniques to complete the construction project. These methods are used to protect freshly disturbed soils until vegetation can be established.*

■ *Prevent slash from entering streams or promptly remove slash that accidentally enters streams to prevent problems related to slash accumulations.*

Slash can be useful if placed as windrows along the base of the fill slope. Right-of-way material that is merchantable can also be used by the operator.

■ *Use turnouts, wing ditches, and dips to disperse runoff and reduce road surface drainage from flowing directly into watercourses.*

■ *Install surface drainage controls to remove stormwater from the roadbed before the flow gains enough volume and velocity to erode the surface. Route discharge from drainage structures onto the forest floor so that water will disperse and infiltrate (Swift, 1985). Methods of road surface drainage include:*

- **Broad-based Dip Construction.** A broad-based dip is a gentle roll in the centerline profile of a road that is designed to be a relatively permanent and self-maintaining water diversion structure and can be traversed by any vehicle (Swift, 1985, 1988) (See Figure 3-17). The dip should be outsloped 3 percent to divert stormwater off the roadbed and onto the forest floor, where transported soil can be trapped by forest litter (Swift, 1988). Broad-based dips should be used on roads having a gradient of 10 percent or less. Proper construction requires an experienced bulldozer operator (Kochenderfer, 1970).

- **Installation of Pole Culverts and/or Ditch Relief Culverts.** Culverts are placed at varying intervals in a road to safely conduct water from the ditch to the outside portion of the road. Figures 3-18 and 3-19 highlight the design and installation of pole and pipe culverts, respectively. Culverts often need outlet and inlet protection to keep water from scouring away supporting material and to keep debris from plugging the culvert. Energy dissipators, such as riprap and slash, should be installed at culvert outlets (Rothwell, 1978). Culvert spacing depends on rainfall intensity, soil type, and road grade. Culvert size selection should be based on drainage area size and should be able to handle large flows. Open-top or pole culverts are temporary drainage structures that are most useful for intercepting runoff flowing down road surfaces (Kochenderfer, 1970). They can also be used as a substitute for pipe culverts on roads of smaller operations, if properly built and maintained, but they should not be used for handling intermittent or live streams. Open-top culverts should be placed at angles across a road to provide gradient to the culvert and to ensure that no two wheels of a vehicle hit the ditch at once.

- **Road Outsloping and Grading.** Grade and outslope roadbeds to minimize water accumulation on road surfaces (Kochenderfer, 1970). This practice minimizes erosion and road failure potential. Outsloping involves grading the road so that it slopes downward from the toe of the road cut to the shoulder. The

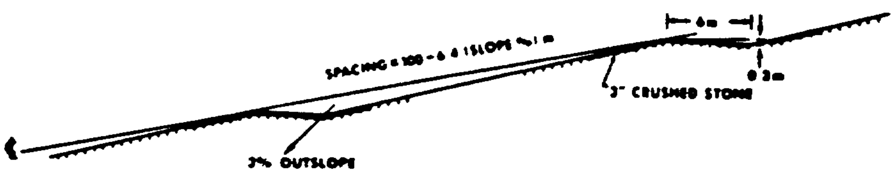

Figure 3-17. Diagram of broad-based dip design for forest access roads (Swift, 1985).

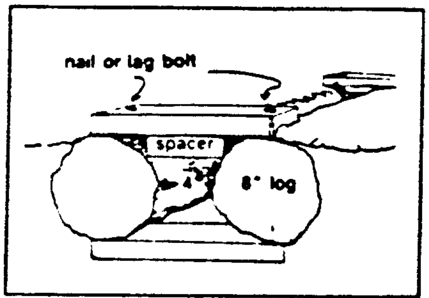

Figure 3-18. Design of pole culverts (Vermont Department of Forests, Parks and Recreation, 1987).

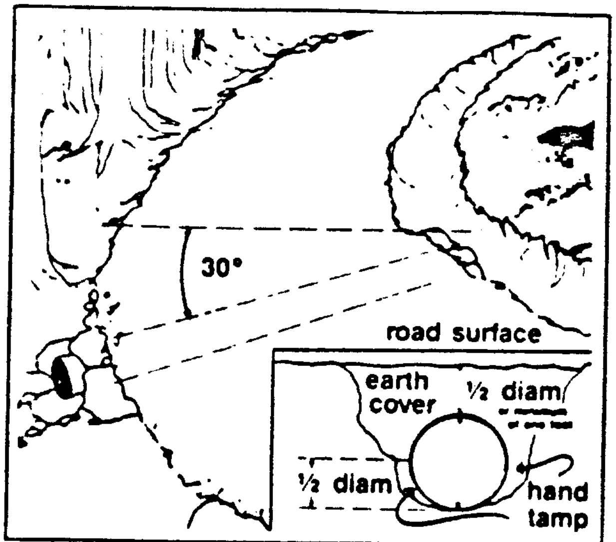

Figure 3-19. Design and installation of pipe culverts (Vermont Department of Forests, Parks and Recreation, 1987).

slope should be about 3-4 percent (Rothwell, 1978). Outsloping the roadbed keeps water from flowing next to and undermining the cut bank, and is intended to spill water off the road in small volumes at many random sites. In addition to outsloping the roadbed, a short reverse grade should be constructed to turn water off the surface. Providing a berm on the outside edge of an outsloped road during construction, and until loose fill material is protected by vegetation, can eliminate fill erosion (Swift, 1985). The effectiveness of outsloping is limited by roadbed rutting during wet conditions. Also, berms may form along the edge of older roadbeds and block drainage (Swift, 1985). Therefore, proper maintenance of these structures is necessary.

- **Ditch and Turnout Construction.** Ditches should be used only where necessary and should discharge water into vegetated areas through the use of turnouts. The less water ditches carry and the more frequently water is discharged, the better. Construct wide, gently sloping ditches, especially in areas with highly erodible soils. Ditches should be stabilized with rock and/or vegetation (Yoho, 1980) and outfalls protected with rock, brush barriers, live vegetation, or other means. Roadside ditches should be large enough to carry runoff from moderate storms. A standard ditch used on secondary logging roads is a triangular section 45 cm deep, 90 cm wide on the roadway side, and 30 cm wide on the cut bank side. Minimum ditch gradient should be 0.5 percent, but 2 percent is preferred to ensure good drainage. Runoff should be frequently diverted into culverts to prevent erosion or overflow (Rothwell, 1978).

■ ***Install appropriate sediment control structures to trap suspended sediment transported by runoff and prevent its discharge into the aquatic environment.***

Methods to trap sediment include:

- **Brush Barriers.** Brush barriers are slash materials piled at the toe slope of a road or at the outlets of culverts, turnouts, dips, and water bars. Brush barriers should be installed at the toe of fills if the fills are located within 150 feet of a defined stream channel (Swift, 1988). Figure 3-20 shows the use of a brush barrier at the toe of fill. Proper installation is important because if the brush barrier is not firmly anchored and embedded in the slope, brush material may be ineffective for sediment removal and may detach to block ditches or culverts (Ontario Ministry of Natural Resources, 1988). In addition to use as brush barriers, slash can be spread over exposed mineral soils to reduce the impact of precipitation events and surface flow.

- **Silt Fences.** Silt fences are temporary barriers used to intercept sediment- laden runoff from small areas. They act as a strainer: silt and sand are trapped on the surface of the fence while water passes through.

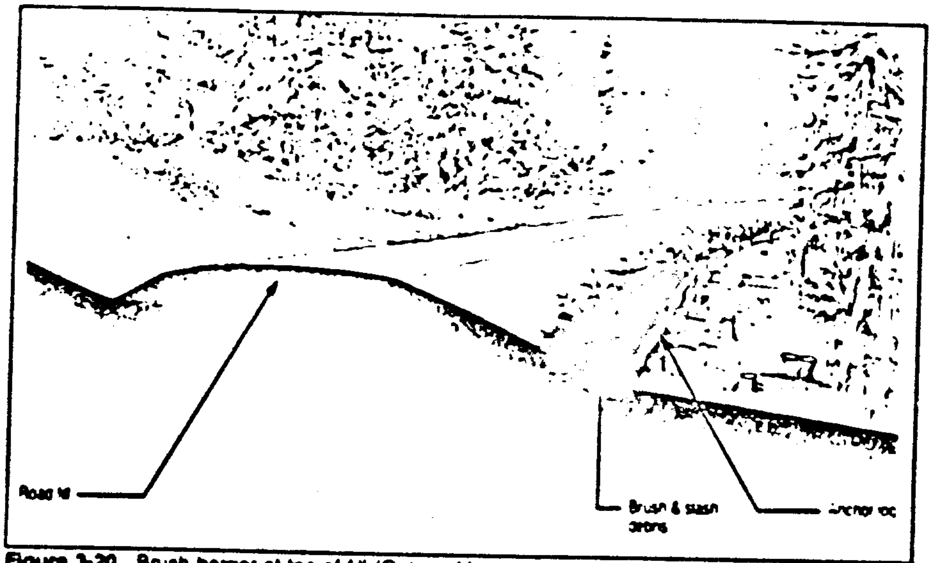

Figure 3-20. Brush barrier at toe of fill (Ontario Ministry of Natural Resources, 1988).

They may consist of woven geotextile filter fabric or straw bales. Silt fences should be installed prior to earthmoving operations and should be placed as close to the contour as possible.

- **Riprap.** Riprap is a layer of rocks or rock fragments placed over exposed soil to protect it from erosive forces. Riprap is generally used only in areas where the velocity of water flow, seriousness of erosion, steepness of slope, or material type prevents satisfactory establishment of vegetation. Stones of suitable size are fitted and implanted in the slope to form a contiguous cover (Figure 3-21). When used near streams, riprap should be extended below the stream channel scour depth and above the high water line. Commonly, a filter cloth or graded filter blanket of small gravel is laid beneath the riprap. Riprap should not be used on slopes that are naturally subject to deep-seated or avalanche-type slide failure. Riprap should be used in conjunction with other slope stabilization techniques and then only if these techniques are ineffective alone. Riprap is not recommended for very steep slopes or fine-grained soils (Hynson et al., 1982).

- **Filter Strips.** Sediment control is achieved by providing a filter or buffer strip between streams and construction activities in order to use the natural filtering capabilities of the forest floor and litter. The Streamside Management Area management measure requires the presence of a filter or buffer strip around all waterbodies.

■ *Revegetate or stabilize disturbed areas, especially at stream crossings.*

Cutbanks and fillslopes along forest roads are often difficult to revegetate (Berglund, 1978). Properly condition slopes to provide a seedbed, including rolling of embankments and scarifying of cut slopes. The rough soil surfaces will provide niches for seeds to lodge and germinate. Seed as soon as possible after disturbance, preferably during road construction or immediately following completion and within the same season (Larse, 1971). Early grassing and spreading of brush or erosion-resisting fabrics on exposed soils at stream crossings are imperative (Swift, 1985). See the Revegetation of Disturbed Areas management measure for a more detailed discussion.

■ *Protect access points to the site that lead from a paved public right-of-way with stone, wood chips, corduroy logs, wooden mats, or other material to prevent soil or mud from being tracked onto the paved road.*

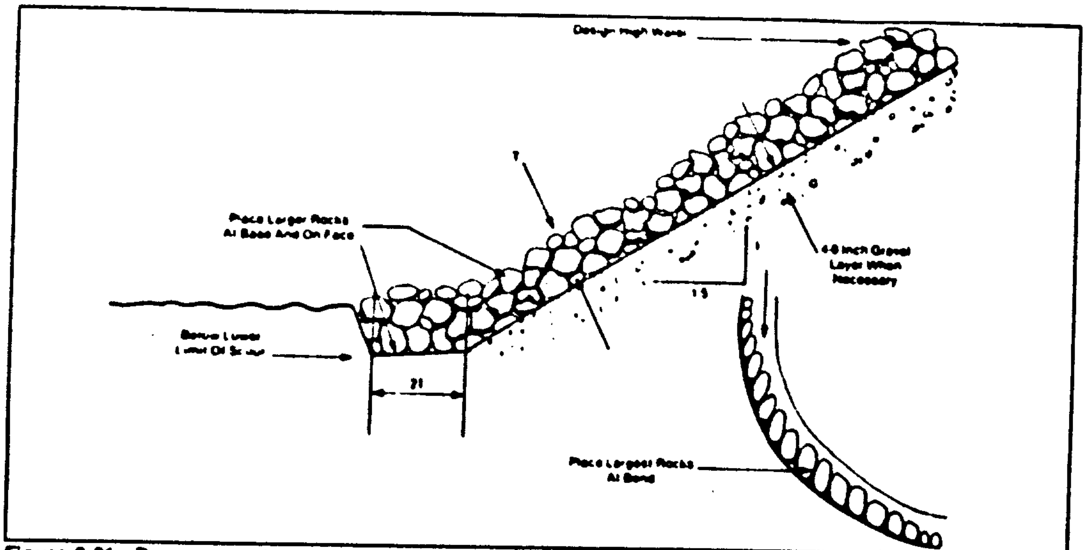

Figure 3-21. Dimensions of typical rock riprap blanket. T equals 1.5 times the diameter of the average size rock. When rock is spherical cobbles, or when machine-placed, T=1.9D (Hynson et al., 1982).

This will prevent tracking of sediment onto roadways, thereby preventing the subsequent washoff of that sediment during storm events. When necessary, clean truck wheels to remove sediment prior to entering a public right-of-way.

■ *Construct stream crossings to minimize erosion and sedimentation.*

Avoid operating machinery in waterbodies. Work within or adjacent to live streams and water channels should not be attempted during periods of high streamflow, intense rainfall, or migratory fish spawning. Avoid channel changes and protect embankments with riprap, masonry headwalls, or other retaining structures (Larse, 1971).

If possible, culverts should be installed within the natural streambeds. The inlet should be on or below the streambed to minimize flooding upstream and to facilitate fish passage. Culverts should be firmly anchored and the earth compacted at least halfway up the side of the pipe to prevent water from leaking around it (Figure 3-22). Both ends of the culvert should protrude at least 1 foot beyond the fill (Hynson et al., 1982). Large culverts should be aligned with the natural course and gradient of the stream unless the inlet condition can be improved and the erosion potential reduced with some channel improvement (Larse, 1971). Use energy dissipators at the downstream end of the culverts to reduce the erosion energy of emerging water. Armor inlets to prevent undercutting and armor outlets to prevent erosion of fill or cut slopes.

■ *Excavation for a bridge or a large culvert should not be performed in flowing water. The water should be diverted around the work site during construction with a cofferdam or stream diversion.*

Isolating the work site from the flow of water is necessary to minimize the release of soil into the watercourse and to ensure a satisfactory installation in a dry environment. Limit the duration of construction to minimize environmental impacts by establishing disturbance limits, equipment limitations, the operational time period when disturbance can most easily be limited, and the use of erosion and sediment controls, such as silt fences and sediment catch basins. Diversions should be used only where constructing the stream crossing structure without diverting the stream would result in instream disturbance greater than the disturbance from diverting the stream. Figure 3-23 portrays a procedure for installing a large culvert when excavation in the channel of the stream would cause sedimentation and increase turbidity.

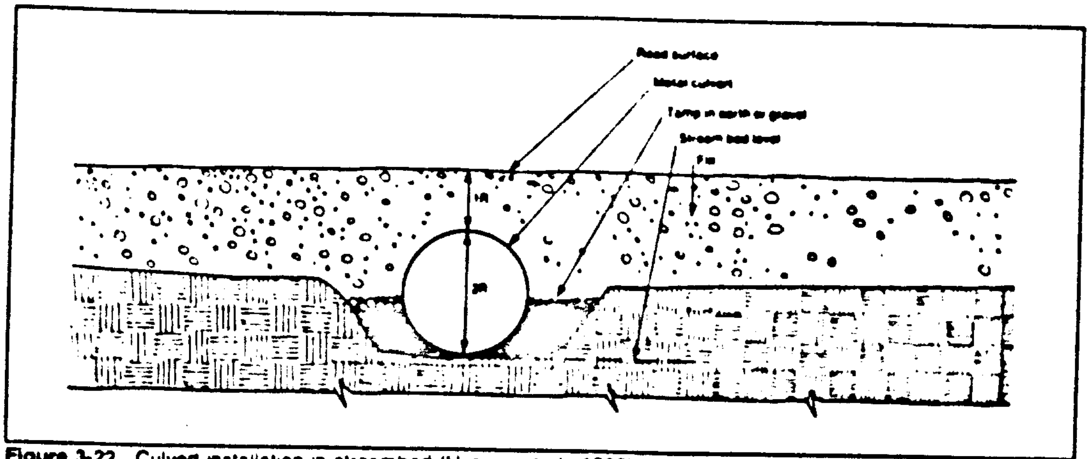

Figure 3-22. Culvert installation in streambed (Hynson et al., 1982).

■ *Compact the fill to minimize erosion and ensure road stability (Hynson et al., 1982).*

During construction, fills or embankments are built up by gradual layering. Compact the entire surface of each layer with a tractor or other construction equipment. If the road is to be grassed, the final layer should not be compacted in order to provide an acceptable seedbed.

■ *Properly dispose of organic debris generated during road construction (Hynson et al., 1982).*

- Stack usable materials such as timber, pulpwood, and firewood in suitable locations and use them to the extent possible. Alternatives for use of other materials include piling and burning, chipping, scattering, windrowing, and removal to designated sites.
- Organic debris should not be used as fill material for road construction since the organic material would eventually decompose and cause fill failure (Hynson et al., 1982; Larse, 1971).
- Debris that is accidently deposited in streams during road construction should be removed before work is terminated.
- All work within the stream channel should be accomplished by hand to avoid the use of machinery in the stream and riparian zone (Hynson et al., 1982).

■ *Use pioneer roads to reduce the amount of area disturbed and ensure stability of the area involved.*

Pioneer roads are temporary access ways used to facilitate construction equipment access when building permanent roads.

- Confine pioneer roads to the construction limits of the surveyed permanent roadway.
- Fit the pioneer road with temporary drainage structures (Hynson et al., 1982).

■ *When soil moisture conditions are excessive, promptly suspend earthwork operations and take measures to weatherproof the partially completed work (Larse, 1971; Hynson et al., 1982).*

Regulating traffic on logging roads during unfavorable weather is an important phase of erosion control. Construction and logging under these conditions destroy drainage structures, plug up culverts, and cause excessive rutting, thereby increasing the amount and the cost of required maintenance (Kochenderfer, 1970).

Locate burn bays away from water and drainage courses.

If the use of borrow or gravel pits is needed during forest road construction, locate rock quarries, gravel pits, and borrow pits outside SMAs and above the 50-year flood level of any waters to minimize the adverse impacts caused by the resulting sedimentation. Excavation should not occur below the water table.

Gravel mining directly from streams causes a multitude of impacts including destruction of fish spawning sites, turbidity, and sedimentation (Hynson et al., 1982). During the construction and use of rock quarries, gravel pits, or borrow pits, runoff water should be diverted onto the forest floor or should be passed through one or more settling basins. Rock quarries, gravel pits, spoil disposal areas, and borrow pits should be revegetated and reclaimed upon abandonment.

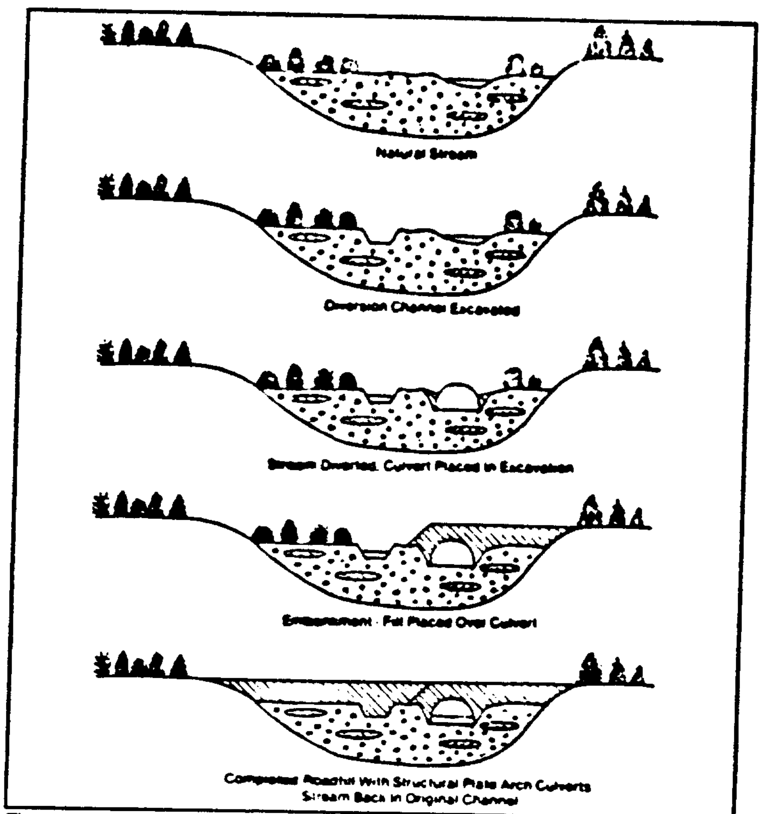

Figure 3-23. Culvert installation using a diversion (Hynson et al., 1982).

(1) Avoid using roads where possible for timber hauling or heavy traffic during wet or thaw periods on roads not designed and constructed for these conditions.
(2) Evaluate the future need for a road and close roads that will not be needed. Leave closed roads and drainage channels in a stable condition to withstand storms.
(3) Remove drainage crossings and culverts if there is a reasonable risk of plugging or failure from lack of maintenance.
(4) Following completion of harvesting, close and stabilize temporary spur roads and seasonal roads to control and direct water away from the roadway. Remove all temporary stream crossings.
(5) Inspect roads to determine the need for structural maintenance. Conduct maintenance practices, when conditions warrant, including cleaning and replacement of deteriorated structures and erosion controls, grading or seeding of road surfaces, and, in extreme cases, slope stabilization or removal of road fills where necessary to maintain structural integrity.
(6) Conduct maintenance activities, such as dust abatement, so that chemical contaminants or pollutants are not introduced into surface waters to the extent practicable.
(7) Properly maintain permanent stream crossings and associated fills and approaches to reduce the likelihood (a) that stream overflow will divert onto roads, and (b) that fill erosion will occur if the drainage structures become obstructed.

1. Applicability

This management measure pertains to lands where silvicultural or forestry operations are planned or conducted. It is intended to apply to active and inactive roads constructed or used for silvicultural activities.

Under the Coastal Zone Act Reauthorization Amendments of 1990, States are subject to a number of requirements as they develop coastal nonpoint source programs in conformity with this measure and will have some flexibility in doing so. The application of this management measure by States is described more fully in *Coastal Nonpoint Pollution Control Program: Program Development and Approval Guidance*, published jointly by the U.S. Environmental Protection Agency (EPA) and the National Oceanic and Atmospheric Administration (NOAA) of the U.S. Department of Commerce.

2. Description

The objective of this management measure is to manage existing roads to maintain stability and utility and to minimize sedimentation and pollution from runoff-transported materials. Roads that are actively eroding and providing significant sediment to waterbodies, whether in use or not, must be managed. If roads are no longer in use or needed in the foreseeable future, an effective treatment is to remove drainage crossings and culverts if there is a risk of plugging or failure from lack of maintenance. In other cases (e.g., roads in use), it may be more economically viable to periodically maintain crossing and drainage structures.

Sound planning, design, and construction measures often reduce the future levels of necessary road maintenance. Roads constructed with a minimum width in stable terrain, and with frequent grade reversals or dips, require minimum maintenance. However, older roads remain one of the greatest sources of sediment from forest land management. In some locations, problems associated with altered surface drainage and diversion of water from natural channels can result in serious gully erosion or landslides. After harvesting is complete, roads are often forgotten. Erosion problems may go unnoticed until after there is severe resource damage. In western Oregon, 41 out of the 104 landslides reported on private and State forest lands during the winter of 1989-90 were associated with older (built before 1984) forest roads. These landslides were related to both road drainage and original construction problems. Smaller erosion features, such as gullies and deep ruts, are far more common than landslides and very often are related to road drainage.

Drainage of the road prism, road fills in stream channels, and road fills on steep slopes are the elements of greatest concern in road management. Roads used for active timber hauling usually require the most maintenance, and mainline roads typically require more maintenance than spur roads. Use of roads during wet or thaw periods can result in a badly rutted surface, impaired drainage, and excessive sediment leading to waterbodies. Inactive roads, not being used for timber hauling, are often overlooked and receive little maintenance. Many forest roads that have been abandoned may be completely overgrown with vegetation, which makes maintenance very difficult.

Figure 3-24 illustrates some differences between a road with a well-maintained surface, good revegetation, and open drainage structures, and a poorly maintained road.

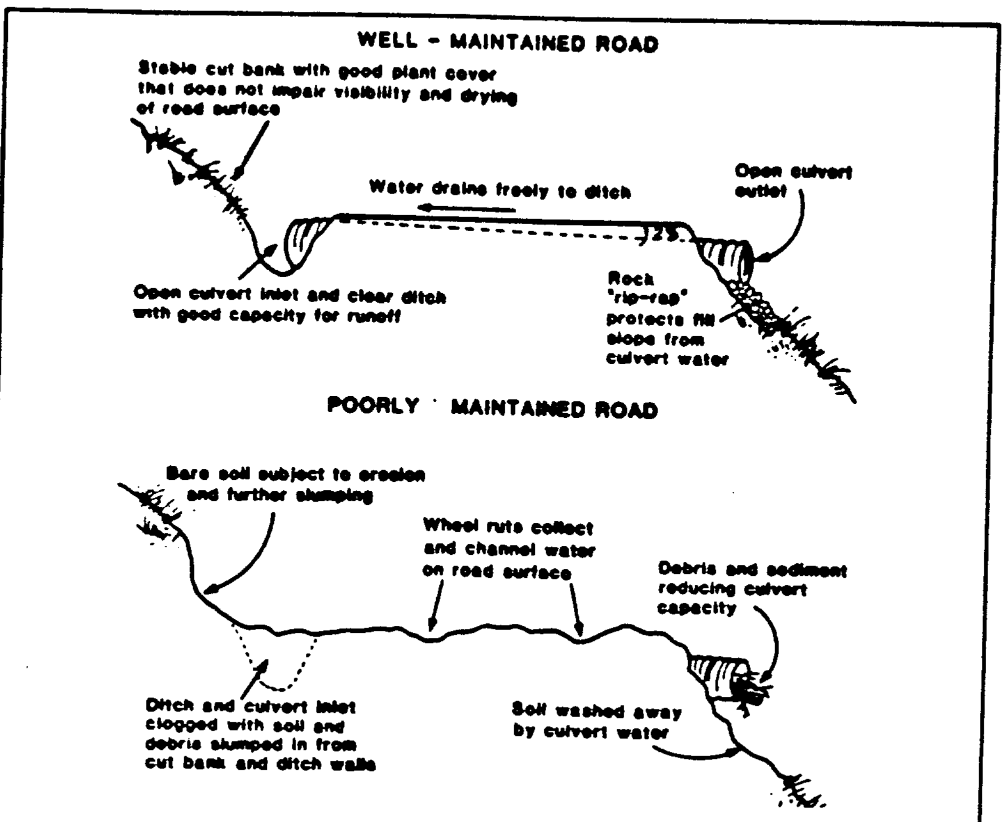

Figure 3-24. Road maintenance examples (Adams, 1991).

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3. Management Measure Selection

a. Effectiveness Information

Drainage structures must be maintained to function properly. Culverts and ditches must be kept free of debris that can restrict water flow. Routine cleaning can minimize clogging and prevent flooding, gullying, and washout (Kochenderfer, 1970). Routine maintenance of road dips and surfaces and quick response to problems can significantly reduce road-caused slumps and slides and prevent the creation of berms that could channelize runoff (Oregon Department of Forestry 1981; Ontario Ministry of Natural Resources, 1988).

Proper road/trail closure is essential in preventing future erosion and sedimentation from abandoned roads and skid trails. Proper closure incorporates removal of temporary structures in watercourses, returning stream crossing approaches to their original grades, revegetating disturbed areas, and preventing future access (Kochenderfer, 1970; Rothwell, 1978) Revegetation of disturbed areas protects the soil from raindrop impact and aids soil aggregation, and therefore reduces erosion and sedimentation (Rothwell, 1978).

b. Cost Information

Benefits of proper road maintenance were effectively shown by Dissmeyer and Frandsen (1988). Maintenance costs for road repair were 44 percent greater without implementation of control measures than for installation of BMPs (Table 3-31).

Dissmeyer and Foster (1987) presented an analysis of the economic benefits of various watershed treatments associated with roads (Table 3-32). Specifically, they examined the cost of revegetating cut-and-fill slopes and the costs of various planning and management technical services (e.g., preparing soil and water prescriptions, compiling soils data, and reviewing the project in the field). These costs were compared to savings in construction and maintenance costs resulting from the watershed treatments. Specifically, savings were realized from avoiding problem soils, wet areas, and unstable slopes. The economic analysis showed that the inclusion of soil and water resource management (i.e., revegetating and technical services) in the location and construction of forest roads resulted in an estimated savings of $311 per kilometer in construction costs and $186 per kilometer in maintenance costs.

As part of the Fisher Creek Watershed Improvement Project, Rygh (1990) examined the various costs of ripping and scarification using different techniques. The major crux of Rygh's work was to compare the relative advantages of using a track hoe for ripping and scarification versus the use of large tractor-mounted rippers. He found track hoes to be preferable to tractor-mounted rippers for a variety of reasons, including the following:

- A reduction in furrows and resulting concentrated runoff caused by tractors;
- Improved control over the extent of scarification;
- Increased versatility and maneuverability of track hoes; and
- Cost savings.

Rygh estimated that the cost of ripping with a track hoe ranged from $220 to $406 per mile compared to a cost of $550 per mile for ripping with a D7 or D8 tractor (Table 3-33).

4. Practices

As discussed more fully at the beginning of this chapter and in Chapter 1, the following practices are described for illustrative purposes only. State programs need not require implementation of these practices. However, as a practical matter, EPA anticipates that the management measure set forth above generally will be implemented by applying one or more management practices appropriate to the source, location, and climate. The practices set forth below have been found by EPA to be representative of the types of practices that can be applied successfully to achieve the management measure described above.

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Table 3-31. Comparison of Road Repair Costs for a 20-Year Period With and Without BMPs[a] (Dissmeyer and Frandsen, 1988)

Maintenance Costs Without BMPs		Costs of BMP Installation	
Equipment	$365	Labor to construct terraces and water diversions	$ 780
Materials (gravel)	122	Materials to revegetate	120
Work supervision	40	Cost of technical assistance	300
Repair cost per 3 years	527	Total cost over 20 years	$1,200
Total cost over 20 years[b]	$2,137		

IRR: 11.2%
PNV: $937
B/C ratio: 1.78 to 1.00 for road BMP installation versus reconstruction/repair.

[a] BMPs include construction of terraces and water diversions, and seeding.
[b] Discounted @ 4%.

Table 3-32. Analysis of Costs and Benefits of Watershed Treatments Associated with Roads (SE U.S.) (Dissmeyer and Foster, 1987)

	Treatment[a]		
	Seed Without Mulch	Seed With Mulch	Hydroseed With Mulch
Costs			
Cost per kilometer ($)	356	569	701
Cost per kilometer for soil and water technical services ($)	62	62	62
Total cost of watershed treatment ($)	418	631	763
Benefits[b]			
Savings in construction costs ($/km)	311	311	311
Savings in annual maintenance costs ($/km)	186	186	186
Benefit/cost (10-year period)	4.4:1	2.9:1	2.4:1

Adapted from West, S., and B.R. Thomas, 1982. Effects of Skid Roads on Diameter, Height, and Volume Growth in Douglas-Fir. *Soil Sci. Soc. Am. J.*, 45:629-632.
[a] Treatments included fertilization and liming where needed.
[b] Cost savings were associated with soil and water resource management in the location and construction of forest roads by avoiding problem soils, wet areas, and unstable slopes. Maintenance cost savings were derived from revegetating cut and fill slopes, which reduced erosion, prolonging the time taken to fill ditch lines with sediment and reducing the frequency of ditch line reconstruction.

■ *Blade and reshape the road to conserve existing surface material; to retain the original, crowned, self-draining cross section; and to prevent or remove berms (except thosedesigned for slope protection) and other irregularities that retard normal surface runoff (Larse, 1971).*

Ruts and potholes can weaken road subgrade materials by channeling runoff and allowing standing water to persist (Rothwell, 1978). Periodic grading of the road surface is necessary to fill in wheel ruts and to reshape the road (Haussman and Pruett, 1978). Maintenance practices must be modified for roads with broad-based dips (Swift, 1985). Maintenance by a motor grader is difficult because scraping tends to fill in the dips, the blade cannot be

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Table 3-33. Comparative Costs of Reclamation of Roads and Removal of Stream Crossing Structures (ID) (Rygh, 1990)

Method	Cost (dollar/mile)
Ripping/scarification	
Ripping with D7 or D8 tractor	$550
Scarifying with D8-mounted brush blade	$844
Scarification to 6-inch depth and installation of water bars with track hoe	$1,673
Ripping and slash scattering with track hoe	$440 - $660
Ripping, slash scattering, and water bar installation with track hoe	$812
Ripping with track hoe	$220 - $408

maneuvered to clean the dip outlet, and cut banks are destabilized when the blade undercuts the toe of the slope. Small bulldozers or front-end loaders appear to be more suitable for periodic maintenance of intermittent-use forest roads (Swift, 1988).

■ *Clear road inlet and outlet ditches, catch basins, culverts, and road-crossing structures of obstructions (Larse, 1971).*

Avoid undercutting backslopes when cleaning silt and debris from roadside ditches (Rothwell, 1978). Minimize machine cleaning of ditches during wet weather. Do not disturb vegetation when removing debris or slide blockage from ditches (Larse, 1971; Rothwell, 1978). The outlet edges of broad-based dips need to be cleaned of trapped sediment to eliminate mudholes and prevent the bypass of stormwaters. The frequency of cleaning depends on traffic load (Swift, 1988). Clear stream-crossing structures and their inlets of debris, slides, rocks, and other materials prior to and following any heavy runoff period (Hynson et al., 1982).

■ *Maintain road surfaces by mowing, patching, or resurfacing as necessary.*

Grassed roadbeds carrying fewer than 20-30 vehicle trips per month usually require only annual roadbed mowing and periodic trimming of encroaching vegetation (Swift, 1988).

■ *Remove temporary stream crossings to maintain adequate streamflow (Hynson et al., 1982).*

Failure or plugging of abandoned temporary crossing structures can result in greatly increased sedimentation and turbidity in the stream, and channel blowout.

■ *Wherever possible, completely close the road to travel and restrict access by unauthorized persons by using gates or other barriers (Haussman and Pruett, 1978).*

Where such restrictions are not feasible, traffic should be regulated (Rothwell, 1978).

■ *Install or regrade water bars on roads that will be closed to vehicle traffic and that lack an adequate system of broad-based dips (Kochenderfer, 1970).*

Water bars will help to minimize the volume of water flowing over exposed areas and remove water to areas where it will not cause erosion. Water bar spacing depends on soil type and slope. Table 3-34 contains suggested guidelines for water bar spacing. Water should flow off the water bar onto rocks, slash, vegetation, duff, or other less erodible material and should never be diverted directly to streams or bare areas (Oregon Department of Forestry, 1979a). Outslope closed road surfaces to disperse runoff and prevent closed roads from routing water to streams.

■ *Revegetate to provide erosion control and stabilize the road surface and banks.*

Refer to Revegetation of Disturbed Areas management measure for a more detailed discussion.

■ *Replace open-top culverts with cross drains (water bars, dips, or ditches) to control and divert runoff from road surfaces (Rothwell, 1978; Haussman and Pruett, 1978).*

Open-top culverts are for temporary drainage of ongoing operations. It is important to replace them with more permanent drainage structures to ensure adequate drainage and reduce erosion potential prior to establishment of vegetation on the roadbed.

■ *Periodically inspect closed roads to ensure that vegetational stabilization measures are operating as planned and that drainage structures are operational (Hynson et al., 1982; Rothwell, 1978). Conduct reseeding and drainage structure maintenance as needed.*

Table 3-34. Water Bar Spacing by Soil Type and Slope (Oregon Department of Forestry, 1979a)

Road Grade (percent)	Soil Type		
	Granitic or Sandy	Shale or Gravel	Clay
2	900	1000	1000
4	600	1000	800
6	500	1000	600
6	400	900	500
10	300	600	400
12	200	700	400
15	150	500	300
20	150	300	200
25+	100	200	150

Note: Distances are approximate and should be varied to take advantage of natural features.

E. Timber Harvesting

The timber harvesting management measure consists of implementing the following:

(1) Timber harvesting operations with skid trails or cable yarding follow layouts determined under Management Measure A.

(2) Install landing drainage structures to avoid sedimentation to the extent practicable. Disperse landing drainage over sideslopes.

(3) Construct landings away from steep slopes and reduce the likelihood of fill slope failures. Protect landing surfaces used during wet periods. Locate landings outside of SMAs.

(4) Protect stream channels and significant ephemeral drainages from logging debris and slash material.

(5) Use appropriate areas for petroleum storage, draining, dispensing. Establish procedures to contain and treat spills. Recycle or properly dispose of all waste materials.

For cable yarding:

(1) Limit yarding corridor gouge or soil plowing by properly locating cable yarding landings.

(2) Locate corridors for SMAs following Management Measure B.

For groundskidding:

(1) Within SMAs, operate groundskidding equipment only at stream crossings to the extent practicable. In SMAs, fell and endline trees to avoid sedimentation.

(2) Use improved stream crossings for skid trails which cross flowing drainages. Construct skid trails to disperse runoff and with adequate drainage structures.

(3) On steep slopes, use cable systems rather than groundskidding where groundskidding may cause excessive sedimentation.

1. Applicability

This management measure pertains to lands where silvicultural or forestry operations are planned or conducted. It is intended to apply to all harvesting, yarding, and hauling conducted as part of normal silvicultural activities on harvest units larger than 5 acres. This measure does not apply to harvesting conducted for precommercial thinnings or noncommercial firewood cutting.

Under the Coastal Zone Act Reauthorization Amendments of 1990, States are subject to a number of requirements as they develop coastal nonpoint source programs in conformity with this measure and will have some flexibility in doing so. The application of this management measure by States is described more fully in *Coastal Nonpoint Pollution Control Program: Program Development and Approval Guidance*, published jointly by the U.S. Environmental Protection Agency (EPA) and the National Oceanic and Atmospheric Administration (NOAA) of the U.S. Department of Commerce.

2. Description

The goal of this management measure is to minimize sedimentation resulting from the siting and operation of timber harvesting, and to manage petroleum products properly.

Logging practices that protect water quality and soil productivity can also reduce total mileage of roads and skid trails, lower equipment maintenance costs, and provide better road protection and lower road maintenance. Careful logging can disturb soil surfaces as little as 8 percent, while careless logging practices can disturb soils as much as 40 percent (Golden et al., 1984). In the Appalachians, skid roads perpendicular to the contour, instead of along the contour, yielded 40 tons of sediment per acre of skid road surface (Hornbeck and Reinhart, 1964). Higher bulk densities and lower porosity of skid road soils due to compaction by rubber-tired skidders result in reduced soil infiltration capacity and corresponding increases in runoff and erosion (Dickerson, 1975). Douglass and Swank (1975) found that poor logging techniques increased sediment production during storms by 10 to 20 times more than sediment production from the undisturbed control watershed. A properly logged watershed experienced only slightly increased sedimentation compared to the undisturbed control watershed.

Locating landings for both groundskidding and cable yarding harvesting systems according to preharvest planning minimizes erosion and sediment delivery to surface waters. However, final siting of landings may need to be adjusted in the field based on site characteristics.

Landings and loading decks can become very compacted and puddled and are therefore a source of runoff and erosion (Golden et al., 1984). Practices that prevent or disperse runoff from these areas before the runoff reaches watercourses will minimize sediment delivery to surface waters. Also, any chemicals or petroleum products spilled in harvest areas can be highly mobile, adversely affecting the water quality of nearby surface waters. Correct spill prevention and containment procedures are therefore necessary to prevent petroleum products from entering surface waters. Designation of appropriate areas for petroleum storage will also minimize water quality impacts due to spills or leakage.

3. Management Measure Selection

This management measure is based on the experience and information gained from studies and from States using similar harvesting practices. Many studies have evaluated and compared the effects of different timber harvest techniques on sediment loss (erosion), soil compaction, and overall ground disturbance associated with various harvesting techniques. The data presented in Tables 3-35 through 3-40 were compiled from many different studies conducted throughout the United States and Canada. Many local factors such as climatic conditions, soil type, and topography affected the results of each study. The studies also examined harvesting techniques under a variety of conditions, including clearcuts, selective cuts, and fire-salvaged areas. However, the major conclusions from the studies on the relative impacts of different timber harvesting techniques on soil erosion and the causes and consequences of ground disturbance remain fairly constant between the studies and enable cross-geographic comparison.

Some of the most significant water quality impacts from logging operations (especially increased sedimentation) result from the actual yarding operations and activities on landings. The critical factors that affect the degree of soil disturbance associated with a particular yarding technique include the amount of disturbance caused by the yarding machinery itself and the amount of road construction needed to support each system. Stone (1973) presented information suggesting that roads may contribute greater than 90 percent of the sedimentation problems associated with logging operations. Therefore, since road areas represent potential erosion sites, it is important to recognize and consider the amount of land used for roads by various logging systems (Sidle, 1980).

a. *Effectiveness Information*

The amount of total soil disturbance varies considerably between the different yarding techniques. Megahan (1980) presented the most comprehensive survey of the available information on these impacts, presenting the data in two ways: soil disturbance associated with the actual yarding operation and soil disturbance associated with the construction of roads needed for the practice (Tables 3-35 and 3-36). The results of his investigation echoed other studies presented in this section and clearly show that aerial and skyline cable techniques are far less damaging than other yarding techniques.

The amount of soil disturbance by yarding depends on the slope of the area, volume yarded, size of logs, and the logging system. Table 3-36 presents data on the extent of soil disturbance associated with particular yarding systems. Megahan's ranking of yarding techniques (from greatest impact to lowest impact) based on percent area disturbed is summarized as follows: tractor (21 percent average), ground cable (21 percent, one study), high-lead (16 percent

Table 3-35. Soil Disturbance from Roads for Alternative Methods of Timber Harvesting (Megahan, 1980)

Logging System (State)	Percent of Logged Area Bared			Reference
	Roads	Skid Roads and Landings	Total	
Tractor:				
Tractor — clearcut (BC)	30.0	—	30.0	Smith, 1979
Tractor — selection (CA)	2.7	5.7	8.4	Rice, 1961
Tractor — selection (ID)	2.2	6.8	9.0	Haupt and Kidd, 1965
Tractor — group selection (ID)	1.0	6.7	7.7	Haupt and Kidd, 1965
Tractor and helicopter — fire salvage (WA)	4.5	0.4	4.9	Klock, 1975
Tractor and cable — fire salvage (WA)	16.9	—	16.9	Klock, 1975
Ground Cable:				
Jammer — group selection (ID)	25-30	—	25-30	Megahan and Kidd, 1972
Jammer — clearcut (BC)	8.0	—	8.0	Smith, 1979
High-lead — clearcut (BC)	14.0	—	14.0	Smith, 1979
High-lead — clearcut (OR)	6.2	3.6	9.8	Silen and Gratkowski, 1953
High-lead — clearcut (OR)	3.0	1.0	4.0	Brown and Krygier, 1971
High-lead — clearcut (OR)	6.0	1.0	7.0	Brown and Krygier, 1971
High-lead — clearcut (OR)	6.0	—	6.0	Fredriksen, 1970
Skyline:				
Skyline — clearcut (OR)	2.0	—	2.0	Binkley, 1965
Skyline — clearcut (BC)	1.0	—	1.0	Smith, 1979
Aerial:				
Helicopter — clearcut	1.2	—	1.2	Binkley[a]

[a] Estimated by Virgil W. Binkley, Pacific Northwest Region, USDA Forest Service, Portland, OR.

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Table 3-36. Soil Disturbance from Logging by Alternative Harvesting Methods (Megahan, 1980)

Method of Harvest	Location	Disturbance (%)	Reference
Tractor:			
Tractor — clearcut	E. WA	29.4	Wooldridge, 1960
Tractor — clearcut	W. WA	26.1	Steinbrenner and Gessel, 1955
Tractor — fire salvage	E. WA	36.2	Klock[a], 1975
Tractor on snow — fire salvage	E. WA	9.9	Klock[a], 1975
Tractor — clearcut	BC	7.0	Smith, 1979
Tractor — selection	E. WA, OR	15.5	Garrison and Rummel, 1951
Ground Cable:			
Cable - selection	E. WA, OR	20.9	Garrison and Rummel, 1951
High-lead — fire salvage	E. WA	32.0	Klock[a], 1975
High-lead — clearcut	W. OR	14.1	Dyrness, 1965
High-lead — clearcut	W. OR	12.1	Ruth, 1967
High-lead — clearcut	BC	6.0	Smith, 1979
Jammer — clearcut	BC	5.0	Smith, 1979
Grapple — clearcut	BC	1.0	Smith, 1979
Skyline:			
Skyline — clearcut	W. OR	12.1	Dyrness, 1965
Skyline — clearcut	E. WA	11.1	Wooldridge, 1960
Skyline — clearcut	BC	7.0	Smith, 1979
Skyline — clearcut	W. OR	6.4	Ruth, 1967
Skyline — fire salvage	E. WA	2.8	Klock[a], 1975
Balloon — clearcut	W. OR	6.0	Dyrness[b]
Aerial:			
Helicopter — fire salvage	E. WA	0.7	Klock[a], 1975
Helicopter — clearcut	ID	5.0	Clayton (in press)

[a] Disturbance shown is classified as severe.
[b] Dyrness, C.T., unpublished data on file, Pacific Northwest Forest and Range Experiment Station, Corvallis, OR.

average), skyline (8 percent average), jammer in clearcut (5 percent, one study), and aerial techniques (4 percent average).

The amount of road required for different yarding techniques varies considerably. Sidle (1980) defined the amount of land used for haul roads by various logging methods. Skyline techniques require the least amount of road area, with only 2-3.5 percent of the land area in roads. Tractor and single-drum jammer techniques require the greatest amount of road area (10-15 and 18-24 percent of total area, respectively). High-lead cable techniques fall in the middle, with 6-10 percent of the land used for roads. Megahan (1980) concluded that tractor, jammer, and high-lead cable methods result in significantly higher amounts of disturbed soil than do the skyline and aerial techniques.

Sidle (1980) also presented data showing that tractors cause the greatest amount of soil disturbance (35 percent of land area) and soil compaction (26 percent of land area). Sidle (1980) concluded that skyline and aerial balloon techniques created the least disturbance (12 and 6 percent, respectively) and compaction (3 and 2 percent, respectively) (Table 3-37).

Miller and Sirois (1986) compared the land area disturbed by cable, skyline, and groundskidding systems (Table 3-38). They found groundskidding operations to affect 31 percent of the total land area, whereas cable yarding only affected 16 percent of the total land area. Similarly, Patric (1980) found skidders to serve the smallest area per mile of road (20 acres), with skyline yarding serving the largest area per mile of road (80 acres) (Table 3-39).

Table 3-37. Relative Impacts of Four Yarding Methods on Soil Disturbance and Compaction in Pacific Northwest Clearcuts (OR, WA, ID) (Sidle, 1980)

Yarding Method	Bare Soil (%)	Compacted Soil (%)
Tractor	35	26
High-lead	15	9
Skyline	12	3
Balloon	6	2

Table 3-38. Percent of Land Area Affected by Logging Operations (Southwest MS) (Miller and Sirois, 1986)

Operational Area	Cable Skyline	Groundskidding
Landings	4.1	6.4
Spur roads	2.6	3.5
Cable corridors or skid trails	9.2	21.4
Total	15.9	31.3

Table 3-39. Skidding/Yarding Method Comparison (Patric, 1980)[a]

Harvesting System	Acres Served per Mile of Road
Wheeled skidder	20
Jammer	31
High-lead	40
Skyline	80

[a] Adapted from Kochenderfer and Wendel (1978) and unpublished work by Thorsen.

b. Cost Information

The costs and benefits of rehabilitation of skid trails by planting hardwood, hardwood pine, and shortleaf pine in the southeastern United States were studied by Dissmeyer and Foster (1986). The average rehabilitation cost per acre was $360 and included water barring, ripping or disking, seeding, fertilizing, and mulching where needed (Table 3-40). The benefit/cost ratio of the rehabilitation cost was $1.33 for hardwood, $2.82 for hardwood pine, and $5.07 for shortleaf pine. The real rate of return over inflation ranged from 2.4 to 4.8 percent.

4. Practices

As discussed more fully at the beginning of this chapter and in Chapter 1, the following practices are described for illustrative purposes only. State programs need not require implementation of these practices. However, as a

Table 3-40. Analysis of Costs and Benefits of Skid Trail Rehabilitation in the Management of Three Southern Timber Types in the Southeast (Dissmeyer and Foster, 1986)

		Timber Type		
	Units	Hardwood	Hardwood Pine	Shortleaf Pine
Rotation	Years	70	60	60
Harvest volume per hectare	m^3	301	350	420
Value per cubic meter	$[b]	28.57	42.86	64.29
Total value of timber per hectare for uncompacted soil	$[b]	8,600	15,001	27,002
Timber volume per acre on skid trails (26% of uncompacted soil)	m^3	78	91	109
Timber volume lost per acre	m^3	223	259	311
Cost per hectare for skid trail rehabilitation[a]	$[b]	900	900	900
Timber volume recovered (75% of loss)	m^3	167	194	233
Value of timber volume recovered	$[b]	4,771	8,315	14,980
Internal rate of return based upon timber volume recovered	%[c]	2.4	3.8	4.8
Net present value of timber volume recovered (@ 2%)	$[b]	1,193	2,538	4,568
B/C ratio of rehab. cost	Ratio	1.33:1	2.82:1	5.07:1

Note: Skid trail rehabilitation reduces sediment yields.
m^3: cubic meters.
[a] Average cost for skid trail rehabilitation includes water barring, ripping or disking, seeding, fertilizing, and mulching where needed ($900/ha = $360/ac).
[b] 1986 dollars.
[c] Percentage points over inflation.

practical matter, EPA anticipates that the management measure set forth above generally will be implemented by applying one or more management practices appropriate to the source, location, and climate. The practices set forth below have been found by EPA to be representative of the types of practices that can be applied successfully to achieve the management measure described above.

a. Harvesting Practices

- *Fell trees away from watercourses, whenever possible, keeping logging debris from the channel, except where debris placement is specifically prescribed for fish or wildlife habitat (Megahan, 1983).*

- *Any tree accidently felled in a waterway should be immediately removed (Huff and Deal, 1982).*

- *Remove slash from the waterbody and place it out of the SMA.*

This will allow unrestricted water flow and protection of the stream's nutrient balance. Remove only logging-generated debris. Leave pieces of large woody debris in place during stream cleaning to preserve channel integrity and maintain stream productivity. Bilby (1984) concluded that indiscriminate removal of large woody debris can adversely affect channel stability. Table 3-41 presents a possible way to determine debris stability.

b. Practices for Landings

- *Landings should be no larger than necessary to safely and efficiently store logs and load trucks.*

- *Install drainage and erosion control structures as necessary.*

Diversion ditches placed around the uphill side of landings minimize accumulation of water on the landing. Landings should have a slight slope to facilitate drainage. Also, adequate drainage on approach roads will prevent road drainage water from entering the landing area.

- *The slope of the landing surface should not exceed 5 percent and should be shaped to promote efficient drainage.*

Table 3-41. General Large Woody Debris Stability Guide Based on Salmon Creek, Washington (Bilby, 1984)

1.a.	If debris is anchored or buried in the streambed or bank at one or both ends or along the upstream face - LEAVE.
1.b.	If debris is not anchored, go to 2.
2.a.	If debris is longer than 10.0 m - LEAVE.
2.b.	If debris is shorter than 10.0 m - go to 3.
3.a.	If debris is greater than 50 cm in diameter - go to 4.
3.b.	If debris is less than 50 cm in diameter - go to 5.
4.a.	If debris is longer than 5.0 m - LEAVE.
4.b.	If debris is shorter than 5.0 m - go to 5.
5.a.	If debris is braced on the downstream side by boulders, bedrock outcrops, or stable pieces of debris - LEAVE.
5.a.	If debris is not braced on the downstream side - REMOVE.

■ *The slope of landing fills should not exceed 40 percent, and woody or organic debris should not be incorporated into fills.*

■ *If landings are to be used during wet periods, protect the surface with a suitable material such as wooden matting or gravel surfacing.*

■ *Install drainage structures for the landings such as water bars, culverts, and ditches to avoid sedimentation. Disperse landing drainage over sideslopes. Provide filtration or settling if water is concentrated in a ditch.*

■ *Upon completion of harvest, clean up landing, regrade, and revegetate (Rothwell, 1978).*

- Upon abandonment, minimize erosion on landings by adequately ditching or mulching with forest litter.
- Establish a herbaceous cover on areas that will be used again in repeated cutting cycles, and restock landings that will not be reused (Megahan, 1983).
- If necessary, install water bars for drainage control.

■ *Locate landings for cable yarding where slope profiles provide favorable deflection conditions so that the yarding equipment used does not cause yarding corridor gouge or soil plowing, which concentrates drainage or causes slope instability.*

■ *Locate cable yarding corridors for streamside management areas following Management Measure B components. Yarded logs should not cause disturbance of the major channel banks of the watercourse of the SMA.*

c. Groundskidding Practices

■ *Skid uphill to log landings whenever possible. Skid with ends of logs raised to reduce rutting and gouging.*

This practice will disperse water on skid trails away from the landing. Skidding uphill lets water from trails flow onto progressively less-disturbed areas as it moves downslope, reducing erosion hazard. Skidding downhill concentrates surface runoff on lower slopes along skid trails, resulting in significant erosion and sedimentation hazard (Figure 3-25). If skidding downhill, provide adequate drainage on approach trails so that drainage does not enter landing.

■ *Skid perpendicular to the slope (along the contour), and avoid skidding on slopes greater than 40 percent.*

Following the contour will reduce soil erosion and encourage revegetation. If skidding must be done parallel to the slope, then skid uphill, taking care to break the grade periodically.

■ *Avoid skid trail layouts that concentrate runoff into draws, ephemeral drainages, or watercourses. Use endlining to winch logs out of SMAs or directionally fell trees so tops extend out of SMAs and trees can be skidded without operating equipment in SMAs. In SMAs, trees should be carefully endlined to avoid soil plowing or gouge.*

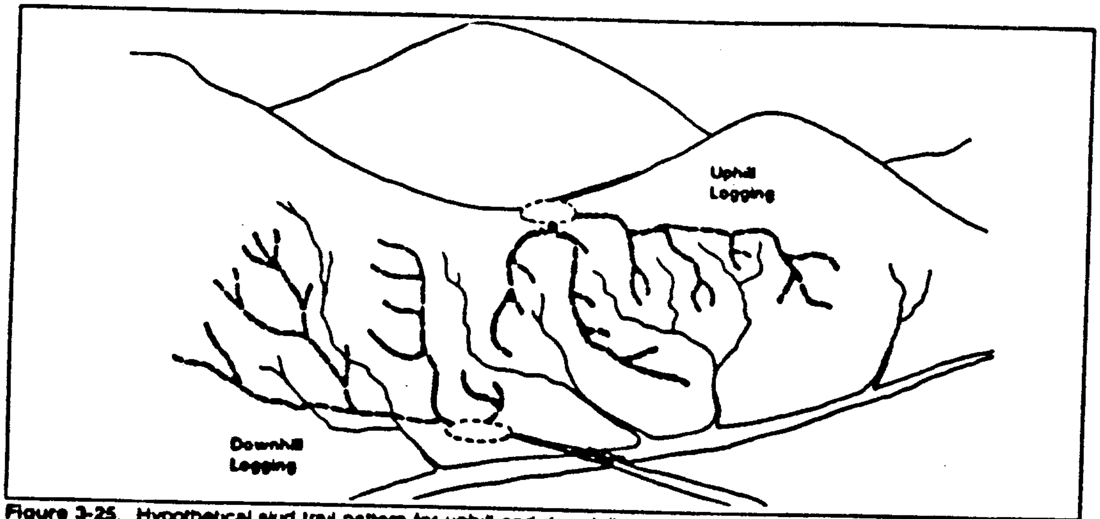

Figure 3-25. Hypothetical skid trail pattern for uphill and downhill logging (Megahan, 1983).

■ *Suspend groundskidding during wet periods, when excessive rutting and churning of the soil begins, or when runoff from skid trails is turbid and no longer infiltrates within a short distance from the skid trail. Further limitation of groundskidding of logs, or use of cable yarding, may be needed on slopes where there are sensitive soils and/or during wet periods.*

■ *Retire skid trails by installing water bars or other erosion control and drainage devices, removing culverts, and revegetating (Rothwell, 1978; Lynch et al, 1985).*

- After logging, obliterate and stabilize all skid trails by mulching and reseeding.
- Build cross drains on abandoned skid trails to protect stream channels or side slopes in addition to mulching and seeding.
- Restore stream channels by removing temporary skid trail crossings (Megahan, 1983).
- Scatter logging slash to supplement water bars and seeding to reduce erosion on skid trails (Lynch et al., 1985).

d. Cable Yarding Practices

■ *Use cabling systems or other systems when groundskidding would expose excess mineral soil and induce erosion and sedimentation.*

- Use high-lead cable or skyline cable systems on slopes greater than 40 percent.
- To avoid soil disturbance from sidewash, use high-lead cable yarding on average-profile slopes of less than 15 percent.

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■ *Avoid cable yarding in or across watercourses.*

When cable yarding across streams cannot be avoided, use full suspension to minimize damage to channel banks and vegetation in the SMA.

■ *Yard logs uphill rather than downhill.*

In uphill yarding, log decks are placed on ridge or hill tops rather than in low-lying areas (Megahan, 1983). This creates less soil disturbance because the lift imparted to the logs reduces frictional resistance and the outward radiation of yard trails downhill from the landing disperses runoff evenly over the slope and reduces erosion potential. Downhill yarding should be avoided because it concentrates surface erosion.

e. Petroleum Management Practices

■ *Service equipment where spilled fuel and oil cannot reach watercourses, and drain all petroleum products and radiator water into containers. Dispose of wastes and containers in accordance with proper waste disposal procedures.[1] Waste oil, filters, grease cartridges, and other petroleum-contaminated materials should not be left as refuse in the forest.*

■ *Take precautions to prevent leakage and spills. Fuel trucks and pickup-mounted fuel tanks must not have leaks.*

- Use and maintain seepage pits or other confinement measures to prevent diesel oil, fuel oil, or other liquids from running into streams or important aquifers.
- Use drip collectors on oil-transporting vehicles (Hynson et al., 1982).

■ *Develop a spill contingency plan that provides for immediate spill containment and cleanup, and notification of proper authorities.*

- Provide materials for adsorbing spills, and collect wastes for proper disposal.

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[1] The Resource Conservation and Recovery Act (RCRA) regulates the transportation, handling, storage, and disposal of hazardous materials, including petroleum products and by-products.

[illegible]

Confine on-site potential NPS pollution and erosion resulting from site preparation and the regeneration of forest stands. The components of the management measure for site preparation and regeneration are:

(1) Select a method of site preparation and regeneration suitable for the site conditions.
(2) Conduct mechanical tree planting and ground-disturbing site preparation activities on the contour of sloping terrain.
(3) Do not conduct mechanical site preparation and mechanical tree planting in streamside management areas.
(4) Protect surface waters from logging debris and slash material.
(5) Suspend operations during wet periods if equipment used begins to cause excessive soil disturbance that will increase erosion.
(6) Locate windrows at a safe distance from drainages and SMAs to control movement of the material during high runoff conditions.
(7) Conduct bedding operations in high-water-table areas during dry periods of the year. Conduct bedding in sloping areas on the contour.
(8) Protect small ephemeral drainages when conducting mechanical tree planting.

1. Applicability

This management measure pertains to lands where silvicultural or forestry operations are planned or conducted. It is intended to apply to all site preparation and regeneration activities conducted as part of normal silvicultural activities on harvested units larger than 5 acres.

Under the Coastal Zone Act Reauthorization Amendments of 1990, States are subject to a number of requirements as they develop coastal nonpoint source programs in conformity with this measure and will have some flexibility in doing so. The application of this management measure by States is described more fully in *Coastal Nonpoint Pollution Control Program: Program Development and Approval Guidance*, published jointly by the U.S. Environmental Protection Agency (EPA) and the National Oceanic and Atmospheric Administration (NOAA) of the U.S. Department of Commerce.

2. Description

Regeneration of harvested forest lands not only is important in terms of restocking a valuable resource, but also is important to provide water quality protection from disturbed soils. Tree roots stabilize disturbed soils by holding the soil in place and aiding soil aggregation, decreasing slope failure potential. The presence of vegetation on disturbed soils also slows storm runoff, which in turn decreases erosion.

Leaving the forest floor litter layer intact during site preparation operations for regeneration minimizes mineral soil disturbance and detachment, thereby minimizing erosion and sedimentation (Golden et al., 1984). Maintenance of an unbroken litter layer prevents raindrop detachment, maintains infiltration, and slows runoff (McClurkin et al.,

1987) Mechanical site preparation can potentially impact water quality in areas that have steep slopes and erodible soils and where the prepared site is located near a waterbody. Use of mechanical site preparation treatments that expose mineral soils on steep slopes can greatly increase erosion and landslide potential. Alternative methods, such as drum chopping, herbicide application, or prescribed burning, disturb the soil surface less than mechanical practices (Golden et al., 1984).

Mechanical planting using machines that scrape or plow the soil surface can produce erosion rills, increasing surface runoff and erosion. Natural regeneration, hand planting, and direct seeding minimize soil disturbance, especially on steep slopes with erodible soils (Golden et al., 1984).

3. Management Measure Selection

This measure is based in part on information and experience gained from studies and from the use of similar management practices by States. The information summarized provides comparisons and relative levels of effects and costs for site preparation and regeneration. The majority of the data in Tables 3-42 through 3-46 compare sediment loss or erosion rates for shearing, chopping, root-raking and disking. Many of the data are site-specific, and site characteristics and experimental conditions are provided (when available) in the text below. Regional differences in effects are summarized by Dissmeyer and Stump (1978); however, most of the experimental information is from the Southeast and Texas.

a. Effectiveness Information

Effects of different site preparation techniques depend greatly on care of application and site conditions. Beasley (1979) studied the relative soil disturbance effects of site preparation following clearcutting on three small watersheds in the hilly northern Mississippi Coastal Plain. Slopes were mostly 30 percent or greater. One site was single drum-chopped and burned; one was sheared and windrowed (windrows were burned); and the third was sheared, windrowed, and bedded to contour. The control watershed was instrumented and left uncut. The treatments exposed soil on approximately 40-70 percent of the three watersheds (Table 3-42). A temporary cover crop of clover was sown after site preparation to protect the soil from rainfall impact and erosion. Similar increases in sediment production were measured for the three treatments in the first year after site preparation, with amounts decreasing during the second year except for the bedded site, which was attributed to gully formation from increased stormflow. During the second year, the clover and other vegetation covered 85-95 percent of the surface, effectively decreasing sediment production.

A summary of work on erosion from site preparation by Dissmeyer and Stump is presented in Golden et al. (1984)(Table 3-43). These erosion rates were compiled from the Erosion Data Bank of the U.S. Forest Service and are based on observations throughout the Southeast. The rates reflect soil movement measured at the bottom of the slope, not sediment actually reaching a stream. Therefore, the numbers estimate the worst-case erosion if the stream is located directly at the toe of the slope with no intervening vegetation. Rates are given as tons per acre per year average for 3- to 4-year recovery periods.

The degree of erosion produced by site preparation practices is directly related to the amount of soil disturbed and the percentage of good ground cover remaining. Dissmeyer (1980) showed that disking produced more than twice the erosion rate of any other method (Table 3-44). Bulldozing, shearing, and sometimes grazing were associated with relatively high rates of erosion. Chopping or chopping and burning produced moderate erosion rates. Logging also produced moderate erosion rates in this study when it included the impact of skid and spin roads. The lowest rate of erosion is associated with burning.

Beasley and Granillo (1985) compared stormflow and sediment losses from mechanically and chemically prepared sites in southwest Arkansas (Table 3-45). Mechanical preparation (clearcutting followed by shearing, windrowing, and replanting with pine seedlings) significantly increased sediment losses in the first 2 years after treatment. A subsequent decline in sediment losses in the mechanically prepared watersheds was attributed to rapid growth of ground cover. Windrowing brush into ephemeral drainages and leaving it unburned effectively minimized soil losses

Table 3-42. Deposited, Suspended, and Total Sediment Losses and Percentage of Exposed Soil in the Experimental Watersheds During Water Years 1976 and 1977 for Various Site Preparation Techniques (MS, AR) (Beasley, 1979)

Treatment	Percent of Exposed Soil
Chopped	37
Sheared and windrowed	53
Bedded	69

Treatment	1976 (tons/ha)			1977 (tons/ha)		
	Deposited	Suspended	Total	Deposited	Suspended	Total
Control	--	--	0.62	--	--	0.11
Chopped	2.19	10.34	12.54	0.74	1.58	2.31
Sheared	2.14	10.66	12.80	0.81	1.41	2.22
Bedded	3.26	10.98	14.25	2.18	3.36	5.54

by trapping sediment on-site and reducing channel scouring. Chemical site preparation (herbicides) had no significant effect on sediment losses.

Water quality changes associated with two site preparation methods were studied by Blackburn, DeHaven, and Knight (1982). Table 3-46 shows that shearing and windrowing (which exposed 59 percent of the soil) can produce 400 times more sediment loadings than chopping (which exposed 16 percent of the soil) during site preparation. Total

Table 3-43. Predicted Erosion Rates[a] Using Various Site Preparation Techniques for Physiographic Regions in the Southeastern United States (Golden et al., 1984)

Physiographic Regions	Treatment	Average Erosion Rate (tons/acre/year)
Ridge and Valley	Bulldozing	13.70
Sand Mountain	KG-blade	4.00
Southern Piedmont	Chopping	0.22
	Chop and burn	0.38
	KG-blade	1.80
	Disking	4.10
	Bulldozing	1.90
Southern Coastal Plain	Chopping	0.24
	Chop and burn	0.41
	KG-blade	0.65
	Disking	2.46
	Bulldozing	0.66
		0.89
Blackland Prairies, AL and MS	KG-blade	1.20
	Disking	3.30

[a] Rates are averages for the recovery period.

Table 3-44. Erosion Rates for Site Preparation Practices in Selected Land Resource Areas in the Southeast (Dissmeyer, 1980)

Condition or Activity	Recovery Period (Years)	Erosion Rates by Land Resource Area (Tons/Acre/Year): Ouachita Mtns	Southern Appalachians	Southern Coastal Plains	Southern MS Valley Silty Uplands	Southern Piedmont	Carolina & GA Sand Hills	Atlanta & Gulf Coast Flatwoods
Natural	–	0.00	0.00	0.00	0.05	0.00	0.00	0.00
Logged[a]	3	2.3	1.7	0.48	0.27	0.48	0.20	0.13
Burned	2	0.23	0.16	0.17	0.7	0.14	0.06	0.05
Chopped	3	0.60	–	0.24	–	0.22	0.36	0.05
Chopped and burned	3-4	1.7	–	0.41	–	0.38	–	0.15
Sheared	4	3.6	–	0.65	2.4	1.8	1.0	0.20
Disked	4	–	–	2.46	9.8	4.1	–	–
Bulldozed	4	–	–	0.89	–	1.9	–	–
Grazed	–	0.80	–	0.18	1.0	0.95	–	0.01

[a] Includes the impact of skid and spur roads.

Table 3-45. Effectiveness of Chemical and Mechanical Site Preparation in Controlling Water Flows and Sediment Losses (AR) (Beasley and Granillo, 1985)

Water Year	Treatment	Annual Stormflow (in): Mean	Annual Stormflow (in): Std Dev	Annual Sediment Losses (lb/ac): Mean	Annual Sediment Losses (lb/ac): Std Dev
1981	Clearcut - Mechanical[a]	5.7	5.0	56	56
(Pretreatment)	Clearcut - Chemical[b]	4.7	5.5	39	50
	Control	7.9	7.5	28	26
1982	Clearcut - Mechanical	12.8	10.7	477	460
	Clearcut - Chemical	6.2	5.8	224	196
	Control	6.3	5.4	64	79
1983	Clearcut - Mechanical	24.0	19.3	897	949
	Clearcut - Chemical	15.6	15.8	183	157
	Control	8.7	7.3	131	196
1984	Clearcut - Mechanical	19.7	16.6	275	160
	Clearcut - Chemical	10.2	8.0	80	80
	Control	10.3	7.2	41	59

[a] Clearcutting followed by shearing, windrowing, and replanting with pine seedlings.
[b] Clearcutting followed by chemical treatments (injection of residual trees and foliar and/or aerial spraying).

Table 3-46. Sediment Loss (kg/ha) in Stormflow by Site Treatment from January 1 to August 31, 1981 (TX) (Blackburn, DeHaven, and Knight, 1982)

Treatment	Watershed	Sediment Loss (kg/ha)		
		Suspended	Bedload	Total
Sheared and windrowed	1	815.2	643.5	1,458.7
	2	1,217.0	920.4	2,137.4
	3	736.7	2,270.8	3,007.5
	Mean	923.0	1,278.2	2,201.2
Chopped	5	5.3	0	5.3
	7	10.7	0	10.7
	9	23.2	0	23.2
	Mean	13.1	0	13.1
Undisturbed	4	1.1	0	1.1
	6	7.2	0	7.2
	8	0.8	0	0.8
	Mean	3.0	0	3.0

nitrogen losses were nearly 20 times greater from sheared than from undisturbed watersheds, and three times greater from sheared than from chopped (Table 3-47).

b. Cost Information

The way a site is prepared for reforestation can make a 3- to 14-foot difference in site index for pine in the Southeast (Dissmeyer and Foster, 1987). In an analysis of different site preparation techniques, Dissmeyer and Foster concluded that maintaining site quality yields larger trees and more valuable products (Table 3-48). The heavy site preparation methods required a greater initial investment than did the light site preparation methods, but did not yield a greater harvest. The cost-benefit for light site preparation was a 2.3 percent greater internal rate of return than that for heavy site preparation. Dissmeyer (1986) evaluated the economic benefits of erosion control with respect to different site preparation techniques. Increased timber production and savings in site preparation costs are returns the landowner can enjoy if care is taken to reduce soil exposure, displacement, and compaction (Table 3-49). Using light site preparation techniques such as chopping and light burn reduces erosion, increases the site index and the value of timber, and costs less per unit area treated. Heavy site preparation techniques such as shearing and windrowing remove nutrients, compact soil, increase erosion and site preparation costs, and result in a lower present net value for timber.

Table 3-47. Nutrient Loss (kg/ha) in Stormflow by Site Treatment from January 1 to August 31, 1981 (TX) (Blackburn, DeHaven, and Knight, 1982)

Treatment	Nitrates	Ammonia	Total-N	Ortho-P	Total-P	K	Ca	Mg	Na
Sheared and windrowed	0.227	0.114	2.145	0.033	0.197	4.40	0.72	1.45	1.36
Chopped	0.066	0.042	0.759	0.010	0.012	2.48	1.19	0.71	0.79
Undisturbed	0.001	0.007	0.115	0.001	0.002	0.29	0.19	0.21	0.18

Table 3-48. Analysis of Two Management Schedules Comparing Cost and Site Productivity in the Southeast (Dissmeyer and Foster, 1987)

		Light Site Preparation[a]		Heavy Site Preparation[b]	
Year	Silviculture Treatment	Investment Per Hectare[c]	Wood Produced M³/ha	Investment Per Hectare[c]	Wood Produced M³/ha
1984	Site Prep/Tree Planting	$297		$420	
1999	Thinning	$252	64.2 pulpwood	$180	46.0 pulpwood
2010	Thinning	$256	22.3 saw timber 33.3 pulpwood	$331	5.3 saw timber 22.0 pulpwood
2020	Final Harvest	$2,422	133.5 saw timber 15.2 pulpwood	$2,071	112.3 saw timber 22.0 pulpwood
Present Net Value (@ 4%)		$623		$304	
Internal Rate of Return		12.4%[d]		10.1%	

Adapted from Patterson, T. 1984. Dollars in Your Dirt. *Alabama's Treasured Forests*. Spring: 20-21.

[a] Light site preparation includes chop and light burn or chop with herbicides, and reduces soil exposure and erosion.

[b] Heavy site preparation includes bulldozing or windrowing or shearing and windrowing, and increases erosion and sediment yields over those for light site preparation.

[c] 1984 dollars.

[d] Based on 4% inflation rate assumed.

The U.S. Forest Service (1987) examined the costs of three alternatives to slash treatment: broadcast burn and protection of streamside management zones, yarding of unmerchantable material (YUM) of 15 inches in diameter or more, and YUM of 8 inches in diameter or more (Table 3-50). YUM alternatives cost approximately $435-$820/acre, in comparison to broadcast burning at $900/acre. In addition, the YUM alternatives protect highly erodible soils from direct rainfall and runoff impacts, reduce fire hazards, meet air and water quality standards, and allow for the rapid establishment of seedlings on clearcuts.

Table 3-49. Site Preparation Comparison (VA, SC, NC) (Dissmeyer, 1986)

Treatment	Treatment Cost ($/acre)	Erosion Index[a]
No site preparation	$40	1.0
Burn only	$45	1.1
Single chop and burn	$80	2.3
Double chop and burn	$120	3.0
Single shear and burn	$145	4.3
Shear twice and burn	$170	5.1
Rootrake and disk and burn	$170	16.0
Rootrake and burn	$170	16.0

[a] The index is an expression of relative erosion potential resulting from each treatment.

Table 3-50. Comparison of Costs for Yarding Unmerchantable Material (YUM) vs. Broadcast Burning (OR) (USDA, 1987)

Activity	Broadcast Burn and Protect SMA	YUM 15" in Diameter and No Burn	YUM 8" in Diameter and No Burn
Broadcast burn	$350/acre	N/A	N/A
SMA protection	$450/acre	N/A	N/A
YUM, fell hardwood, lop and scatter	N/A	$305/acre	$700/acre
Planting cost	$100/acre	$130/acre	$120/acre
Totals	$900/acre	$435/acre	$820/acre

Tables 3-51 and 3-52 present comparisons of estimated total costs for different site preparation and regeneration practices, respectively, for which cost-share assistance is provided by the State of Minnesota through its Stewardship Incentives Program (SIP) (Minnesota Department of Natural Resources, 1991). Table 3-53 presents total costs of forest regeneration by various methods, along with the cost-share amount provided by the State of Illinois' SIP.

4. Practices

As discussed more fully at the beginning of this chapter and in Chapter 1, the following practices are described for illustrative purposes only. State programs need not require implementation of these practices. However, as a practical matter, EPA anticipates that the management measure set forth above generally will be implemented by applying one or more management practices appropriate to the source, location, and climate. The practices set forth below have been found by EPA to be representative of the types of practices that can be applied successfully to achieve the management measure described above.

a. Site Preparation Practices

■ *Mechanical site preparation should not be applied on slopes greater than 30 percent.*

On sloping terrain greater than 10 percent, or on highly erosive soils, operate mechanical site preparation equipment on the contour.

■ *Mechanical site preparation should not be conducted in SMAs.*

■ *Construct beds along the contour (Huff and Deal, 1982). Avoid connecting beds to drainage ditches or other waterways.*

■ *Use haystack piling where possible instead of windrows.*

Leave sufficient slash and duff on the site to provide good ground cover and minimize erosion from the harvest site. If the soil Basic Erosion Rate (BER) is low, leave at least 40 percent good ground cover; if the BER is medium, leave at least 50 percent good ground cover; if the BER is high, leave at least 60 percent good ground cover.

■ *Minimize incorporation of soil material into windrows and piles during their construction.*

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Table 3-51. Estimated Costs for Site Preparation (1991 Costs) (Minnesota Department of Natural Resources, 1991)

Site Preparation Practice	Total Cost[a]
Chemical	$67.00/acre
Mechanical	
Light (includes hand site preparation)	$47.00/acre
Heavy[b]	$107.00/acre
Chemical-Mechanical[b]	$113.00/acre

[a] The costs shown represent the total cost of the practice. Calculations were made by dividing the maximum Federal cost share by 0.75 to get the total cost.
[b] Where slope exceeds 20 percent or primary cover is standing hardwoods greater than 12 inches in diameter, the above may be increased by $40.00 per acre.

Table 3-52. Estimated Costs for Regeneration (1991 Costs) (Minnesota Department of Natural Resources, 1991)

Regeneration Practice	Total Cost[a]
Planting[b]	
Softwoods (when purchased from State nurseries)	$21.00/100 seedlings planted
Hardwoods (when purchased from State nurseries)	$29.00/100 seedlings planted
Softwoods (when purchased from private nurseries)	$28.00/100 seedlings planted
Hardwoods (when purchased from private nurseries)	$41.00/100 seedlings planted
Shrubs	$40.00/100 seedlings planted
Seeding (includes both purchase of seed and seeding)	
Aerial seeding	$23.00/acre
Cyclone seeding	$40.00/acre
Hand or hot cap seeding	$53.00/acre

[a] The costs shown represent the total cost of the practice. Calculations were made by dividing the maximum Federal cost share by 0.75 to get the total cost.
[b] Where planting is to be done on areas of heavy slash from recent harvesting operations or on areas with slopes over 30 percent or on sites having other particularly difficult planting conditions, the limits may be increased an additional $10.00 per 100 seedlings planted and, where the planting has a guaranteed end result, the above rates may be increased by $5.00 per 100 trees planted.

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Table 3-53. Cost-Share Information for Revegetation/Tree Planting (Illinois Administrative Code, 1990)

Practice Description	Cost-Share Amount[a]	Total Cost
Tree planting (trees and labor)		
No-cost planting stock	NTE $70.00/acre	$87.50/acre
Purchased planting stock	NTE $170.00/acre	$212.50/acre
Direct seeding (including seed collected or purchased plus labor and any machinery use)	NTE $40.00/acre	$50.00/acre

NTE = not to exceed.
[a] Cost-share amounts represent 80 percent of the actual cost.

This can be accomplished by using a rake or, if use of a blade is unavoidable, keeping the blade above the soil surface and removing only the slash. Rapid site recovery and tree growth are promoted by the retention of nutrient-rich topsoil, and the effectiveness of the windrow in minimizing sedimentation is increased.

■ *Locate windrows and piles away from drainages to prevent movement of materials during high-runoff conditions.*

■ *Avoid mechanical site preparation operations during periods of saturated soil conditions that may cause rutting or accelerate soil erosion.*

■ *Do not place slash in natural drainages, and remove any slash that accidentally enters drainages.*

Slash can clog the channel and cause alterations in drainage configuration and increases in sedimentation. Extra organic material can lower the dissolved oxygen content of the stream. Slash also allows silt to accumulate in the drainage and to be carried into the stream during storm events.

■ *Provide filter strips of sufficient width to protect drainages that do not have SMAs from sedimentation by the 10-year storm.*

b. Practices for Regeneration

■ *Distribute seedlings evenly across the site.*

■ *Order seedlings well in advance of planting time to ensure their availability.*

■ *Hand plant highly erodible sites, steep slopes, and lands adjacent to stream channels (SMAs)(Yoho, 1980).*

■ *Operate planting machines along the contour to avoid ditch formation.*

- Soil conditions (slope, moisture conditions, etc.) should be suitable for adequate machine operation.
- Slits should be closed periodically to avoid channeling flow.

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Prescribe fire for site preparation and control or suppress wildfire in a manner which reduces potential nonpoint source pollution of surface waters:

(1) Intense prescribed fire should not cause excessive sedimentation due to the combined effect of removal of canopy species and the loss of soil-binding ability of subcanopy and herbaceous vegetation roots, especially in SMAs, in streamside vegetation for small ephemeral drainages, or on very steep slopes.
(2) Prescriptions for prescribed fire should protect against excessive erosion or sedimentation to the extent practicable.
(3) All bladed firelines, for prescribed fire and wildfire, should be plowed on contour or stabilized with water bars and/or other appropriate techniques if needed to control excessive sedimentation or erosion of the fireline.
(4) Wildfire suppression and rehabilitation should consider possible NPS pollution of watercourses, while recognizing the safety and operational priorities of fighting wildfires.

1. Applicability

This management measure pertains to lands where silvicultural or forestry operations are planned or conducted. It is intended to apply to all prescribed burning conducted as part of normal silvicultural activities on harvested units larger than 5 acres and for wildfire suppression and rehabilitation on forest lands.

Under the Coastal Zone Act Reauthorization Amendments of 1990, States are subject to a number of requirements as they develop coastal nonpoint source programs in conformity with this measure and will have some flexibility in doing so. The application of this management measure by States is described more fully in *Coastal Nonpoint Pollution Control Program: Program Development and Approval Guidance*, published jointly by the U.S. Environmental Protection Agency (EPA) and the National Oceanic and Atmospheric Administration (NOAA) of the U.S. Department of Commerce.

2. Description

The goal of this management measure is to minimize potential NPS pollution and erosion resulting from prescribed fire for site preparation and from the methods used for wildfire control or suppression.

Prescribed burning is aimed at reducing slash and competition for nutrients among seedlings and protecting against wildfire. Slash burning destroys vegetation that reduces nitrogen-nitrate loadings. If uncontrolled, the burn may reach SMAs or highly erodible soils, causing increased sedimentation and erosion. Prescribed burning causes changes in the chemical cycling of elements by influencing biological and microclimate changes, volatilization, and mineralization processes.

The intensity and severity of burning and the proportion of the watershed burned are the major factors affecting the influence of prescribed burning on streamflow and water quality (Baker, 1990). Fires that burn intensely on steep slopes close to streams and that remove most of the forest floor and litter down to the mineral soil are most likely to adversely affect water quality (Golden et al., 1984). The amount of erosion following a fire depends on the following:

- Amount of ground cover remaining on the soil;
- Steepness of slope;
- Time, amount, and intensity of rainfall;
- Intensity of fire;
- Inherent erodibility of the soil; and
- Rapidity of revegetation.

Mersereau and Dyrness (1972) found slash burning on steep slopes to contribute to surface soil movement by removing litter and vegetation, and baring 55 percent of the mineral soil. Richter and others (1982), however, found that periodic, low-intensity prescribed fires had little effect on water quality in the Atlantic and Gulf coastal plain. Revegetation of burned areas also drastically reduces sediment yield from prescribed burning and wildfires (Baker, 1990).

3. Management Measure Selection

This measure is based in part on information and experience gained from studies and from the use of similar management practices by States. To avoid many of the negative impacts from prescribed burning, Pope (1978) recommends that those in charge of managing the fire construct water diversions on firelines in steep terrain to drain the water away from the burn, leave an adequate strip of undisturbed surface between the prescribed burn area and water sources, and avoid intense fires on soils that are uncohesive and highly erodible.

Dyrness (1963) studied the effects of slash burning in the Pacific Northwest, finding that severe burning decreases soil porosity and infiltration capacity, thus increasing the potential for soil erosion. Clayton (1981) found that after the helicopter logging and broadcast burning of slash in the Idaho batholith, erosion increased approximately 10 times the natural rate for a short period of time as the result of to a high-intensity rain storm and then decreased substantially within the following year.

Feller (1981) examined the effects of (1) clearcutting and (2) clearcutting and slash burning on stream temperatures in southwestern British Columbia. Both treatments resulted in increased summer temperatures as well as daily temperature fluctuations. These effects lasted for 7 years in the case of the clearcut stream but longer in the case of the clearcut and slash-burned stream. Clearcutting increased winter temperatures, while slash burning decreased temperatures. The study concluded that clearcutting and slash burning had a greater impact on stream temperatures than did clearcutting alone.

Biswell and Schultz (1957) found that surface runoff and erosion in northern California ponderosa pine forests are not attributable to prescribed burning. While conducting observations during heavy rains, the authors found that the duff and debris left after burning were effective in maintaining high infiltration and percolation capacity, and they traced surface runoff to bare soil areas caused by human activity. A study by Page and Lindenmuth (1971) examined the effects of prescribed fire on vegetation and sediment on a watershed in the oak-mountain mahogany chaparral of central Arizona. The study found that the average sediment movement from the treated drainages during the 5-year period was 0.30 acre-feet per square mile per year, which is substantially less than the sediment loss of 3.2 acre-feet per square mile per year for the first 5 years following a wildfire in a comparable area in Arizona.

Stednick and others (1982) found increased concentrations of suspended sediments, phosphorus, and potassium in streamflows below the burned area after the slash burning of coastal hemlock-spruce forests of southeastern Alaska. Stream monitoring indicated an immediate flush of elements, followed by a slower release of these elements into surface water. No reduction in the nitrogen content or depth of the soil organic horizon was found, but there were significant reductions in the potassium and magnesium contents of the soil.

Minnesota's Landowner Forest Stewardship Plan (1991) estimates the cost for prescribed burning to be $27/acre.

4. Practices

As discussed more fully at the beginning of this chapter and in Chapter 1, the following practices are described for illustrative purposes only. State programs need not require implementation of these practices. However, as a practical matter, EPA anticipates that the management measure set forth above generally will be implemented by applying one or more management practices appropriate to the source, location, and climate. The practices set forth below have been found by EPA to be representative of the types of practices that can be applied successfully to achieve the management measure described above.

a. Prescribed Fire Practices

■ *Carefully plan burning to adhere to weather, time of year, and fuel conditions that will help achieve the desired results and minimize impacts on water quality.*

Evaluate ground conditions to control the pattern and timing of the burn.

■ *Intense prescribed fire for site preparation should not be conducted in the SMA.*

■ *Piling and burning for slash removal purposes should not be conducted in the SMA.*

■ *Avoid construction of firelines in the SMA.*

■ *In prescriptions for burns, avoid conditions requiring extensive blading of firelines by heavy equipment.*

Use handlines, firebreaks, and hose lays to minimize blading of firelines.

■ *Use natural or in-place barriers (e.g., roads, streams, lakes, wetlands) as an acceptable way to minimize the need for fireline construction in situations where artificial construction of firelines will result in excessive erosion and sedimentation.*

■ *Construct firelines in a manner that minimizes erosion and sedimentation and prevents runoff from directly entering watercourses.*

- Locate firelines on the contour whenever possible, and avoid straight uphill-downhill placement.
- Install grades, ditches, and water bars while the line is being constructed.
- Install water bars on any fireline running up and down the slope, and direct runoff onto a filter strip or sideslope, not into a drainage (Huff and Deal, 1982).
- Construct firelines at a grade of 10 percent or less where possible.
- Adequately cross-ditch all firelines at the time of construction (Megahan, 1983).
- Construct simple diversion ditches or turnouts at intervals as needed to direct surface water off the plowed line and onto undisturbed forest cover for dispersion of water and soil particles.
- Construct firelines only as deep and wide as necessary to control the spread of the fire.

■ *Maintain the erosion control measures on firelines after the burn.*

■ *Revegetate firelines with adapted herbaceous species (Megahan, 1983).*

Refer to the Revegetation of Disturbed Areas management measure for more detailed information.

■ *Execute the burn with a trained crew and avoid intense burning.*

Intense burning can accelerate erosion by consuming the organic cover.

■ *Avoid burning on steep slopes with high-erosion-hazard areas or highly erodible soils.*

b. Wildfire Practices

■ *Whenever possible avoid using fire-retardant chemicals in SMAs and over watercourses, and prevent their runoff into watercourses. Do not clean application equipment in watercourses or locations that drain into watercourses.*

■ *Close water wells excavated for wildfire-suppression activities as soon as practical following fire control.*

■ *Provide advance planning and training for firefighters that considers water quality impacts when fighting wildfires. This can include increasing awareness so direct application of fire retardants to waterbodies is avoided and firelines are placed in the least detrimental position.*

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Reduce erosion and sedimentation by rapid revegetation of areas disturbed by harvesting operations or road construction:

(1) Revegetate disturbed areas (using seeding or planting) promptly after completion of the earth-disturbing activity. Local growing conditions will dictate the timing for establishment of vegetative cover.
(2) Use mixes of species and treatments developed and tailored for successful vegetation establishment for the region or area.
(3) Concentrate revegetation efforts initially on priority areas such as disturbed areas in SMAs or the steepest areas of disturbance near drainages.

1. Applicability

This management measure pertains to lands where silvicultural or forestry operations are planned or conducted. It is intended to apply to all disturbed areas resulting from harvesting, road building, and site preparation conducted as part of normal silvicultural activities. Disturbed areas are those localized areas within harvest units or road systems where mineral soil is exposed or agitated (e.g., road cuts, fill slopes, landing surfaces, cable corridors, or skid trail ruts).

Under the Coastal Zone Act Reauthorization Amendments of 1990, States are subject to a number of requirements as they develop coastal nonpoint source programs in conformity with this measure and will have some flexibility in doing so. The application of this management measure by States is described more fully in *Coastal Nonpoint Pollution Control Program: Program Development and Approval Guidance*, published jointly by the U.S. Environmental Protection Agency (EPA) and the National Oceanic and Atmospheric Administration (NOAA) of the U.S. Department of Commerce.

2. Description

Revegetation of areas of disturbed soil can successfully prevent sediment and pollutants associated with the sediment (such as phosphorus and nitrogen) from entering nearby surface waters. The vegetation controls soil erosion by dissipating the erosive forces of raindrops, reducing the velocity of surface runoff, stabilizing soil particles with roots, and contributing organic matter to the soil, which increases soil infiltration rates. In areas such as the Pacific Northwest, the construction of forest roads without revegetation has led to significant increases in stream sedimentation. According to Carr and Ballard (1980), studies have found that stream sedimentation increased 250 times during the first rainfalls following construction of a 2.5-km logging road within a 100-hectare watershed and remained higher than an undisturbed companion watershed for the next 2 years.

Vegetation can trap and prevent dry ravel from moving further downslope, and it produces organic matter that is incorporated into the soil, increasing infiltration rates (Berglund, 1978). Nutrient and soil losses to streams and lakes also can be reduced by revegetating burned, cut over, or otherwise disturbed areas (Crumrine, 1977). In some cases, double plantings are used: an early planting to establish erosion protection quickly and a later planting to provide more permanent protection (Hynson et al., 1982).

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3. Management Measure Selection

a. Effectiveness Information

This measure is based in part on information and experience gained from studies and from the use of similar management practices by States. Significant reductions in soil erosion have been achieved by revegetating bare cut-and-fill slopes alongside forest roads. A study of forest roadside slopes at two sites on Vancouver Island, Canada, by Carr and Ballard (1980) found revegetation to be an effective management practice in preventing soil erosion. At the control sites where no plant cover was present, the soil eroded to an average depth of 2-3 cm over 7 months, amounting to an estimated soil loss of 345 cubic meters per kilometer of road. In contrast, sites with hydroseeding had a net accumulation of soil material. In terms of practices, a single hydroseeding application of both seed and fertilizer was as effective as sequential hydroseeding application of seed and fertilizer in terms of preventing soil erosion. The practice of mulching on non-gully-prone soils, as a supplement to hydroseeding, was found to be unnecessary because mulch is incorporated into the hydromulch.

Kuehn and Cobourn (1989) studied the Basic Erosion Rate (BER) for soils on commercial forest land in the Eldorado National Forest and concluded that good ground cover is key to reducing erosion. Figure 3-26 demonstrates the relationship between percent ground cover and slope, and the resulting soil loss. Good ground cover is defined as "living plants within 5 feet of the ground and litter or duff with a depth of 2 inches or more."

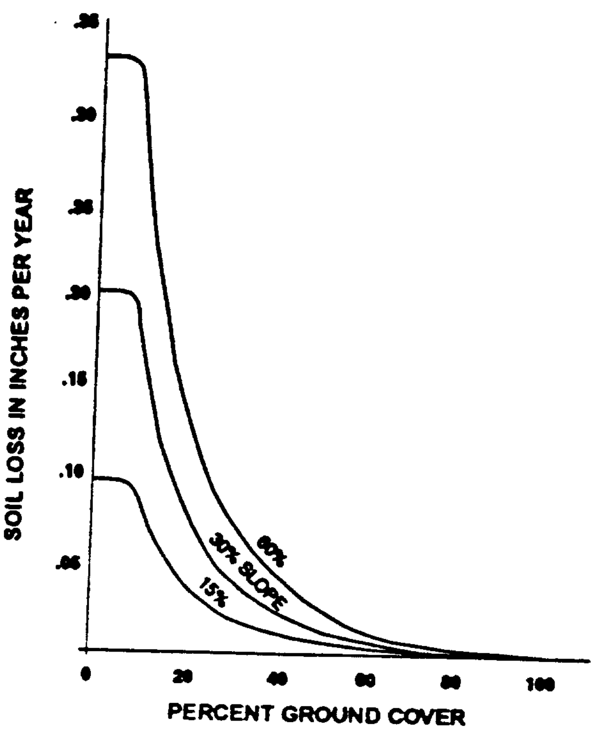

Figure 3-26. Relation of soil loss to good ground cover (Kuehn and Cobourn, 1989).

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Seeding was also cited by Berglund (1978) as a successful management practice for controlling erosion along forest roads in Oregon. When establishing a revegetation erosion control program, the author suggested that the program address criteria for seed selection, site preparation guidelines, timing of seeding, application methods, fertilization, and mulching. Several guidelines for seed cover, fertilization, and mulching rates were also presented. For example, Berglund suggests that a vegetative cover of 40 percent or more is necessary to significantly reduce soil erosion from disturbed areas.

Bethlahmy and Kidd (1966) described the extent to which revegetation controls erosion from steep road fills as dependent upon the amount of protection given to the seeded slopes (Table 3-54). Seed and fertilizer alone did not control erosion, but the addition of straw mulch reduced erosion by one-eighth to one-half. Adding more protection, netting as well as mulch, reduced erosion by almost 100 percent to nearly negligible levels.

b. Cost Information

Megahan (1987) found the costs of seeding with plastic netting placed over the seeded area to be almost 50 times more than the costs of dry seeding alone (Table 3-55). The economic impacts of other revegetation management measures were estimated by Dubensky (1991)(Table 3-56). Seeding firelines or rough logging roads adds $19.75 per 100 feet of road or fireline. Ripping, shaping, and seeding log decks costs about 178.50 per log deck. Fiber for road and landing maintenance adds $4 per ton used, and water bars add $12.50 each for construction and seeding.

Lickwar (1989) compared the costs for revegetation of disturbed areas for various slope gradients in the Southeast. He found that revegetation costs decreased slightly as slope decreased; however, costs remained fairly high (Table 3-57). Minnesota's Stewardship Incentives Program (SIP) estimated the costs of reestablishment of permanent vegetation to vary from $80.00/acre to $147.00/acre of disturbed area, depending on type of vegetation (Table 3-58).

Table 3-54. Comparison of the Effectiveness of Seed, Fertilizer, Mulch, and Netting in Controlling Cumulative Erosion from Treated Plots on a Steep Road Fill in Idaho (Bethlahmy and Kidd, 1966)

Cumulative Elapsed Time (days)	Cumulative Precipitation (inches)	Control Plot[a]	Group A (seed, fertilizer)		Group B (seed, mulch, fertilizer)		Group C (seed, fertilizer, mulch, netting)		
			Erosion (in 1,000 lb/ac) by Plot Number[b]						
			2	4	3	8	5	6	7
17	1.41	31.9	38.7	38.0	0.1	32.6	0	0	0
80	4.71	70.0	99.2	85.7	7.4	34.6	0.9	0	0.3
157	12.46	72.2	100.2	86.9	11.1	35.1	1.1	0	0.4
200	15.25	79.1	101.0	87.6	11.4	35.7	1.1	0	0.4
255	17.02	82.3	102.8	88.8	11.5	35.8	1.1	0	0.4
322	20.40	84.2	104.7	89.4	11.9	36.0	1.1	0	0.4

[a] The control plot received no treatment at all.
[b] Plot 2 had contour furrows, seed, fertilizer, holes.
Plot 3 had contour furrows, straw mulch, seed, fertilizer, holes.
Plot 4 had polymer emulsion, seed, fertilizer.
Plot 5 had straw mulch, paper netting, seed, fertilizer.
Plot 6 had straw mulch, jute netting, seed, fertilizer.
Plot 7 had seed, fertilizer, straw mulch, chicken wire netting.
Plot 8 had seed, fertilizer, straw mulch with asphalt emulsion.

Table 3-55. Costs of Erosion Control Measures (Megahan, 1987)

Measure[a]	Cost ($/acre)
Dry seeding	124
Plastic netting placed over seeded area	5,662

[a] Haber, D.F., and T. Kadoch. 1982. Costs of Erosion Control Measures Used on a Forest Road in the Silver Creek Watershed in Idaho, University of Idaho, Dept. of Civil Engineering.

Table 3-56. Economic Impact of Implementation of Proposed Management Measures on Road Construction and Maintenance (Dubensky, 1991)[a]

Management Practice	Increased Cost
Fiber for road and landing construction/maintenance	$4.00/ton
Ripping, shaping, and seeding log decks	$178.50/deck
Seeding firelines or rough logging roads	$19.75/100 ft
Construction and seeding of water bars	$12.50 each
Construction of rolling dips on roads	$19.75 each

[a] Public comment information provided by the American Paper Institute and the National Forest Products Association.

Table 3-57. Cost Estimates (and Cost as a Percent of Gross Revenues) for Seed, Fertilizer, and Mulch (1987 Dollars) (Lickwar, 1989)

Practice Component	Steep Sites[a]	Moderate Sites[b]	Flat Sites[c]
Seed, fertilizer, and mulch	$13,625.00 (3.41%)	$12,849.95 (2.72%)	$12,258.70 (1.36%)

[a] Based on a 1,148-acre forest and gross harvest revenues of $399,685. Slopes average over 9 percent.
[b] Based on a 1,104-acre forest and gross harvest revenues of $473,182. Slopes ranged from 4 percent to 8 percent.
[c] Based on a 1,832-acre forest and gross harvest revenues of $899,491. Slopes ranged from 0 percent to 3 percent.

Table 3-58. Estimated Costs for Revegetation (1991 Costs) (Minnesota Department of Natural Resources, 1991)

Practice	Total Cost[a]
Establishment of permanent vegetative cover (includes seedbed preparation, fertilizer, chemicals and application, seed, and seeding as prescribed in the plan)	
Introduced grasses	$80.00/acre
Native grasses	$147.00/acre

[a] The costs shown represent the total cost of the practice. Calculations were made by dividing the maximum Federal cost share by 0.75 to obtain the total cost.

4. Practices

As described more fully at the beginning of this chapter and in Chapter 1, the following practices are described for illustrative purposes only. State programs need not require implementation of these practices. However, as a practical matter, EPA anticipates that the management measure set forth above generally will be implemented by applying one or more management practices appropriate to the source, location, and climate. The practices set forth below have been found by EPA to be representative of the types of practices that can be applied successfully to achieve the management measure described above.

- *Use seed mixtures adapted to the site, and avoid the use of exotic species (Larse, 1971). Species should consist primarily of annuals to allow natural revegetation of native understory plants, and they should have adequate soil-binding properties.*

The selection of appropriate grasses and legumes is important for vegetation establishment. Grasses vary as to climatic adaptability, soil chemistry, and plant growth characteristics (Berglund, 1978). USDA Soil Service technical guides at the State-wide level are excellent sources of information for seeding mixtures and planting prescriptions (Hynson et al., 1982). The U.S. Forest Service, State foresters, and County Extension agents can also provide helpful suggestions (Kochenderfer, 1970). The use of native species is important and practical. Because non-native species can take over and destroy native vegetation, use of non-native species often results in increased maintenance activities and expense, and plenty of hardy native species are usually available (Hynson et al., 1982). In addition to selecting a seeding mixture, the seeding rate must be determined so that adequate soil protection can be achieved without the excess cost of overseeding. Berglund (1978) describes how to determine seeding rates in *Seeding to Control Erosion Along Forest Roads*.

- *On steep slopes, use native woody plants planted in rows, cordons, or wattles.*

These species may be established more effectively than grass and are preferable for binding soils.

- *Seed during optimum periods for establishment, preferably just prior to fall rains (Larse, 1971).*

Timing will depend on the species to be planted and the schedule of operations, which determines when protection is needed (Hynson et al., 1982).

- *Mulch as needed to hold seed, retard rainfall impact, and preserve soil moisture (Larse, 1971).*

Critical, first-year mulch applications provide the necessary ground cover to curb erosion and aid plant establishment (Berglund, 1978). Many different kinds of mulches can be used to improve conditions for germination (Rothwell, 1978). Various materials, including straw, bark, and wood chips, can be used to temporarily stabilize fill slopes and other disturbed areas immediately after construction. In most cases, mulching is used in combination with seeding and planting to establish stable banks. Both the type and the amount of mulch applied vary considerably between regions and depend on the extent of the erosion potential and the available materials (Hynson et al., 1982). Figure 3-27 is a summary of mulching effectiveness in reducing erosion.

- *Fertilize according to site-specific conditions.*

Fertilization is often necessary for successful grass establishment because road construction commonly results in the removal or burial of fertile topsoil (Berglund, 1978). To determine fertilizer formulations, it is best to compare available nitrogen, phosphorus, potassium, and sulphur in the soils to be treated with the requirements of the species to be sown (Rothwell, 1978). It may be necessary to refertilize periodically after vegetation establishment to maintain growth and erosion control capabilities (Larse, 1971; Berglund, 1978).

■ *Protect seeded areas from grazing and vehicle damage until plants are well established.*

If the stand is over 60 percent damaged, reestablish it following the original specifications.

■ *Inspect all seeded areas for failures, and make necessary repairs and reseed within the planting season.*

■ *During non-growing seasons, apply interim surface stabilization methods to control surface erosion.*

Possible methods include mulching (without seeding) and installation of commercially produced matting and blankets. Alternative methods for planting and seeding include hand operations, the use of a wide variety of mechanical seeders, and hydroseeding (Hynson et al., 1982).

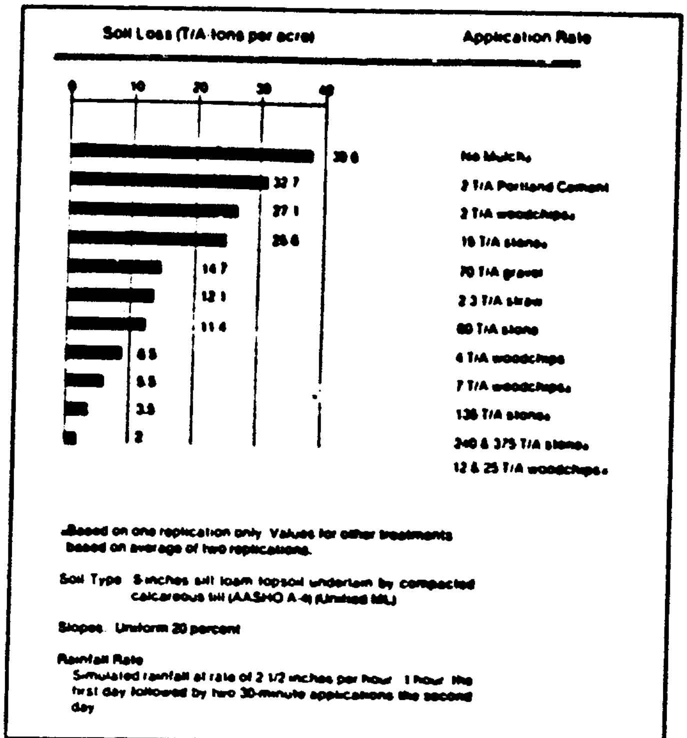

Figure 3-27. Soil losses from a 35-foot long slope by mulch type (Hynson et al., 1982).

Use chemicals when necessary for forest management in accordance with the following to reduce nonpoint source pollution impacts due to the movement of forest chemicals off-site during and after application:

(1) Conduct applications by skilled and, where required, licensed applicators according to the registered use, with special consideration given to impacts to nearby surface waters.
(2) Carefully prescribe the type and amount of pesticides appropriate for the insect, fungus, or herbaceous species.
(3) Prior to applications of pesticides and fertilizers, inspect the mixing and loading process and the calibration of equipment, and identify the appropriate weather conditions, the spray area, and buffer areas for surface waters.
(4) Establish and identify buffer areas for surface waters. (This is especially important for aerial applications.)
(5) Immediately report accidental spills of pesticides or fertilizers into surface waters to the appropriate State agency. Develop an effective spill contingency plan to contain spills.

1. Applicability

This management measure pertains to lands where silvicultural or forestry operations are planned or conducted. It is intended to apply to all fertilizer and pesticide applications (including biological agents) conducted as part of normal silvicultural activities.

Under the Coastal Zone Act Reauthorization Amendments of 1990, States are subject to a number of requirements as they develop coastal nonpoint source programs in conformity with this measure and will have some flexibility in doing so. The application of this management measure by States is described more fully in *Coastal Nonpoint Pollution Control Program: Program Development and Approval Guidance*, published jointly by the U.S. Environmental Protection Agency (EPA) and the National Oceanic and Atmospheric Administration (NOAA) of the U.S. Department of Commerce.

2. Description

Chemicals used in forest management are generally pesticides (insecticides, herbicides, and fungicides) and fertilizers. Since pesticides may be toxic, they must be mixed, transported, loaded, and applied properly and their containers disposed of properly in order to prevent potential nonpoint source pollution. Since fertilizers may also be toxic or may shift the ecosystem energy dynamics, depending on the exposure and concentration, they must also be properly handled and applied.

Pesticides and fertilizers are occasionally introduced into forests to reduce mortality of desired tree species, improve forest production, and favor particular plant species. Many forest stands or sites never receive chemical treatment, and of those that do receive treatment, typically no more than two or three applications are made during an entire tree rotation (40 to 120 years) (Megahan, 1980). Despite the low rate of applications in an area, pesticides can still accumulate within a watershed because there may be many forest sites that receive applications.

Although pesticides and fertilizers are used infrequently in forest operations, they can still pose a risk to the aquatic environment depending on the application technique used (Feller, 1989; Neary, 1985). These chemicals can directly enter surface waters through five major pathways: direct application, drift, mobilization in ephemeral streams, overland flow, and leaching. The input from direct application is the most important source of increased chemical concentrations and is also one of the most easily prevented.

Most adverse water quality effects related to the application of pesticides and fertilizers result from direct application of chemicals to surface waters or from chemical spills (Golden et al., 1984; Fredriksen et al., 1973; Norris and Moore, 1971). Hand application of herbicides generally poses little or no threat to water quality in areas where there is no potential for herbicides to wash into watercourses through gullies (Golden et al., 1984). Norris and Moore (1971) also found that providing buffer areas around streams and waterbodies effectively eliminated adverse water quality effects from forestry chemicals.

3. Management Measure Selection

This measure is based in part on information and experience gained from studies and from use of similar management practices by States. Information on the effects of various pesticide application and fertilization techniques on water quality are summarized in Tables 3-59 through 3-62. Many of the data presented are site-specific or lack clearly specified experimental conditions. However, general trends can be discerned among the studies, and general conclusions on the effectiveness of stream protection practices can be drawn.

a. Pesticide Effects

Most data show that the delivery of pesticides to surface waters from forestry operations is variable, depending on application technique, the presence or absence of buffers, and pesticide characteristics. The studies suggest that negative effects can be greatly reduced by taking precautions to avoid drift or direct application of chemicals to streams and other waterbodies. Norris and Moore (1971) noted that the concentration of 2,4-D in streams after aerial application was one to two orders of magnitude greater in forestry operations without buffers than in areas with buffers (Table 3-59). The elevated concentrations in the nonbuffered area returned to levels comparable to the buffered area after roughly 81 hours from the time of application. Fredriksen and others (1973) noted that in 8 years of monitoring Northwest forest streams for pesticide effects, no herbicide residues were detected in water column samples more than 1 month after aerial application. However, neither aquatic organisms nor sediments were sampled. Herbicide-induced changes in vegetation density and composition may cause indirect effects on streams such as increases in water temperature or nutrient concentration after desiccation of streamside vegetation. Use of unsprayed buffer strips should minimize these effects (Fredriksen et al., 1973).

Riekerk and others (1989) also found that the greatest risk to water quality from pesticide application in forestry operations occurs from aerial applications because of drift, wash-off, and erosion processes. As shown in Table 3-60, they found that aerial applications of herbicides resulted in a surface runoff concentration roughly 3.5 times greater than that of applications to the ground. They suggested that tree injection application methods would be considered the least hazardous for water pollution, but would also be the most labor-intensive.

Norris and others (1991) compiled information from multiple studies that evaluated the peak concentrations of herbicides, insecticides, and fertilizers in soils, lakes, and streams (Table 3-61). These studies were conducted from 1967 to 1987. Norris (1967) found that application of 2,4-D to marshy areas lead to higher-than-normal levels of stream contamination. When ephemeral streams were treated, residue levels of hexazinone and picloram greatly increased with storm-generated flow. Glyphosate was aerially applied (3.3 kg/hectare) to an 8-hectare forest ecosystem in the Oregon Coast Range. The study area contained two ponds and a small perennial stream. All were unbuffered and received direct application of the herbicide. Glyphosate residues were detected for 55 days after application with peak stream concentrations of 0.27 mg/L. It was demonstrated that the concentration of insecticides

Table 3-59. Concentrations of 2,4-D After Aerial Application in Two Treatment Areas (OR) (Norris and Moore, 1971)

Treatment Without Buffers		Treatment With Buffers	
Time After Spraying (hr)	2,4-D (mg/l)	Time After Spraying (hr)	2,4-D (mg/l)
4.7	0.085	5.4	0.001
6.0	0.010	8.7	0.001
7.0	0.026	84.5	0.003
8.0	0.075	168.0	0
9.0	0.059		
13.9	0.051		
26.9	0.003		
37.9	0.009		
78.0	0.008		
80.8	0.001		
168.0	0		

in streams was significantly greater when the chemicals were applied without a buffer strip to protect the watercourse. When streams were unbuffered, the peak concentrations of malathion ranged from 0.037-0.042 mg/L. However, when buffers were provided, the concentrations of malathion were reduced to levels that ranged from undetectable to 0.017 mg/L. The peak concentrations of carbaryl ranged from 0.000-0.0008 mg/L when watercourses were protected with a buffer, but increased to 0.016 mg/L when watercourses were unbuffered.

Another study concluded that the effects of a pellet formulation of picloram applied to an Appalachian mountain forest did not produce any adverse effect on water quality within the 2-year study period (Neary et al., 1985). Similar results were found for a study on the application of sulfometuron methyl in Coastal Plain flatwoods (Neary et al., 1989). These researchers concluded that chemical application should not pose a threat to water quality when chemicals are applied at rates established on the product label and well away from flowing streams.

b. Fertilizer Effects

Moore (1971), as cited in Norris et al. (1991), compared nitrogen loss from a watershed treated with 224 kg urea-N per hectare to nitrogen loss from an untreated watershed. The study demonstrated that the loss of nitrogen from the fertilized watershed was 28.02 kg per hectare while the loss of nitrogen from the unfertilized watershed was only 2.15 kg per hectare (Table 3-62).

Table 3-60. Peak Concentrations in Streamflow from Herbicide Application Methods (Southeastern United States) (Riekerk et. al., 1989)

Method	Residue Levels in Surface Runoff (µg/l)
Ground	< 36
Aerial	< 130

Table 3-61. Peak Concentrations of Forest Chemicals in Soils, Lakes, and Streams After Application (Norris et al., 1991)

Chemicals[a] and System[b]	Application Rate (kg/hectare)	Concentration (mg/L or mg/kg[c]) Peak	Subsequent	Time Interval[f]	Time to Non-detection	Source[d]
Herbicides						
2,4-D	2.24	0.001-0.13			1-168 h[e]	
Marsh	2.24	0.09				17
2,4-D BE						17,18
Built pond	23.0					
Water		3.0	1.0	85 d		1
			0.2	180 d		
Sediment		8.0[e]	4.0[e]	13+ d		
			0.4-0.6[e]	82-182 d		
Aquatic plants			206[e]	7 d		
			8[e]	82 d	182 d	
2,4-D AS						
Reservoir		3.6	0	13 d		7
Picloram						
Runoff		0.078				
Runoff		0.038				19
Ephemeral stream	2.8	0.32		157 d	915 d	23
Stream	0.37					9
Hexazinone						3
Stream (GA)	1.68	0.044		3-4 m		11
Forest (GA)	1.68					14
Litter		0.177[e]	<0.01[e]	60+ d		
Soil		0.108[e]	<0.01[e]	90 d		
Ephemeral stream		0.514		3 d		
Perennial stream		0.442		3 d		
Atrazine						
Stream	3.0	0.42	0.02	17 d		16
Built ponds						10
Water		0.50	0.05	14 d		
			0.005	56 d		
Sediments		0.50[e]	0.9[e]	4 d		
		0.50[e]	0.25[e]	56 d		
Triclopyr						
Pasture (OR)	3.34	0.095[e]				20
Glyphosate						
Water	3.3	0.27	0.09	5.5 h		15
			<0.01	3 d		
Dalapon						
Field irrigation water		0.023-3.65	<0.01	Sev h		5

Table 3-61. (Continued)

Chemicals[a] and System[b]	Application Rate (kg/hectare)	Concentration (mg/L or mg/kg[c]) Peak	Subsequent	Time Interval[c]	Time to Non-detection	Source[d]
Insecticides						
Malathion						
Streams	0.91					24
Unbuffered		0.037-0.042				
Buffered		0-0.017				
Carbaryl						
Streams & ponds (E)		0-0.03				24
Streams, unbuffered (PNW)		0.005-0.011			48 h	24
Water	0.84	0.026-0.042				8
Brooks with buffer	0.84	0.001-0.008				22
Rivers with buffer	0.84	0.000-0.002				22
Streams, unbuffered	0.84	0.016				22
Ponds	0.84					6
Water		0.254			100-400 d	
Sediment		<0.01-5.0[f]				
Acephate						
Streams		0.003-0.981				4
Streams	0.56	0.113-0.135	0.013-0.065	1 d		21
Pond sediment & fish				14 d		2
Fertilizers						
Urea	224					
Urea-N						
Forest stream (OR)		0.39	0.39	48 h		12
Dollar Cr (WA)		44.4				13
NH_4^+-N						
Forest stream (OR)		<0.10				12
Tahuya Cr (WA)		1.4				13
NO_3^--N						
Forest stream (OR)		0.168				12
Elochoman R (WA)		4.0				13

[a] 2,4-D BE = 2,4-D butoxyethanol ester; 2,4-D AS = 2,4-D amine salt + ester.
[b] E = eastern USA; Cr = Creek; GA = Georgia; PNW = Pacific Northwest; OR = Oregon; R = River; WA = Washington; buffer = wooded riparian strip.
[c] d = day; h = hours; m = months; sev h = several hours. Intervals are times from application to measurement of peak or subsequent concentration, whichever is the last measurement indicated.
[d] 1 = Birmingham and Colman (1985); 2 = Bocsor and O'Connor (1975); 3 = Davis et al. (1968); 4 = Flavell et al. (1977); 5 = Frank et al. (1970); 6 = Gibbs et al. (1984); 7 = Hoeppel and Westerdahl (1983); 8 = Hulbert (1978); 9 = Johnsen (1980); 10 = Maier-Bode (1972); 11 = Mayack et al. (1982); 12 = Moore (1970); 13 = Moore (1975b); 14 = Neary et al. (1983); 15 = Newton et al. (1984); 16 = M. Newton (Oregon State University, personal communication, 1967); 17 = Norris (1967); 18 = Norris (1968); 19 = Norris (1969); 20 = Norris et al. (1987); 21 = Rabeni and Stanley (1979); 22 = Stanley and Trial (1980); 23 = Suffling et al. (1974); 24 = Tracy et al. (1977).
[e] Normally less than 48 h.
[f] One extreme case: 23.8 mg/kg peak concentration, 16 months to nondetection.

Studies by Moore (Table 3-61) indicated that the concentrations of urea-N in runoff varied greatly, but that the greatest opportunity for water quality damage from fertilizer application occurred when the chemical directly entered

Table 3-62. Nitrogen Losses from Two Watersheds in Umpqua Experimental Watershed (OR) (Norris et al., 1991)

Loss Locus or Statistic	Urea-N	NH_3-N	NO_3-N	Total
Absolute loss (kg/hectare)				
Watershed 2 (treated)	0.65	0.28	27.09	28.02
Watershed 4 (untreated)	0.02	0.06	2.07	2.15
Net loss (2-4)	0.63	0.22	25.02	25.87
Proportional loss				
Percent of total	2.44	0.85	96.71	100.00

the waterbody. The peak concentrations were directly proportional to the amount of open surface water within the treated areas, and increases resulted almost entirely from direct applications to surface water. Megahan (1980) summarized data from Moore (1975), who examined changes in water quality following the fertilization of various forest stands with urea. The major observations from this research are summarized as follows (Megahan, 1980):

- Increases in the concentration of urea-N ranged from very low to a maximum of 44 ppm, with the highest concentrations attributed to direct application to water surfaces.
- Higher concentrations occurred in areas where buffer strips were not left beside streambanks.
- Chemical concentrations of urea and its by-products tended to be relatively short-lived due to transport downstream, assimilation by aquatic organisms, or adsorption by stream sediments.

Based on his literature review, Megahan (1980) concluded that the impacts of fertilizer application in forested areas could be significantly reduced by avoiding application techniques that could result in direct deposition into the waterbody and by maintaining a buffer area along the streambank. Malueg and others (1972) and Hetherington (1985) also presented information in support of Megahan's conclusions.

4. Practices

As discussed more fully at the beginning of this chapter and in Chapter 1, the following practices are described for illustrative purposes only. State programs need not require implementation of these practices. However, as a practical matter, EPA anticipates that the management measure set forth above generally will be implemented by applying one or more management practices appropriate to the source, location, and climate. The practices set forth below have been found by EPA to be representative of the types of practices that can be applied successfully to achieve the management measure described above.

■ *For aerial spray applications maintain and mark a buffer area of at least 50 feet around all watercourses and waterbodies to avoid drift or accidental application of chemicals directly to surface water.*

A wider buffer may be needed for major streams and lakes and for application of pesticides with high toxicity to aquatic life. A 100-foot buffer should be used for aerial applications and a 25-foot buffer used for ground spray. Aerial application methods require careful and precise marking of application areas to avoid accidental contamination of open waters (Riekerk, 1989). For specific applications such as hypo hatchet or wick applicator, buffer area widths used for spray applications may be reduced.

■ *Apply pesticides and fertilizers during favorable atmospheric conditions.*

- Do not apply pesticides when wind conditions increase the likelihood of significant drift.
- Avoid pesticide application when temperatures are high or relative humidity is low because these conditions influence the rate of evaporation and enhance losses of volatile pesticides.

■ *Users must abide by the current pesticide label which may specify: whether users must be trained and certified in the proper use of the pesticide; allowable use rates; safe handling, storage, and disposal requirements; and whether the pesticide can only be used under the provision of an approved Pesticide State Management Plan, management measures and practices for pesticides should be consistent with and/or complement those in the approved Pesticide State Management Plans.*

■ *Locate mixing and loading areas, and clean all mixing and loading equipment thoroughly after each use, in a location where pesticide residues will not enter streams or other waterbodies.*

■ *Dispose of pesticide wastes and containers according to State and Federal laws.*

■ *Take precautions to prevent leaks and/or spills.*

■ *Develop a spill contingency plan that provides for immediate spill containment and cleanup, and notification of proper authorities.*

An adequate spill and cleaning kit that includes the following should be maintained:

- Detergent or soap;
- Hand cleaner and water;
- Activated charcoal, adsorptive clay, vermiculite, kitty litter, sawdust, or other adsorptive materials;
- Lime or bleach to neutralize pesticides in emergency situations;
- Tools such as a shovel, broom, and dustpan and containers for disposal; and
- Proper protective clothing.

■ *Apply slow-release fertilizers, when possible.*

This practice will reduce potential nutrient leaching to ground water, and it will increase the availability of nutrients for plant uptake.

■ *Apply fertilizers during maximum plant uptake periods to minimize leaching.*

■ *Base fertilizer type and application rate on soil and/or foliar analysis.*

To determine fertilizer formulations, it is best to compare available nitrogen, phosphorus, potassium, and sulphur in the soils to be treated with the requirements of the species to be sown (Rothwell, 1978).

■ *Consider the use of pesticides as part of an overall program to control pest problems.*

Integrated Pest Management (IPM) strategies have been developed to control forest pests without total reliance on chemical pesticides. The IPM approach uses all available techniques, including chemical and nonchemical. An extensive knowledge of both the pest and the ecology of the affected environment is required for IPM to be effective.

A more in-depth discussion of IPM strategies and components can be found in the Pesticide management measure section of the Agriculture chapter of this guidance.

Base selection of pesticide on site factors and pesticide characteristics.

These factors include vegetation height, target pest, adsorption to soil organic matter, persistence or half-life, toxicity, and type of formulation.

Check all application equipment carefully, particularly for leaking hoses and connections and plugged or worn nozzles. Calibrate spray equipment periodically to achieve uniform pesticide distribution and rate.

Always use pesticides in accordance with label instructions, and adhere to all Federal and State policies and regulations governing pesticide use.[2]

5. Relationship of Management Measure Components for Pesticides to Other Programs

Under the Federal Insecticide, Fungicide and Rodenticide Act (FIFRA), EPA registers pesticides on the basis of evaluation of test data showing whether a pesticide has the potential to cause unreasonable adverse effects on humans, animals, or the environment. Data requirements include environmental fate data showing how the pesticide behaves in the environment, which are used to determine whether the pesticide poses a threat to ground water or surface water. If the pesticide is registered, EPA imposes enforceable label requirements, which can include, among other things, maximum rates of application, classification of the pesticide as a "restricted use" pesticide (which restricts use to certified applicators trained to handle toxic chemicals), or restrictions on use practices, including requiring compliance with EPA-approved Pesticide State Management Plans (described below). EPA and the U.S. Department of Agriculture Cooperative Extension Service provide assistance for pesticide applicator and certification training in each State.

FIFRA allows States to develop more stringent pesticide requirements than those required under FIFRA, and some States have chosen to do this. At a minimum, management measures and practices under State Coastal Nonpoint Source Programs must not be less stringent than FIFRA label requirements or any applicable State requirements.

EPA's *Pesticides and Groundwater Strategy* (USEPA, 1991) describes the policies and regulatory approaches EPA will use to protect the Nation's ground-water resources from risks of contamination by pesticides under FIFRA. The objective of the strategy is the prevention of ground-water contamination by regulating the use of certain pesticides (i.e., use according to EPA-approved labeling) in order to reduce and, if necessary, eliminate releases of the pesticide in areas vulnerable to contamination. Priority for protection will be based on currently used and reasonably expected sources of drinking water supplies, and ground water that is closely hydrogeologically connected to surface waters. EPA will use Maximum Contaminant Levels (MCLs) under the Safe Drinking Water Act as "reference points" for water resource protection efforts when the ground water in question is a current or reasonably expected source of drinking water.

The Strategy describes a significant new role for States in managing the use of pesticides to protect ground water from pesticides. In certain cases, when there is sufficient evidence that a particular use of a pesticide has the potential for ground-water contamination to the extent that it might cause unreasonable adverse effects, EPA may (through the use of existing statutory authority and regulations) limit legal use of the product to those States with an acceptable Pesticide State Management Plan, approved by EPA. Plans would tailor use to local hydrologic conditions and would address:

[2] The Federal Insecticide, Fungicide and Rodenticide Act governs the storage and application of pesticides.

- State philosophy,
- Roles and responsibilities of State and local agencies;
- Legal and enforcement authority;
- Basis for assessment and planning;
- Prevention measures;
- Ground-water monitoring;
- Response to detections;
- Information dissemination; and
- Public participation.

In the absence of such an approved Plan, affected pesticides could not be legally used in the State.

Since areas to be managed under Pesticide State Management Plans and Coastal Nonpoint Source Programs can overlap, State coastal zone and nonpoint source agencies should work with the State lead agency for pesticides (or the State agency that has a lead role in developing and implementing the Pesticide State Management Plan) in the development of pesticide management measure components and practices under both programs. This is necessary to avoid duplication of effort and conflicting pesticide requirements between programs. Further, ongoing coordination will be necessary since both programs and management measures will evolve and change with increasing technology and data.

[illegible]

Plan, operate, and manage normal, ongoing forestry activities (including harvesting, road design and construction, site preparation and regeneration, and chemical management) to adequately protect the aquatic functions of forested wetlands.

1. Applicability

This management measure is intended for forested wetlands where silvicultural or forestry operations are planned or conducted. It is intended to apply specifically to forest management activities in forested wetlands and to supplement the previous management measures by addressing the operational circumstances and management practices appropriate for forested wetlands. Chapter 7 provides additional information on wetlands and wetland management measures for other, nonforestry source categories and activities.

Under the Coastal Zone Act Reauthorization Amendments of 1990, States are subject to a number of requirements as they develop coastal nonpoint source programs in conformity with this measure and will have some flexibility in doing so. The application of this management measure by States is described more fully in *Coastal Nonpoint Pollution Control Program: Program Development and Approval Guidance*, published jointly by the U.S. Environmental Protection Agency (EPA) and the National Oceanic and Atmospheric Administration (NOAA) of the U.S. Department of Commerce.

This management measure applies specifically to forest management activities in forested wetlands, including those currently undertaken under the exemptions of section 404(f) (40 CFR, Part 232). Many normal, ongoing forestry activities are exempt under section 404(f)(1) unless recaptured under the provisions of section 404(f)(2). This management measure is not intended to prohibit these silvicultural activities but to reduce incidental or indirect effects on aquatic functions as a result of these activities. Chapter 7 provides additional information on wetlands and wetland management measures for other, nonforestry source categories and activities.

2. Description

Forested wetlands provide many beneficial functions that need to be protected. Among these are floodflow alteration, sediment trapping, nutrient retention and removal, provision of important habitat for fish and wildlife, and provision of timber products (Clairain and Kleiss, 1989). The extent of palustrine (forested) wetlands in the continental United States has declined greatly in the past 40 years due to conversion to other land uses, with a net annual loss of 300,000 acres occurring between 1950 and 1970 (Frayer et al., 1983). Forested wetland productivity is dependent upon hydrologic conditions and nutrient cycling, and alteration of a wetland's hydrologic or nutrient-cycling processes can adversely affect wetland functions (Conner and Day, 1989). Refer to Chapter 7 for a wetland definition and a more complete description of the values and functions of wetlands.

The primary difference between forestry activities on wetland sites as compared to activities on upland sites is the result of flooding that occurs in most wetlands during some or most of the year. Potential impacts of forestry operations in wetlands include:

- Sediment production as a result of road construction and use and equipment operation;

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- Drainage alteration as a result of improper road construction;
- Stream obstruction caused by failure to remove logging debris;
- Soil compaction caused by operation of logging vehicles during flooding periods or wet weather (skid trails, haul roads, and log landings are areas where compaction is most severe); and
- Contamination from improper application and/or use of pesticides.

The primary adverse impacts associated with road construction in forested wetlands are alteration of drainage and flow patterns, increased erosion and sedimentation, habitat degradation, and damage to existing timber stands. In an effort to prevent these adverse effects, section 404 of the Federal Water Pollution Control Act requires usage of appropriate BMPs for road construction and maintenance in wetlands so that flow and circulation patterns and chemical and biological characteristics are not impaired. Additional section 404(f) BMPs specific to forestry can be found at 40 CFR 232.3.

Harvest planning and selection of the right harvest system are essential in achieving the management objectives of timber production, ensuring stand establishment, and avoiding adverse impacts to water quality and wetland habitat. The potential impacts of reproduction methods and cutting practices on wetlands include changes in water quality, temperature, nutrient cycling, and aquatic habitat (Toliver and Jackson, 1989). Streams can also become blocked with logging debris if SMAs are not properly maintained or if appropriate practices are not employed in SMAs.

Site preparation includes but is not limited to the use of prescribed fire, chemical, or mechanical site preparation. Extensive site preparation on bottoms where frequent flooding occurs can cause excessive erosion and stream siltation. The degree of acceptable site preparation is governed by the amount and frequency of flooding, soil type, and species suitability, and is dependent upon the regeneration method used.

Clean Water Act section 404 establishes a permit program that regulates the discharge of dredged or fill material into waters of the United States, including certain forested areas that meet the criteria for wetlands. Section 404(f)(1) of the Act provides an exemption from the permitting requirement for discharges in waters of the United States associated with normal, ongoing silviculture operations, including such practices as placement of bedding, cultivation, seeding, timber harvesting, and minor drainage. Section 404(f)(2) clarifies that discharges associated with silviculture activities identified at 404(f)(1) as exempt, are not eligible for the exemption if the proposed discharge involves toxic materials or if they would have the effect of converting waters of the United States, including wetlands, to dry land. Regulations implementing section 404(f), as well as describing applicable best management practices for avoiding impairment of the physical, chemical, and biological characteristics of the waters of the United States, were promulgated by EPA at 40 CFR Part 232.

3. Management Measure Selection

Mader and others (1989) assessed the relative impacts of various timber harvesting methods on different parameters in a forested wetland. On-site ecological responses on a clearcut site following timber harvesting with helicopter and rubber-tired skidder systems were compared to a clearcut, harvested, herbicide-treated area and an undisturbed stand in southwest Alabama. They found total nitrogen concentrations in soil water to be significantly lower for the skidder treatment when compared with all other treatments (Table 3-63). Total phosphorus concentrations were also significantly different for the helicopter treatment as compared to the control stand. Sediment accumulation was greatest for the helicopter treatment and least for the herbicide treatment, and all differences between treatments were significant.

Table 3-63. Total Nitrogen and Phosphorus Concentrations in Soil Water, and Sedimentation During Wet Season Flooding[a] (Mader et al., 1989)

Treatment	n[b]	Nutrient Concentration (parts per million)		n	Sediment Accumulation (millimeters)
		TN[c]	TP[d]		
Herbicide	36	11.1 (2.1)	9.8 (2.6)	81	0.7 (0.3)
Skidder	36	7.4 (1.0)	10.1 (2.1)	81	1.2 (0.5)
Helicopter	36	10.6 (1.4)	11.4 (2.0)	81	2.2 (0.6)
Undisturbed	36	11.0 (1.6)	8.8 (2.0)	81	1.1 (0.1)

[a] Values are treatment means (±SE) of nine replications.
[b] n = Number of samples.
[c] TN = Total nitrogen in soil water.
[d] TP = Total phosphorus in soil water.

4. Practices

As discussed more fully at the beginning of this chapter and in Chapter 1, the following practices are described for illustrative purposes only. State programs need not require implementation of these practices. However, as apractical matter, EPA anticipates that the management measure set forth above generally will be implemented by applying one or more management practices appropriate to the source, location, and climate. The practices set forth below have been found by EPA to be representative of the types of practices that can be applied successfully to achieve the management measure described above.

a. Road Design and Construction Practices

■ *Locate and construct forest roads according to preharvest planning.*

Improperly constructed and located forest roads may cause changes in hydrology, accelerate erosion, reduce or degrade fisheries habitat, and destroy or damage existing stands of timber.

■ *Utilize temporary roads in forested wetlands.*

Permanent roads should be constructed only to serve large and frequently used areas, as approaches to watercourse crossings, or as access for fire protection. Use the minimum design standard necessary for reasonable safety and the anticipated traffic volume.

■ *Construct fill roads only when absolutely necessary for access since fill roads have the potential to restrict natural flow patterns.*

Where construction of fill roads is necessary, use a permeable fill material (such as gravel or crushed rock) for at least the first layer of fill. The use of pervious materials maintains the natural flow regimes of subsurface water. Figures 3-28 and 3-29 demonstrate the impact of impervious and pervious road fills on wetland hydrology. Permeable fill material is not a substitute for using bridges where needed, or for installation of adequately spaced culverts present at all natural drainageways. This practice should be used in conjunction with cross drainage structures to ensure that natural wetland flows are maintained (i.e., so that fill does not become clogged by sediment and obstruct flows (Hynson et al., 1982).

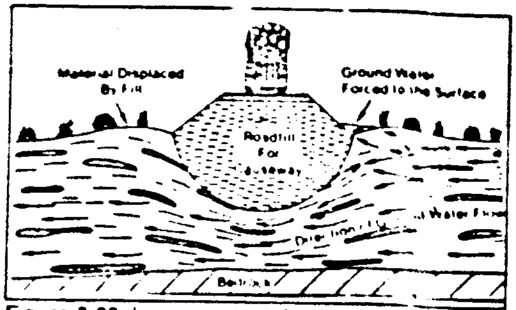

Figure 3-28. Impervious roadfill section placed on wetlands consisting of soft organic sediments with sand lenses. The natural material consolidates and restricts ground-water flow (Hynson et al., 1982).

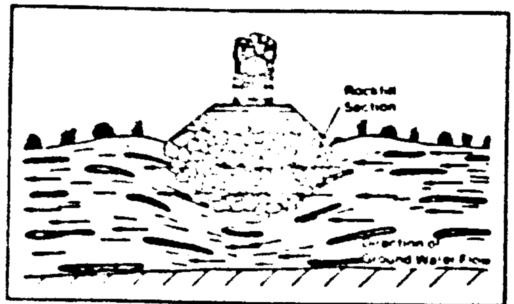

Figure 3-29. Pervious roadfill section on wetland allows movement of ground water through it and minimizes flow changes (Hynson et al., 1982).

■ *Provide adequate cross drainage to maintain the natural surface and subsurface flow of the wetland.*

This can be accomplished through adequate sizing and spacing of water crossing structures, proper choice of the type of crossing structure, and installation of drainage structures at a depth adequate to pass subsurface flow. Bridges, culverts, and other structures should not perceptibly diminish or increase the duration, direction, or magnitude of minimum, peak, or mean flow of water on either side of the structure (Hynson et al., 1982).

■ *Construct roads at natural ground level to minimize the potential to restrict flowing water.*

Float the access road fill on the natural root mat. If the consequences of the natural root mat failing are serious, use reinforcement materials such as geotextile fabric, geo-grid mats, or log corduroy. Figure 3-30 depicts a cross section

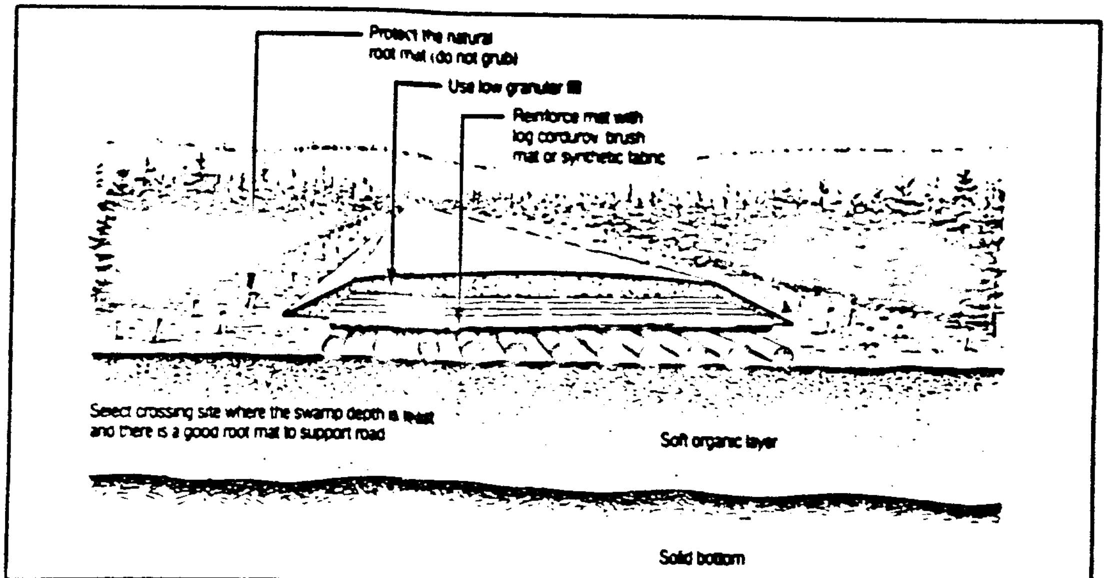

Figure 3-30. Cross section of a wetland road (Ontario Ministry of Natural Resources, 1988).

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of the "floating the road" practice. Protect the root mat beneath the roadway from equipment damage. This can be facilitated by diverting through traffic to the edge of the right-of-way, shear-blading stumps instead of grubbing, and using special wide-pad equipment. Also, protect the root mat from damage or puncture by using fill material that does not contain large rocks or boulders.

b. Harvesting Practices

■ *Conduct forest harvesting according to preharvest planning designs and locations.*

Planning and close supervision of harvesting operations are needed to protect site integrity and enhance regeneration. Harvesting without regard to season, soil type, or type of equipment can damage the site productivity; retard regeneration; cause excessive rutting, churning, and puddling of saturated soils; and increase erosion and siltation of streams.

■ *Establish a streamside management area adjacent to natural perennial streams, lakes, ponds, and other standing water in the forested wetland following the components of the SMA management measure.*

■ *Ensure that planned harvest activities or chemical use do not contribute to problems of cumulative effects in watersheds of concern.*

■ *Select the harvesting method to minimize soil disturbance and hydrologic impacts to the wetland.*

In seasonally flooded wetlands, a guideline is to use conventional skidder logging that employs equipment with low-ground-pressure tires, cable logging, or aerial logging (Doolittle, 1990). Willingham (1989) compared cable logging to helicopter logging and concluded that helicopter operations caused less site disturbance, were more economical, and provided greater yield. Table 3-64 depicts harvesting systems recommended by the Florida Division of Forestry by type of forested wetland. These recommendations are based on both water quality and economic considerations. Another alternative is to conduct harvesting during winter months when the ground is frozen.

■ *When groundskidding, use low-ground-pressure tires or tracked machines and concentrate skidding to a few primary skid trails to minimize site disturbance, soil compaction, and rutting.*

■ *When soils become saturated, suspend groundskidding harvesting operations. Use of groundskidding equipment during excessively wet periods may result in unnecessary site disturbance and equipment damage.*

c. Site Preparation and Regeneration Practices

■ *Select a regeneration method that meets the site characteristics and management objectives.*

Choice of regeneration method has a major influence on the stand composition and structure and on the silvicultural practices that will be applied over the life of the stand (Toliver and Jackson, 1989). Natural regeneration may be achieved by clearcutting the existing stand and relying on regeneration from seed from adjacent stands, the cut trees, or stumps and from root sprouts (coppice). Successful regeneration depends on recognizing the site type and its characteristics; evaluating the stocking and species composition in relation to stand age and site capability; planning regeneration options; and using sound harvesting methods. Schedule harvest during the dormant season to take advantage of seed sources and to favor coppice regeneration. Harvest trees at a stump height of 12 inches or less when practical to encourage vigorous coppice regeneration. Artificial regeneration may be accomplished by planting seedlings or direct seeding. Table 3-65 contains the regeneration system recommendations of the Georgia Forestry Association.

Table 3-64. Recommended Harvesting Systems by Forested Wetland Site[a]
(Florida Department of Agriculture and Consumer Services, 1988)

Site Type	Conventional	Conventional with Controlled Access[b]	Cable or Aerial	Barge or High Flotation Boom
Flowing Water				
Mineral Soil				
Alluvial River Bottom	B	A	C	C
Organic Soil				
Black River Bottom	B	A	C	C
Branch Bottom	A[c]	B	C	C
Cypress Strand	B	A	A	A
Muck Swamp	C	A	A	A
Nonflowing Water				
Mineral Soil				
Wet Hammock	B	A	C	C
Organic Soil				
Cypress Dome	B	A	A	A
Peat Swamp	C	A	A	A

A = recommended; B = recommended when dry; C = not recommended.
[a] Recommendations include cost considerations.
[b] Preplanned and designated skid trails and access roads.
[c] Log from the hill (high ground).

Conduct mechanized site preparation and planting sloping areas on the contour.

To reduce disturbance, conduct bedding operations in high-water-table areas during dry periods of the year.

The degree of acceptable site preparation depends on the amount and frequency of flooding, the soil type, and the species suitability.

Minimize soil degradation by limiting operations on saturated soils.

d. Chemical Management Practices

Apply herbicides by injection or application in pellet form to individual stems.

For chemical and aerial fertilizer applications, maintain and mark a buffer area of at least 50 feet around all surface water to avoid drift or accidental direct application.

Avoid application of pesticides with high toxicity to aquatic life, especially aerial applications.

Table 3-65. Recommended Regeneration Systems by Forested Wetland Type (Georgia Forestry Association, 1990)

Type	Natural Regeneration				Artificial Regeneration		
	Clearcut	Group Selection	Shelter Wood	Seed[a] Tree	Mechanical Site Prep.	Plant	Direct Seed
Flood Plains, Terraces, Bottomland							
Black River	A	B	B	C	D	C	C
Red River	A	B	B	C	D	B	B
Branch Bottoms	A	B	B	C	D	C	C
Piedmont Bottoms	A	B	B	C	D	B	B
Muck Swamps	A	C	C	C	D	C	C
Wet Flats							
Pine Hammocks & Savannahs	A	B	B	B	A	A	B
Pocosins or Bays	A	C	B	B	B	B	B
Cypress Strands	A	C	C	C	D	C	C
Cypress Domes: Peat Swamps							
Peat Swamps	A	C	C	C	C	C	C
Cypress Domes	A	C	C	C	D	C	C
Gulfs, Coves, Lower Slopes	A	B	B	C	C	B	C

A = highly effective; B = effective; C = less effective; D = not recommended.
[a] Seed tree cuts are not recommended on first terraces of flood plains, terraces, and bottomland.

■ ***Apply slow-release fertilizers, when possible.***

This practice will reduce the potential of the nutrients leaching to ground water, and it will increase the availability of nutrients for plant uptake.

■ ***Apply fertilizers during maximum plant uptake periods to minimize leaching.***

■ ***Base fertilizer type and application rate on soil and/or foliar analysis.***

To determine fertilizer formulations, it is best to compare available nitrogen, phosphorus, potassium, and sulphur in the soils to be treated with the requirements of the species to be sown.

III. GLOSSARY

Access road: A temporary or permanent road over which timber is transported from a loading site to a public road. Also known as a haul road.

Alignment: The horizontal route or direction of an access road.

Allochthonous: Derived from outside a system, such as leaves of terrestrial plants that fall into a stream.

Angle of repose: The maximum slope or angle at which a material, such as soil or loose rock, remains stable (stable angle).

Apron: Erosion protection placed below the streambed in an area of high flow velocity, such as downstream from a culvert.

Autochthonous: Derived from within a system, such as organic matter in a stream resulting from photosynthesis by aquatic plants.

Bedding: A site preparation technique whereby a small ridge of surface soil is formed to provide an elevated planting or seed bed. It is used primarily in wet areas to improve drainage and aeration for seeding.

Berm: A low earth fill constructed in the path of flowing water to divert its direction, or constructed to act as a counterweight beside the road fill to reduce the risk of foundation failure (buttress).

Borrow pit: An excavation site outside the limits of construction that provides necessary material, such as fill material for embankments.

Broad-based dip: A surface drainage structure specifically designed to drain water from an access road while vehicles maintain normal travel speeds.

Brush barrier: A sediment control structure created of slash materials piled at the toe slope of a road or at the outlets of culverts, turnouts, dips, and water bars.

Buck: To saw felled trees into predetermined lengths.

Buffer area: A designated area around a stream or waterbody of sufficient width to minimize entrance of forestry chemicals (fertilizers, pesticides, and fire retardants) into the waterbody.

Cable logging: A system of transporting logs from stump to landing by means of steel cables and winch. This method is usually preferred on steep slopes, wet areas, and erodible soils where tractor logging cannot be carried out effectively.

Check dam: A small dam constructed in a gully to decrease the flow velocity, minimize channel scour, and promote deposition of sediment.

Chopping: A mechanical treatment whereby vegetation is concentrated near the ground and incorporated into the soil to facilitate burning or seedling establishment.

Clearcutting: A silvicultural system in which all merchantable trees are harvested within a specified area in one operation to create an even-aged stand.

Contour: An imaginary line on the surface of the earth connecting points of the same elevation. A line drawn on a map connecting the points of the same elevation.

Crown: A convex road surface that allows runoff to drain to either side of the road prism.

Culvert: A metal, wooden, plastic, or concrete conduit through which surface water can flow under or across roads.

Cumulative effect: The impact on the environment that results from the incremental impact of an action when added to other past, present, and reasonably foreseeable future actions regardless of what agency or person undertakes such action.

Cut-and-fill: Earth-moving process that entails excavating part of an area and using the excavated material for adjacent embankments or fill areas.

DBH: Diameter at breast height; the average diameter (outside the bark) of a tree 4.5 feet above mean ground level.

Disking (harrowing): A mechanical method of scarifying the soil to reduce competing vegetation and to prepare a site to be seeded or planted.

Diversion: A channel with a supporting ridge on the lower side constructed across or at the bottom of a slope for the purpose of intercepting surface runoff.

Drainage structure: Any device or land form constructed to intercept and/or aid surface water drainage.

Duff: The accumulation of needles, leaves, and decaying matter on the forest floor.

Ephemeral stream: A channel that carries water only during and immediately following rainstorms. Sometimes referred to as a dry wash.

Felling: The process of cutting down standing trees.

Fill slope: The surface formed where earth is deposited to build a road or trail.

Firebreak: Naturally occurring or man-made barrier to the spread of fire.

Fireline: A barrier used to stop the spread of fire constructed by removing fuel or rendering fuel inflammable by use of fire retardants.

Ford: Submerged stream crossing where tread is reinforced to bear intended traffic.

Forest filter strip: Area between a stream and construction activities that achieves sediment control by using the natural filtering capabilities of the forest floor and litter.

Forwarding: The operation of moving timber products from the stump to a landing for further transport.

Geotextile: A product used as a soil reinforcement agent and as a filter medium. It is made of synthetic fibers manufactured in a woven or loose nonwoven manner to form a blanket-like product.

Grade (gradient): The slope of a road or trail expressed as a percentage of change in elevation per unit of distance traveled.

Harvesting: The felling, skidding, processing, loading, and transporting of forest products.

Haul road: See *access road*.

Intermittent stream: A watercourse that flows in a well-defined channel only in direct response to a precipitation event. It is dry for a large part of the year.

Landing (log deck): A place in or near the forest where logs are gathered for further processing or transport.

Leaching: Downward movement of a soluble material through the soil as a result of water movement.

Logging debris (slash): The unwanted, unutilized, and generally unmerchantable accumulation of woody material, such as large limbs, tops, cull logs, and stumps, that remains as forest residue after timber harvesting.

Merchantable: Forest products suitable for marketing under local economic conditions. With respect to a single tree, it means the parts of the bole or stem suitable for sale.

Mineral soil: Organic-free soil that contains rock less than 2 inches in maximum dimension.

Mulch: A natural or artificial layer of plant residue or other materials covering the land surface that conserves moisture, holds soil in place, aids in establishing plant cover, and minimizes temperature fluctuations.

Mulching: Providing any loose covering for exposed forest soils, such as grass, straw, bark, or wood fibers, to help control erosion and protect exposed soil.

Muskeg: A type of bog that has developed over thousands of years in depressions, on flat areas, and on gentle to steep slopes. These bogs have poorly drained, acidic, organic soils supporting vegetation that can be (1) predominantly sphagnum moss; (2) herbaceous plants, sedges, and rushes; (3) predominantly sedges and rushes; or (4) a combination of sphagnum moss and herbaceous plants. These bogs may have some shrub and stunted conifers, but not enough to classify them as forested lands.

Ordinary high water mark: An elevation that marks the boundary of a lake, marsh, or streambed. It is the highest level at which the water has remained long enough to leave its mark on the landscape. Typically, it is the point where the natural vegetation changes from predominantly aquatic to predominantly terrestrial.

Organic debris: Particles of vegetation or other biological material that can degrade water quality by decreasing dissolved oxygen and by releasing organic solutes during leaching.

Outslope: To shape the road surface to cause drainage to flow toward the outside shoulder.

Patch cutting method: A silvicultural system in which all merchantable trees are harvested over a specified area at one time.

Perennial stream: A watercourse that flows throughout a majority of the year in a well-defined channel.

Persistence: The relative ability of a pesticide to remain active over a period of time.

Pioneer roads: Temporary access ways used to facilitate construction equipment access when building permanent roads.

Prescribed burning: Skillful application of fire to natural fuels that allows confinement of the fire to a predetermined area and at the same time produces certain planned benefits.

Raking: A mechanical method of removing stumps, roots, and slash from a future planting site.

Regeneration: The process of replacing older trees removed by harvest or disaster with young trees.

Residual trees: Live trees left standing after the completion of harvesting.

Right-of-way: The cleared area along the road alignment that contains the roadbed, ditches, road slopes, and back slopes.

Riprap: Rock or other large aggregate that is placed to protect streambanks, bridge abutments, or other erodible sites from runoff or wave action.

Rut: A depression in access roads made by continuous passage of logging vehicles.

Salvage harvest: Removal of trees that are dead, damaged, or imminently threatened with death or damage in order to use the wood before it is rendered valueless by natural decay agents.

Sanitation harvest: Removal of trees that are under attack by or highly susceptible to insect and disease agents in order to check the spread of such agents.

Scarification: The process of removing the forest floor or mixing it with the mineral soil by mechanical action preparatory to natural or direct seeding or the planting of tree seedlings.

Scour: Soil erosion when it occurs underwater, as in the case of a streambed.

Seed bed: The soil prepared by natural or artificial means to promote the germination of seeds and the growth of seedlings.

Seed tree method: Removal of the mature timber in one cutting, except for a limited number of seed trees left singly or in small groups.

Selection method: An uneven-aged silvicultural system in which mature trees are removed, individually or in small groups, from a given tract of forestland over regular intervals of time.

Shearing: A site preparation method that involves the cutting of brush, trees, or other vegetation at ground level using tractors equipped with angles or V-shaped cutting blades.

Shelterwood method: Removal of the mature timber in a series of cuttings that extend over a relatively short portion of the rotation in order to encourage the establishment of essentially even-aged reproduction under the partial shelter of seed trees.

Silt fence: A temporary barrier used to intercept sediment-laden runoff from small areas.

Silvicultural system: A process, following accepted silvicultural principles, whereby the tree species constituting forests are tended, harvested, and replaced. Usually defined by, but not limited to, the method of regeneration.

Site preparation: A silvicultural activity to remove unwanted vegetation and other material, and to cultivate or prepare the soil for regeneration.

Skid: Short-distance moving of logs or felled trees from the stump to a point of loading.

Skid trail: A temporary, nonstructural pathway over forest soil used to drag felled trees or logs to the landing.

Slash: See *logging debris*.

Slope: Degree of deviation of a surface from the horizontal, measured as a numerical ratio, as a percent, or in degrees. Expressed as a ratio, the first number is the horizontal distance (run) and the second number is the vertical distance (rise), as 2:1. A 2:1 slope is a 50 percent slope. Expressed in degrees, the slope is the angle from the horizontal plane, with a 90 degree slope being vertical (maximum) and a 45 degree slope being a 1:1 slope

Stand: A contiguous group of trees sufficiently uniform in species composition, arrangement of age classes, and condition to be a homogeneous and distinguishable unit.

Streamside management area (SMA): A designated area that consists of the stream itself and an adjacent area of varying width where management practices that might affect water quality, fish, or other aquatic resources are modified. The SMA is not an area of exclusion, but an area of closely managed activity. It is an area that acts as an effective filter and absorptive zone for sediments; maintains shade; protects aquatic and terrestrial riparian habitats; protects channels and streambanks; and promotes floodplain stability.

Tread: Load-bearing surface of a trail or road.

Turnout: A drainage ditch that drains water away from roads and road ditches.

Water bar: A diversion ditch and/or hump installed across a trail or road to divert runoff from the surface before the flow gains enough volume and velocity to cause soil movement and erosion, and deposit the runoff into a dispersion area. Water bars are most frequently used on retired roads, trails, and landings.

Watercourse: A definite channel with bed and banks within which concentrated water flows continuously, frequently or infrequently.

Windrow: Logging debris and unmerchantable woody vegetation that has been piled in rows to decompose or to be burned; or the act of constructing these piles.

Yarding: Method of transport from harvest area to storage landing.

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Appendix 3A

Examples of State Processes Useful for Ensuring Implementation of Management Measures

3A-1: Examples from Florida

SRWMD PERMIT NUMBER ________
APPLICATION FOR AGRICULTURE OR FORESTRY
GENERAL SURFACEWATER MANAGEMENT PERMIT
FORM 40B-4-1

SUWANNEE RIVER WATER MANAGEMENT DISTRICT
ROUTE 3, BOX 64
LIVE OAK, FLORIDA 32060
TELEPHONE (904) 362-1001

Landowner/Applicant: ________

Address: ________
Street - Route - Box City State Zip Code

Person Responsible: ________

Phone: ________ Beginning Date: ________

Project Location: ________ Location Sketch:
County

____
Township Range Section

____
Parcel ID Number (from County records)

Project Area: ____ Acres owned or in management block

____ Acres in project area (aerial photograph copy with project area outlined is suggested.)

Wetlands Area: ____ Wetland acres in project area

____ Wetland acres affected by the work

Description of the proposed work to include sizes and dimensions: ________

____

____

____

THE GENERAL SURFACEWATER MANAGEMENT PERMIT AUTHORIZED BY SS.40B-4.2010(1), FLORIDA ADMINISTRATIVE CODE (F.A.C.), REQUIRES PERMITTEES TO COMPLY WITH BEST MANAGEMENT AND ACCEPTED CONSERVATION PRACTICES. ADDITIONAL LIMITATIONS AND/OR STANDARDS ARE CONTAINED IN SS.40B-4.2010(1)(C)1. THROUGH 6. A COPY OF CHAPTER 40B-4, F.A.C., AND BEST MANAGEMENT PRACTICES MANUALS ARE AVAILABLE AT NO CHARGE FROM THE DISTRICT, OR QUESTIONS MAY BE DIRECTED TO THE SUWANNEE RIVER WATER MANAGEMENT DISTRICT AT 904/362-1001 OR 1-800-342-1002. A DISTRICT PERMIT DOES NOT RELIEVE A PERMITTEE FROM OBTAINING APPROVALS THAT MAY BE REQUIRED BY ANY UNIT OF LOCAL, STATE, OR FEDERAL GOVERNMENT.

THIS APPLICATION IS NOT TO BE USED FOR SUBDIVISIONS, COMMERCIAL PROJECTS, OR ANY OTHER NON-AGRICULTURAL OR FORESTRY WORK.

________ Landowner/Applicant's Signature ________ Title ________ Date

________ SRWMD Staff Signature ________ Title ________ Date Approved

SRWMD Form 40B-4-1 (REV. 12/90) White-SRWMD/Yellow-Permittee

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Authorization No. ______________________

NORTHWEST FLORIDA WATER MANAGEMENT DISTRICT

FORESTRY AUTHORIZATION NOTIFICATION FORM

Instructions:

1. Deliver or mail to the appropriate District Office identified on the attached sheet at least two (2) working days before commencing activity.
2. Emergency authorizations may be requested by calling the appropriate District Office.
3. See attached sheet for list of qualifying projects, limiting conditions, and District Offices.

Application is for: ☐ Construction ☐ Replacement ☐ Maintenance

Owner's Name: ______________________ Phone: ______________

Address: ____

City: ______________________ State: ____________ Zip: ____________

Agent's Name: ______________________ Phone: ______________

Address: ____

City: ______________________ State: ____________ Zip: ____________

Only the minor works listed in Section 40A-44.052(1), F.A.C. (see attached sheet), may qualify for an authorization. After reviewing the attached list, which letter identifies the minor work you propose? Please circle the appropriate one(s):

A B C D E F

Detailed description of the proposed work, include water quality protection and site stabilization methods: ______________

____

____

Starting Date: ______________

Location of Proposed Work:

County: ______________

Section: ______________

Township: ______________

Range: ______________

Water Body Affected:

____

Location Sketch

A copy of Chapter 40A-44, F.A.C., is available at any District office. A District authorization does not relieve a permittee from obtaining the necessary approvals of any local, state, or federal government.

I have read and will comply with the requirements of Section 40A-44.052, F.A.C. I understand that this Forestry Authorization Notice is available only under limited circumstances as set forth in Section 40A-44.052, F.A.C., and that permittees are required to comply with all limiting conditions listed in Section 40A-44.052, F.A.C.

______________________ ______________________ ______________

Signature of: (Circle one) Printed Name Date

Owner Agent*

*Signing by someone other than the owner is also certification that the person is authorized to act as the owner's agent.

NWFWMD Form A44-F
40A-44.052(2)(a), F.A.C.
Effective 7-1-92

White - District Copy, Yellow - Applicant's Copy

3A-2: Examples from Oregon

SIDE ONE

NOTIFICATION OF OPERATION / APPLICATION FOR PERMITS
STATE OF OREGON
DEPARTMENT OF FORESTRY
DEPARTMENT OF REVENUE

NOTIFICATION NUMBER: ____

Date Received: ____

Time Received: ____

District: ____

Office: ____

APPLICANT REMARKS

1 County (Enter only one) ____

2

3

CHECK ONE BOX IN THE FAR LEFT COLUMN TO INDICATE WHO FILLED OUT THE APPLICATION

4 Operator Information
Name/Title
Company Name
Mailing Address Street
City State and Zip Code
Phone No

5 Landowner Information
Name/Title
Company Name
Mailing Address Street
City State and Zip Code
Phone No

6 Timberowner and Harvest Tax Payer
Name/Title
Company Name
Mailing Address Street
City State and Zip Code
Phone No

7 Timber Sale Name and/or No

8

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SIDE TWO

8 ACTIVITY CODES

10 LOCATION OF OPERATION

ATTACH MAP AND/OR AERIAL PHOTOS!

WRITTEN PLANS AND PRIOR APPROVALS

Comments

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INSTRUCTIONS FOR FILLING OUT "NOTIFICATION OF OPERATION / APPLICATION FOR PERMITS"

The instructions are numbered to match the numbered form areas. Please print or type the information on the form. Do not fill out any space shaded gray. File notice with the State Forester at least 15 days prior to the date you would like to start operating. A notification is not considered accepted until it is received by the appropriate office. Mail or deliver the form to one of the following offices

Office Address	Phone Number	Office Address	Phone Number
ASTORIA Rt 1 Box 950 97103	325-5451	MOLALLA 14995 S Hwy 211 97038	829-2216
BAKER Rt 1 Box 211 97814	523-5831	MONUMENT P O Box 386 97864 (Hwy Street)	934-2300
CENTRAL POINT 5286 Table Rock Road 97502	664-3328	PENDLETON 1055 Airport Rd 97801	276-3491
COLUMBIA CITY 405 E St 97018	397-2636	PHILOMATH 24533 Alsea Hwy 97370	929-3266
COOS BAY 300 Fifth St Bay Park 97420	267-3161	PRINEVILLE 220710 Ochoco Hwy 97754	447-5658
DALLAS 825 Oak Villa Rd 97338	623-8146	ROSEBURG 1758 N E Airport Road 97470-1499	440-3412
FOREST GROVE 801 Gales Cr Rd 97116-1199	357-2191	SISTERS P O Box 190 97759 (221 SW Washington)	549-2731
FOSSIL Star Route 97830	763-2575	SPRINGFIELD 3150 E Main St 97478	726-3588
GOLD BEACH P O Box 603 97444	247-6666	SWEET HOME 4690 Hwy 20 97386	367-6108
GRANTS PASS 5375 Monument Dr 97526	474-3152	THE DALLES 3701 W 13th St 97058	296-4626
JOHN DAY P O Box 546 97845 (400 NW Bird)	575-1139	TILLAMOOK 4907 E Third St 97141-2999	842-2545
KLAMATH FALLS 3400 Greensprings Dr 97601	883-5681	TOLEDO 763 N W Forestry Rd 97391	336-2273
LA GRANDE 611 20th St 97850	963-3168	VENETA P O Box 157 97487	935-2283
LAKEVIEW 2290 N 4th St 97630	947-3311	WALLOWA Rt 1 Box 85 97885	886-2881

MEHAMA 22965 N Fork Rd S E Lyons 97358 859-2151

SIDE ONE - Notification of Operation/Application for Permits

1. "County (Enter only one)". Fill in the county where the operation will take place. If an operation spans two or more counties, file a separate notification for each county.

An operation can be any combination of the following activities: harvest of forest crops, road construction or reconstruction; site preparation, chemical application, clearing for land use change, treatment of slashing, pre-commercial thinning; or other activities which require separate explanation.

2. "Check Appropriate Boxes (2A, 2B, 2C, or 2D)" next to the notice you are giving and/or the permit(s) you need.

3. "Person to be contacted in case of Fire Emergency (Designated Representative). Phone No." Print the name and telephone number of the person to contact in case a fire starts on the operation. This person should know what resources you have available to fight the fire, and have the authority to commit those resources in case of a fire.

"Check one box in the left column to indicate who filled out the application."

4. "Operator Information" 5. "Landowner Information" 6. "Timberowner and Harvest Tax Payer." You must fill in either a person's or a company's name, address and phone number. Fill in EITHER the timberowner's Employer Identification number or the timberowner's social security number, not both. The person who owns timber at the time of severance from the stump (harvest) is the timberowner, and is responsible for paying the harvest tax.

7. "Timber Sale Name and/or No." Fill in the sale name and/or number. This information is required for all state and federal timber sales and is optional for private land timber sales.

8. "Western Oregon Private Land Only!" If the timber to be harvested is from public land, do not fill out this portion! If it is from private land, check with the landowner to see whether the timber has been certified under the Western Oregon Small Tract Optional Tax (WOSTOT) law. Timber removed from land certified under WOSTOT is normally exempt from the Western Oregon Severance Tax. If you have checked "Part" or "All", please list the certificate number in the WOSTOT Certificate Number box.

SIDE TWO - Site Information

9. "Activity Codes". There are six columns here. You assign a one- or two-digit unit number, beginning with 1 and going sequentially up to 99. Or, if there is a unit number associated with a state or federal timber sale, use that number in the unit column. A unit can be:

- an operating area with a state or federal sale unit number; or
- a single operating area within a continuous boundary; or
- an operating area with a separate harvest tax number; or
- a separate area within your total operation area on which you plan to conduct a single type of activity (for example, 30 acres of clear cut only).

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In all cases, all activities you plan on that piece of land should be listed under the unit number. For example, road construction activity needed prior to starting a commercial timber harvest should be described under the unit number along with the harvesting activity. If there will be more activities happening in the unit than you can fit on one line straight across, continue on the lines below. Leave a blank under the unit number. See the example below.

Activity Code. Write the codes for all activities taking place in one unit under this heading. Use the numbers, code names and associated methods shown below.

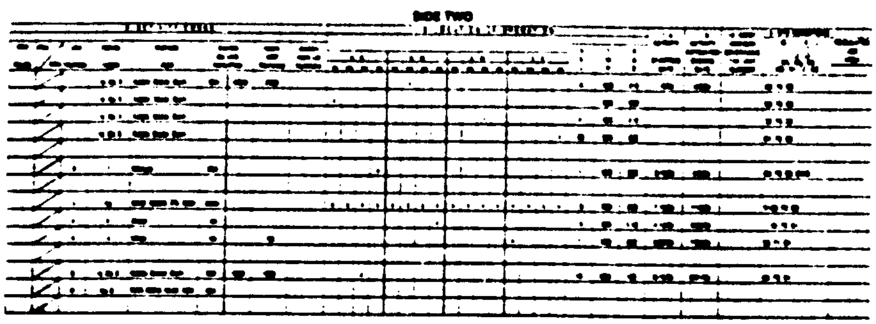
Activity Code	Methods Used	Activity Code	Methods Used
1a. Partial Cut (Partial Cut code must not be used for a pre-commercial thinning operation.)	Cable/Ground/Other	4a. Herbicide Application	Ground/Aerial/Name/Rate/Carrier
1b. Clear Cut	Cable/Ground/Other	4b. Insecticide Application	Ground/Aerial/Name/Rate/Carrier
1c. Cutting only		4c. Rodenticide Application	Ground/Aerial/Name/Rate/Carrier
2a. Road Construction	Dozer/Backhoe/Other	4d. Fertilizer Application	Ground/Aerial/Name/Rate/Carrier
2b. Road Reconstruction	Dozer/Backhoe/Other	5. Clearing for Land Use Change (Local land use rules may apply.)	
3. Site Preparation	Manual/Mechanical/Burning	6. Treatment of Slashing	Burning, Mechanical
		7. Pre-Commercial Thinning	Manual/Chemical
		8. Others	Explain

Write the methods you will use in the "Methods Used" column next to the code for the activity, in the same order as the activity codes are listed. If you need more space, go to the next row down in the same column. Write in the name of the spray product. In Applicant Remarks column list the carrier and rate of application. See the example below.

Quantity Column. Fill in either the acres (A) or lineal feet (F) involved in the activity. The example shows 86 acres of harvest and 3000 ft. of road construction.

Approximate Thousand Board Feet (MBF) Removed. List the approximate MBF to be removed for each unit with commercial timber harvesting.

Government Lot Numbers. List the government lot numbers for each unit. (Not tax lot numbers.)



10. "Location of Operation" (Legal Descriptions). Enter the legal descriptions for each unit number. If you have several rows worth of activities that will take place at one location, REPEAT THE CODES, not the legal descriptions.

11. a. & 11. b. "Activity Starting and Activity Estimated Ending Date". The starting date should be at least 15 days after the date the form is received by the appropriate Department office.

12. "Western Oregon Severance Tax Unit Number". Large landowners will have a list of harvest tax numbers which apply to the site(s).

13. "Site Conditions". Fill in a D, T, and S code for each unit, as shown in the example. Fill in DWS, WG or SW codes when necessary.

D = Distance to Class 1 waters. A Class 1 water is "any portions of streams, lakes, estuaries, significant wetlands, or other waters of the state which are significant for (a) domestic use, including drinking, culinary and other household human use; (b) angling; (c) water dependent recreation; or (d) spawning, rearing or migration of anadromous or game fish."

- D100 = Class 1 waters are within 100 feet of the operation.
- D1 = Class 1 waters are within ¼ mile but greater than 100 feet from the operation.
- D2 = Class 1 waters are within ¼-½ mile of the operation.
- D3 = None within ½ mile.

T = Topography

- T1 is a slope of 0 to 35% (percent)
- T2 is a slope of 35% to 60%
- T3 is a slope greater than 60%

S = Slope Stability

- S1 = No evidence of mass soil movement (landslides, slips, slumps).
- S2 = Evidence of old slides, small failures.
- S3 = Recent or active movement; wet areas.

- DWS = The operation affects a Domestic Water Supply
- WG = The operation takes place in the Willamette Greenway
- SW = The operation takes place near a Scenic Waterway.
- UGB = The operation takes place in an Urban Growth Boundary
- SH = The operation takes place near a Scenic Highway
- CC = The operation will result in a single clearcut or combination of contiguous clearcuts that exceed 120 acres.
- IC2 = The operation takes place near an influential Class II stream.

14. If you request a waiver of the 15 day waiting period, check the box and contact the Forest Practice Forester (FPF). The FPF will decide if a waiver can be granted.

15. a. & 15. b. Print your name in 15. a. and sign your name and write the date in 15. b.

16. ATTACH MAP AND/OR AERIAL PHOTOS! The notification form is not complete unless a map or aerial photo of the operation area is attached!

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3A-3: Examples from New Hampshire

STATE OF NEW HAMPSHIRE
Notice of Intent to Cut Wood or Timber

(RSA 79 10)

PA-7

1992 - 1993

Operation No

DRA USE ONLY

TAX YEAR APRIL 1, 1992 TO MARCH 31, 1993

SEE INSTRUCTIONS FOR FILLING OUT THIS FORM ON REVERSE

PLEASE TYPE OR PRINT

1 To Selectmen/Assessors

Town/City of ______________________ N H

2 Name & Tax Map # by which lot is commonly known ______________________

3 Is this intent an Original ☐ Supplemental ☐

Orig Oper # ______________________

4 Name of road from which accessible ______________________

5 Number of acres to be cut ______________________

6 Type of ownership (check only one)

a Owner of land and stumpage ☐

b Owner of stumpage only ☐

c Right of possession with authority to cut (including public lands) ☐

7 Is any of the wood or timber cut for own use?

(See Item #11) ______________________

8 If required, has a wetland notification or application been filed YES ☐

9 I/we hereby assume responsibility for any yield tax which may be assessed. (If Corporation, An Officer Must Sign)

A ______________________ Signature of Owner(s) Date

B ______________________ Signature

______________________ Print Owner(s) Name Clearly

______________________ Mailing Address

______________________ Town/City Zip Code

Corp ______________________

Tel. No. ______________________

Federal Identification No. or Social Security No. of Landowner

[ ]

CHECK ONE: ☐ Corporation ☐ Proprietorship ☐ Partnership } Landowner

10 DESCRIPTION OF WOOD OR TIMBER TO BE CUT

Species	Estimated Amount To Be Cut	
White Pine		BF
Hemlock		
Red Pine		
Spruce & Fir		
Hard Maple		
White Birch		
Yellow Birch		
Oak		
Ash		
Beech & Soft Maple		
Pallet or Tie Logs		
Others (Specify)		
Pulpwood	Tons or	Cords
Spruce & Fir		
Hardwood & Aspen		
Pine		
Hemlock		
Total Tree Chips		
Miscellaneous		
Birch Bolts		Cords
Cordwood & Fuelwood		

11. AMOUNT OF WOOD OR TIMBER FOR PERSONAL USE

[ ] [ ]

12. PLEASE SIGN THE FOLLOWING:

I, ______________________ Signature of Logger/Forester Responsible for Operation Date

______________________ Print Logger/Forester Name

______________________ Mailing Address

HAVE BECOME FAMILIAR WITH RSA 485-A, RSA 224 44A, 224 44B, 482-A AND RELATED RULES, AND HEREBY AGREE TO ABIDE BY APPROPRIATE BEST MANAGEMENT PRACTICES TO INCLUDE ALL STATE LAWS PERTAINING TO LOGGING OPERATIONS.

13. CERTIFICATE/REPORT TO BE SENT TO ☐ LANDOWNER ☐ LOGGER/FORESTER

SPACE BELOW FOR ASSESSING OFFICIALS ONLY

Amount of Security Required and Posted $ ________ Type of Security Posted (Bond, Certified Check, etc.) ________

______________________ (Selectmen/Assessors)

____

______________________ of ______________________ Date ________

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CHAPTER 4: MANAGEMENT MEASURES FOR URBAN AREAS

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I. INTRODUCTION

A. What "Management Measures" Are

This chapter specifies management measures to protect coastal waters from urban sources of nonpoint pollution. "Management measures" are defined in section 6217 of the Coastal Zone Act Reauthorization Amendments of 1990 (CZARA) as economically achievable measures to control the addition of pollutants to our coastal waters, which reflect the greatest degree of pollutant reduction achievable through the application of the best available nonpoint pollution control practices, technologies, processes, siting criteria, operating methods, or other alternatives.

These management measures will be incorporated by States into their coastal nonpoint programs, which under CZARA are to provide for the implementation of management measures that are "in conformity" with this guidance. Under CZARA, States are subject to a number of requirements as they develop and implement their Coastal Nonpoint Pollution Control Programs in conformity with this guidance and will have some flexibility in doing so. The application of these management measures by States to activities causing nonpoint pollution is described more fully in *Coastal Nonpoint Pollution Control Program: Program Development and Approval Guidance*, published jointly by the U.S. Environmental Protection Agency (EPA) and the National Oceanic and Atmospheric Administration (NOAA).

B. What "Management Practices" Are

In addition to specifying management *measures*, this chapter also lists and describes management *practices* for illustrative purposes only. While State programs are required to specify management *measures* in conformity with this guidance, State programs need not specify or require the implementation of the particular management *practices* described in this document. However, as a practical matter, EPA anticipates that the management measures generally will be implemented by applying one or more management practices appropriate to the source, location, and climate. The practices listed in this document have been found by EPA to be representative of the types of practices that can be applied successfully to achieve the management measures. EPA has also used some of these practices, or appropriate combinations of these practices, as a basis for estimating the effectiveness, costs, and economic impacts of achieving the management measures. (Economic impacts of the management measures are addressed in a separate document entitled *Economic Impacts of EPA Guidance Specifying Management Measures for Sources of Nonpoint Pollution in Coastal Waters.)*

EPA recognizes that there is often site-specific, regional, and national variability in the selection of appropriate practices, as well as in the design constraints and pollution control effectiveness of practices. The list of practices for each management measure is not all-inclusive and does not preclude States or local agencies from using other technically sound practices. In all cases, however, the practice or set of practices chosen by a State needs to achieve the management measure.

C. Scope of This Chapter

This chapter addresses six major categories of sources of urban nonpoint pollution that affect surface waters:

(1) Runoff from developing areas;
(2) Runoff from construction sites;

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(3) Runoff from existing development;
(4) On-site disposal systems;
(5) General sources (households, commercial, and landscaping); and
(6) Roads, highways, and bridges.

Each category of sources is addressed in a separate section of this guidance. Each section contains (1) the management measure; (2) an applicability statement that describes, when appropriate, specific activities and locations for which the measure is suitable; (3) a description of the management measure's purpose; (4) the basis for the management measure's selection; (5) information on management practices that are suitable, either alone or in combination with other practices, to achieve the management measure; (6) information on the effectiveness of the management measure and/or of practices to achieve the measure; and (7) information on costs of the measure and/or practices to achieve the measure.

D. Relationship of This Chapter to Other Chapters and to Other EPA Documents

1. Chapter 1 of this document contains detailed information on the legislative background for this guidance, the process used by EPA to develop this guidance, and the technical approach used by EPA in the guidance.

2. Chapter 6 of this document contains information and management measures for addressing nonpoint source impacts resulting from hydromodification, which often occurs to accommodate urban development.

3. Chapter 7 of this document contains management measures to protect wetlands and riparian areas that provide a nonpoint source pollution abatement function. These measures apply to a broad variety of sources, including urban sources.

4. Chapter 8 of this document contains information on recommended monitoring techniques to (1) ensure proper implementation, operation, and maintenance of the management measures and (2) assess over time the success of the measures in reducing pollution loads and improving water quality.

5. EPA has separately published a document entitled *Economic Impacts of EPA Guidance Specifying Management Measures for Sources of Nonpoint Pollution in Coastal Waters.*

6. NOAA and EPA have jointly published guidance entitled *Coastal Nonpoint Pollution Control Program: Program Development and Approval Guidance*. This guidance contains details on how State Coastal Nonpoint Pollution Control Programs are to be developed by States and approved by NOAA and EPA. It includes guidance on:

   - The basis and process for EPA/NOAA approval of State Coastal Nonpoint Pollution Control Programs;
   - How NOAA and EPA expect State programs to provide for the implementation of management measures "in conformity" with this management measures guidance;
   - How States may target sources in implementing their Coastal Nonpoint Pollution Control Programs;
   - Changes in State coastal boundaries; and
   - Requirements concerning how States are to implement their Coastal Nonpoint Pollution Control Programs.

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E. Overlap Between This Management Measure Guidance for Control of Coastal Nonpoint Sources and Storm Water Permit Requirements for Point Sources

Historically, overlaps and ambiguity have existed between programs designed to control urban nonpoint sources and programs designed to control urban point sources. For example, runoff that originates as a nonpoint source may ultimately may be channelized and become a point source. Potential confusion concerning coverage and implementation of these two programs has been heightened by Congressional enactment of two important pieces of legislation: section 402(p) of the Clean Water Act, which establishes permit requirements for certain municipal and industrial storm water discharges, and section 6217 of CZARA, which requires EPA to promulgate and States to provide for the implementation of management measures to control nonpoint pollution in coastal waters. The discussion below is intended to clarify the relationship between these two programs and describe the scope of the coastal nonpoint program and its applicability to storm water in coastal areas.

1. The Storm Water Permit Program

The storm water permit program is a two-phased program enacted by Congress in 1987 under section 402(p) of the Clean Water Act. Under Phase I, National Pollutant Discharge Elimination System (NPDES) permits are required to be issued for municipal separate storm sewers serving large or medium-sized populations (greater than 250,000 or 100,000 people, respectively) and for storm water discharges associated with industrial activity. Permits are also to be issued, on a case-by-case basis, if EPA or a State determines that a storm water discharge contributes to the violation of a water quality standard or is a significant contributor of pollutants to waters of the United States. EPA published a rule implementing Phase I on November 16, 1990.

Under Phase II, EPA is to prepare two reports to Congress that assess remaining storm water discharges; determine, to the maximum extent practicable, the nature and extent of pollutants in such discharges; and establish procedures and methods to control storm water discharges to the extent necessary to mitigate impacts on water quality. Then, EPA is to issue regulations that designate storm water discharges, in addition to those addressed in Phase I, to be regulated to protect water quality and is to establish a comprehensive program to regulate those designated sources. The program is required to establish (1) priorities, (2) requirements for State storm water management programs, and (3) expeditious deadlines.

These regulations were to have been issued by EPA not later than October 1, 1992. However, because of EPA's emphasis on Phase I, the Agency has not yet been able to complete and issue appropriate regulations as required under section 402(p). The completion of Phase II is now scheduled for October 1993.

2. Coastal Nonpoint Pollution Control Programs

As discussed more fully earlier, Congress enacted section 6217 of CZARA in late 1990 to require that States develop Coastal Nonpoint Pollution Control Programs that are in conformity with the management measures guidance published by EPA.

3. Scope and Coverage of This Guidance

EPA is excluding from coverage under this section 6217(g) guidance all storm water discharges that are covered by Phase I of the NPDES storm water permit program. Thus, EPA is excluding any discharge from a municipal separate storm sewer system serving a population of 100,000 or more; any discharge of storm water associated with industrial activity; any discharge that has already been permitted; and any discharge for which EPA or the State makes a determination that the storm water discharge contributes to a violation of a water quality standard or is a significant contributor of pollutants to waters of the United States. All of these activities are clearly addressed by the storm water permit program and therefore are excluded from the Coastal Nonpoint Pollution Control Programs.

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EPA is adopting a different approach with respect to other (Phase II) storm water discharges. At present, EPA has not yet promulgated regulations that would designate additional storm water discharges, beyond those regulated in Phase I, that will be required to be regulated in Phase II. It is therefore not possible to determine at this point which additional storm water discharges will be regulated by the NPDES program and which will not. Furthermore, because of the great number of such discharges, it is likely that it would take many years to permit all of these discharges even if EPA allows for relatively expeditious State permitting approaches such as the use of general permits.

Therefore, to give effect to the Congressional intent that coastal waters receive special and expeditious attention from EPA, NOAA, and the States, storm water runoff that potentially may be ultimately covered by Phase II of the storm water permits program is subject to this management measures guidance and will be addressed by the States' Coastal Nonpoint Pollution Control Programs. Any storm water runoff that ultimately is regulated under an NPDES permit will no longer be subject to this guidance once the permit is issued.

In addition, it should be noted that some other activities are not presently covered by the NPDES permit requirements and thus would be subject to a State's Coastal Nonpoint Pollution Control Program. Most importantly, construction activities on sites that result in the disturbance of less than 5 acres, which are not currently covered by Phase I storm water application requirements,[1] are covered by the Coastal Nonpoint Pollution Control Program. Similarly, runoff from wholesale, retail, service, or commercial activities, including gas stations, which are not covered by Phase I of the NPDES storm water program, would be subject instead to a State's Coastal Nonpoint Pollution Control Program. Further, onsite disposal systems (OSDS), which are generally not covered by the storm water permit program, would be subject to a State's Coastal Nonpoint Pollution Control Program.

Finally, EPA emphasizes that while different legal authorities may apply to different situations, the goals of the NPDES and CZARA programs are complementary. Many of the techniques and practices used to control storm water are equally applicable to both programs. Yet, the programs do not work identically. In the interest of consistency and comprehensiveness, States have the option to implement the CZARA section 6217(g) management measures throughout the State's 6217 management area as long as the NPDES storm water requirements continue to be met by Phase I sources in that area.

F. Background

The prevention and control of urban nonpoint source pollution in coastal areas pose a distinctive challenge to the environmental manager. Increasing water quality problems and degraded coastal resources point to the need for comprehensive solutions to protect and enhance coastal water quality. This chapter presents a framework for preventing and controlling urban nonpoint sources of pollution.

Urban runoff management requires that a number of objectives be pursued simultaneously. These objectives include the following:

- Protection and restoration of surface waters by the minimization of pollutant loadings and negative impacts resulting from urbanization;
- Protection of environmental quality and social well-being;
- Protection of natural resources, e.g., wetlands and other important aquatic and terrestrial ecosystems;

[1] On May 27, 1992, the United States Court of Appeals for the Ninth Circuit invalidated EPA's exemption of construction sites smaller than 5 acres from the storm water permit program in *Natural Resources Defense Council* v. *EPA*, 965 F.2d 759 (9th Cir. 1992). EPA is conducting further rulemaking proceedings on this issue and will not require permit applications for construction activities under 5 acres until further rulemaking has been completed.

- Minimization of soil erosion and sedimentation problems;
- Maintenance of the predevelopment hydrologic conditions;
- Protection of ground-water resources;
- Control and management of runoff to reduce/prevent flooding; and
- Management of aquatic and riparian resources for active and passive recreation (APWA, 1981).

1. Urbanization and Its Impacts

Urbanization first occurred in coastal areas and this historical trend continues. Approximately 80 percent of the Nation's population lives in coastal areas. The negative impacts of urbanization on coastal and estuarine waters has been well documented in a number of sources, including the Nationwide Urban Runoff Program (NURP) and the States' §305(b) and §319 reports.

During urbanization, pervious spaces, including vegetated and open forested areas, are converted to land uses that usually have increased areas of impervious surface, resulting in increased runoff volumes and pollutant loadings. While urbanization may enhance the use of property under a wide range of environmental conditions (USEPA, 1977), urbanization typically results in changes to the physical, chemical, and biological characteristics of the watershed. Vegetative cover is stripped from the land and cut-and-fill activities that enhance the development potential of the land occur. For example, natural depressions that temporarily pond water are graded to a uniform slope, increasing the volume of runoff during a storm event (Schueler, 1987). As population density increases, there is a corresponding increase in pollutant loadings generated from human activities. These pollutants typically enter surface waters via runoff without undergoing treatment.

a. Changes in Hydrology

As urbanization occurs, changes to the natural hydrology of an area are inevitable. Hydrologic and hydraulic changes occur in response to site clearing, grading, and the addition of impervious surfaces and maintained landscapes (Schueler, 1987). Most problematic are the greatly increased runoff volumes and the ensuing erosion and sediment loadings to surface waters that accompany these changes to the landscape. Uncontrolled construction site sediment loads have been reported to be on the order of 35 to 45 tons per acre per year (Novotny and Chesters, 1981; Wolman and Schick, 1967; Yorke and Herb, 1976, 1978). Loadings from undisturbed woodlands are typically less than 1 ton per year (Leopold, 1968).

Hydrological changes to the watershed are magnified after construction is completed. Impervious surfaces, such as rooftops, roads, parking lots, and sidewalks, decrease the infiltrative capacity of the ground and result in greatly increased volumes of runoff. Elevated flows also necessitate the construction of runoff conveyances or the modification of existing drainage systems to avoid erosion of streambanks and steep slopes. Changes in stream hydrology resulting from urbanization include the following (Schueler, 1987):

- Increased peak discharges compared to predevelopment levels (Leopold, 1968; Anderson, 1970);
- Increased volume of urban runoff produced by each storm in comparison to predevelopment conditions;
- Decreased time needed for runoff to reach the stream (Leopold, 1968), particularly if extensive drainage improvements are made;
- Increased frequency and severity of flooding;

- Reduced streamflow during prolonged periods of dry weather due to reduced level of infiltration in the watershed; and

- Greater runoff velocity during storms due to the combined effects of higher peak discharges, rapid time of concentration, and the smoother hydraulic surfaces that occur as a result of development.

In addition, greater runoff velocities occur during spring snowmelts and rain-on-snow events in suburban watersheds than in less impervious rural areas (Buttle and Xu, 1988). Major snowmelt events can produce peak flows as large as 20 times initial flow runoff rates for urban areas (Pitt and McLean, 1992).

Figures 4-1 and 4-2 illustrate the changes in runoff characteristics resulting from an increasing percentage of impervious areas. Other physical characteristics of aquatic systems that are affected by urbanization include the total volume of watershed runoff baseflow, flooding frequency and severity, channel erosion and sediment generation, and temperature regime (Klein, 1985).

b. Water Quality Changes

Urban development also causes an increase in pollutants. The pollutants that occur in urban areas vary widely, from common organic material to highly toxic metals. Some pollutants, such as insecticides, road salts, and fertilizers, are intentionally placed in the urban environment. Other pollutants, including lead from automobile exhaust and oil drippings from trucks and cars, are the indirect result of urban activities (USEPA, 1977).

Many researchers have linked urbanization to degradation of urban waterways (e.g., Klein, 1985, Livingston and McCarron, 1992, Schueler, 1987). The major pollutants found in runoff from urban areas include sediment, nutrients, oxygen-demanding substances, road salts, heavy metals, petroleum hydrocarbons, pathogenic bacteria, and viruses. Livingston and McCarron (1992) concluded that urban runoff was the major source of pollutants in pollutant loadings to Florida's lakes and streams. Table 4-1 illustrates examples of pollutant loadings from urban areas. Table 4-2 describes potential sources of urban runoff pollutants.

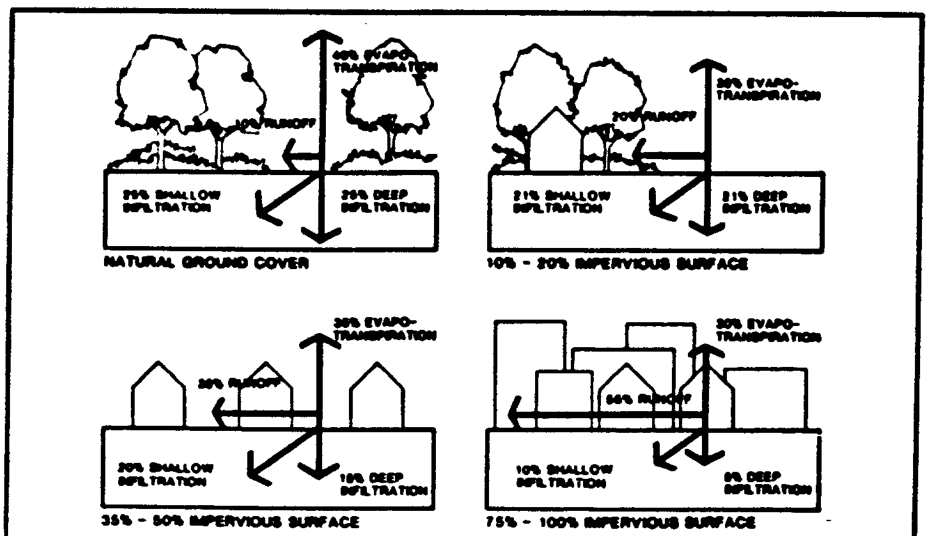

Figure 4-1. Changes in runoff flow resulting from increased impervious area (NC Dept. of Nat. Res. and Community Dev., in Livingston and McCarron, 1992).

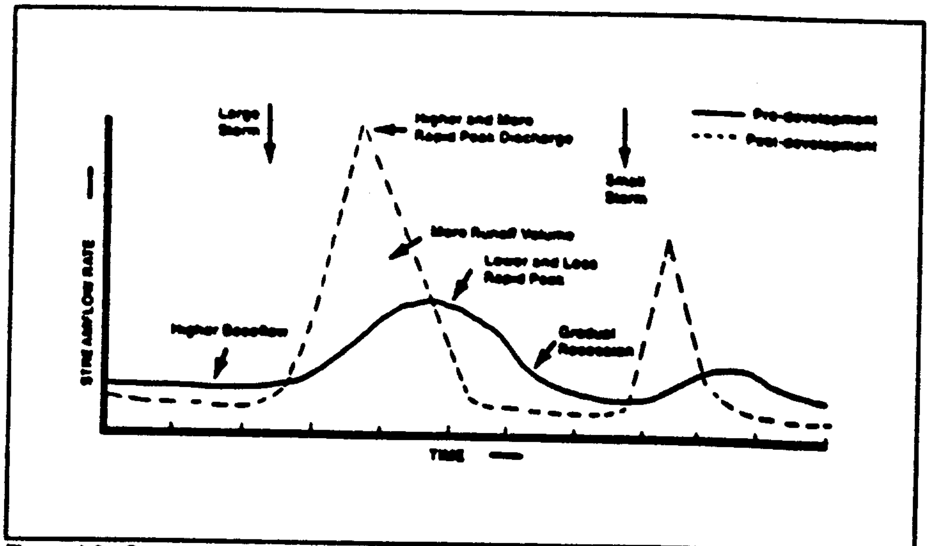

Figure 4-2. Changes in stream hydrology as a result of urbanization (Schueler, 1992).

2. Nonpoint Source Pollutants and Their Impacts

The following discussion identifies the principal types of pollutants found in urban runoff and describes their potential adverse effects (USEPA, 1990).

Sediment. Suspended sediments constitute the largest mass of pollutant loadings to surface waters. Sediment has both short- and long-term impacts on surface waters. Among the immediate adverse impacts of high concentrations of sediment are increased turbidity, reduced light penetration and decreases in submerged aquatic vegetation (SAV) (Chesapeake Implementation Committee, 1988), reduced prey capture for sight-feeding predators, impaired respiration of fish and aquatic invertebrates, reduced fecundity, and impairment of commercial and recreational fishing resources. Heavy sediment deposition in low-velocity surface waters may result in smothered benthic communities/reef systems

Table 4-1. Estimated Mean Runoff Concentrations for Land Uses, Based on the Nationwide Urban Runoff Program (Whalen and Cullum, 1989)

Parameter	Residential	Commercial	Industrial
TKN (mg/l)	0.23	1.5	1.6
$NO_3 + NO_2$ (mg/l)	1.8	0.8	0.93
Total P (mg/l)	0.62	2.29	0.42
Copper (µg/l)	56	50	32
Zinc (µg/l)	254	418	1,063
Lead (mg/l)	293	203	115
COD (mg/l)	102	84	62
TSS (mg/l)	228	168	108
BOD (mg/l)	13	14	62

Table 4-2. Sources of Urban Runoff Pollutants (Adapted from Woodward-Clyde, 1990)

Source	Pollutants of Concern
Erosion	Sediment and attached soil nutrients, organic matter, and other adsorbed pollutants
Atmospheric deposition	Hydrocarbons emitted from automobiles, dust, aromatic hydrocarbons, metals, and other chemicals released from industrial and commercial activities
Construction materials	Metals from flashing and shingles, gutters and downspouts, galvanized pipes and metal plating, paint, and wood
Manufactured products	Heavy metals, halogenated aliphatics, phthalate esters, PAHs, other volatiles, and pesticides and phenols from automobile use, pesticide use, industrial use, and other uses
Plants and animals	Plant debris and animal excrement
Non-storm water connections	Inadvertent or deliberate discharges of sanitary sewage and industrial wastewater to storm drainage systems
Onsite disposal systems	Nutrients and pathogens from failing or improperly sited systems

(CRS, 1991), increased sedimentation of waterways, changes in the composition of bottom substrate, and degradation of aesthetic value. The primary cause of coral reef degradation in coastal areas is attributed to land disturbances and dredging activities due to urban development (Rogers, 1990). Additional chronic effects may occur where sediments rich in organic matter or clay are present. These enriched depositional sediments may present a continued risk to aquatic and benthic life, especially where the sediments are disturbed and resuspended.

Nutrients. The problems resulting from elevated levels of phosphorus and nitrogen are well known and are discussed in detail in Chapter 2 (agriculture).. Excessive nutrient loading to marine ecosystems can result in eutrophication and depressed dissolved oxygen (DO) levels due to elevated phytoplankton populations. Eutrophication-induced hypoxia and anoxia have resulted in fish kills and widespread destruction of benthic habitats (Harper and Gullient, 1989). Surface algal scum, water discoloration, and the release of toxins from sediment may also occur. Species composition and size structure for primary producers may be altered by increased nutrient levels (Hecky and Kilham, 1988; GESAMP, 1989; Thingstad and Sakshaug, 1990).

Occurrences of eutrophication have been frequent in several coastal embayments along the northeast coast (Narragansett and Barnegat Bays), the Gulf Coast (Louisiana and Texas), and the West Coast (California and Washington) (NOAA, 1991). High nitrate concentrations have also been implicated in blooms of nuisance algae in Newport Bay, California (NRC, 1990b). Nutrient loadings in Louisiana coastal waters have decreased productivity, increased hypoxic events, and decreased fisheries yields (NOAA, 1991).

Oxygen-Demanding Substances. Proper levels of DO are critical to maintaining water quality and aquatic life. Decomposition of organic matter by microorganisms may deplete DO levels and result in the impairment of the waterbody. Data have shown that urban runoff with high concentrations of decaying organic matter can severely depress DO levels after storm events (USEPA, 1983). The NURP study found that oxygen-demanding substances can be present in urban runoff at concentrations similar to secondary treatment discharges.

Pathogens. Urban runoff typically contains elevated levels of pathogenic organisms. The presence of pathogens in runoff may result in waterbody impairments such as closed beaches, contaminated drinking water sources, and shellfish bed closings. OSDS-related pathogen contamination has been implicated in a number of shellfish bed closings. Table 4-3 shows the adverse impacts of septic systems and urban runoff on shellfish beds, resulting in closure. This problem may be especially prevalent in areas with porous or sandy soils.

Table 4-3. Percent of Limited or Restricted Classified Shellfish Waters Affected by Types of Pollution (Leonard et al., 1991)

	Septic Systems	Urban Runoff	Ag. Runoff	POTWs	Boats	Industry
North Atlantic	26	23	3	67	17	7
Mid-Atlantic	11	58	12	57	31	20
South Atlantic	34	34	28	44	17	21
Gulf	48	35	8	27	14	14
Pacific	19	36	13	25	15	42
Nationwide	37	38	11	37	18	17

Road Salts. In northern climates, road salts can be a major pollutant in urban areas. Klein (1985) reported on several studies by various authors of road salt contamination in lakes and streams and cases where well contamination had been attributed to road salts in New England. Snow runoff produces high salt/chlorine concentrations at the bottom of ponds, lakes, and bays. Not only does this condition prove toxic to benthic organisms, but it also prevents crucial vertical spring mixing (Bubeck et al., 1971; Hawkins and Judd, 1972).

Hydrocarbons. Petroleum hydrocarbons are derived from oil products, and the source of most such pollutants found in urban runoff is vehicles—auto and truck engines that drip oil. Many do-it-yourself auto mechanics dump used oil directly into storm drains (Klein, 1985). Concentrations of petroleum-based hydrocarbons are often high enough to cause mortalities in aquatic organisms.

Oil and grease contain a wide variety of hydrocarbon compounds. Some polynuclear aromatic hydrocarbons (PAHs) are known to be toxic to aquatic life at low concentrations. Hydrocarbons have a high affinity for sediment, and they collect in bottom sediments where they may persist for long periods of time and result in adverse impacts on benthic communities. Lakes and estuaries are especially prone to this phenomenon.

Heavy Metals. Heavy metals are typically found in urban runoff. For example, Klein (1985) reported on a study in the Chesapeake Bay that designated urban runoff as the source for 6 percent of the cadmium, 1 percent of the chromium, 1 percent of the copper, 19 percent of the lead, and 2 percent of the zinc.

Heavy metals are of concern because of toxic effects on aquatic life and the potential for ground-water contamination. Copper, lead, and zinc are the most prevalent NPS pollutants found in urban runoff. High metal concentrations may bioaccumulate in fish and shellfish and impact beneficial uses of the affected waterbody.

Toxics. Many different toxic compounds (priority pollutants) have been associated with urban runoff. NURP studies (USEPA, 1983) indicated that at least 10 percent of urban runoff samples contained toxic pollutants.

a. Pollutant Loading

Nonpoint source pollution has been associated with water quality standard violations and the impairment of designated uses of surface waters (Davenport, 1990). The 1990 Report to Congress on §319 of the Clean Water Act reported that:

- Siltation and nutrients are the pollutants most responsible for nonpoint source impacts to the Nation's surface waters, and

- Wildlife and recreation, (in particular, swimming, fishing, and shellfishing) are the uses most affected by nonpoint source pollution.

The pollutants described previously can have a variety of impacts on coastal resources. Examples of waterbodies that have been adversely impacted by nonpoint source pollution are varied.

- The Miami River and Biscayne Bay in Florida have experienced loss of habitat, loss of recreational and commercial fisheries, and decrease in productivity partly as the result of urban runoff (SFWMD, 1988).
- Shellfish beds in Port Susan, Puget Sound, Washington, have been declared unsafe for the commercial harvest of shellfish in part because of bacterial contamination from onsite disposal systems (USEPA, 1991).
- Impairment due to toxic pollution from urban runoff continues to be a problem in the southern part of San Francisco Bay (USEPA, 1992).
- Nonpoint sources of pollution have been implicated in degradation of water quality in Westport River, Massachusetts, a tributary of Buzzards Bay. High concentrations of coliform bacteria have been observed after rainfall events, and shellfish bed closures in the river have been attributed to loadings from surface runoff and septic systems (USEPA, 1992).
- In Brenner Bay, St. Thomas, U.S. Virgin Islands, populations of corals and shellfish and marine habitat have been damaged due to increased nutrient and sediment loadings. After several years of rapid urban development, less than 10 percent of original grass beds remain as a result of sediment shoaling, eutrophication, and algae blooms (Nichols and Towle, 1977).

b. Other Impacts

Other impacts not related to a specific pollutant can also occur as a result of urbanization. Temperature changes result from increased flows, removal of vegetative cover, and increases in impervious surfaces. Impervious surfaces act as heat collectors, heating urban runoff as it passes over the impervious surface. Recent data indicate that intensive urbanization can increase stream temperature as much as 5 to 10 degrees Celsius during storm events (Galli and Dubose, 1990). Thermal loading disrupts aquatic organisms that have finely tuned temperature limits. Salinity can also be affected by urbanization.

Freshwater inflows due to increased runoff can impact estuaries, especially if they occur in pulses, disrupting the natural salinity of an area. Increased impervious surface area and the presence of storm water conveyance systems commonly result in elevated peak flows in streams during and after storm events. These rapid pulses or influxes of fresh water into the watershed may be 2 to 10 times greater than normal (ABAG, 1991). This may lead to a decrease in the number of aquatic organisms living in the receiving waters (McLusky, 1989).

The alteration of natural hydrology due to urbanization and the accompanying runoff diversion, channelization, and destruction of natural drainage systems have resulted in riparian and tidal wetland degradation or destruction. Deltaic wetlands have also been impacted by changes in historic sediment deposition rates and patterns. Hydromodification projects designed to prevent flooding may reduce sedimentation rates and decrease marsh aggradation, which would normally offset erosion and apparent changes in sea level within the delta (Cahoon et al., 1983).

3. Opportunities

This chapter was organized to parallel the development process to address the prevention and treatment of nonpoint source pollution loadings during all phases of urbanization. (NOTE: The control of nonpoint source pollution requires the use of two primary strategies: the prevention of pollutant loadings and the treatment of unavoidable loadings. The strategy in this chapter relies primarily on the watershed approach, which focuses on pollution prevention or source reduction practices. While treatment options are an integral component of this chapter, a

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combination of pollution prevention and treatment practices is favored because planning, design, and education practices are generally more effective, require less maintenance, and are more cost-effective in the long term.)

The major opportunities to control NPS loadings occur during the following three stages of development: the siting and design phase, the construction phase, and the postdevelopment phase. Before development occurs, land in a watershed is available for a number of pollution prevention and treatment options, such as setbacks, buffers, or open space requirements, as well as wet ponds or constructed urban runoff wetlands that can provide treatment of the inevitable runoff and associated pollutants. In addition, siting requirements/restrictions and other land use ordinances, which can be highly effective, are more easily implemented during this period. After development occurs, these options may no longer be practicable or cost-effective. Management Measures II.A through II.C address the strategies and practices that can be used during the initial phase of the urbanization process.

The control of construction-related sediment loadings is critical to maintaining water quality. The implementation of proper erosion and sediment control practices during the construction stage can significantly reduce sediment loadings to surface waters. Management Measures II.A and II.B address construction-related practices.

After development has occurred, lack of available land severely limits the implementation of cost-effective treatment options. Management Measure VI.A focuses on improving controls for existing surface water runoff through pollution prevention to mitigate nonpoint sources of pollution generated from ongoing domestic and commercial activities.

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II. URBAN RUNOFF

A. New Development Management Measure

(1) By design or performance:

(a) After construction has been completed and the site is permanently stabilized, reduce the average annual total suspended solid (TSS) loadings by 80 percent. For the purposes of this measure, an 80 percent TSS reduction is to be determined on an average annual basis,* or

(b) Reduce the postdevelopment loadings of TSS so that the average annual TSS loadings are no greater then predevelopment loadings, and

(2) To the extent practicable, maintain postdevelopment peak runoff rate and average volume at levels that are similar to predevelopment levels.

Sound watershed management requires that both structural and nonstructural measures be employed to mitigate the adverse impacts of storm water. Nonstructural Management Measures II.B and II.C can be effectively used in conjunction with Management Measure II.A to reduce both the short- and long-term costs of meeting the treatment goals of this management measure.

* Based on the average annual TSS loadings from all storms less than or equal to the 2-year/24-hour storm. TSS loadings from storms greater than the 2-year/24-hour storm are not expected to be included in the calculation of the average annual TSS loadings.

1. Applicability

This management measure is intended to be applied by States to control urban runoff and treat associated pollutants generated from new development, redevelopment, and new and relocated roads, highways, and bridges. Under the Coastal Zone Act Reauthorization Amendments of 1990, States are subject to a number of requirements as they develop coastal nonpoint source (NPS) programs in conformity with this management measure and will have flexibility in doing so. The application of management measures by States is described more fully in *Coastal Nonpoint Pollution Control Program: Program Development and Approval Guidance*, published jointly by the U.S. Environmental Protection Agency (EPA) and the National Oceanic and Atmospheric Administration (NOAA) of the U.S. Department of Commerce.

For design purposes, postdevelopment peak runoff rate and average volume should be based on the 2-year/24-hour storm.

2. Description

This management measure is intended to accomplish the following: (1) decrease the erosive potential of increased runoff volumes and velocities associated with development-induced changes in hydrology; (2) remove suspended solids and associated pollutants entrained in runoff that result from activities occurring during and after development; (3) retain hydrological conditions to closely resemble those of the predisturbance condition; and (4) preserve natural systems including in-stream habitat.[2] For the purposes of this management measure, "similar" is defined as "resembling though not completely identical."

During the development process, both the existing landscape and hydrology can be significantly altered. As development occurs, the following changes to the land may occur (USEPA, 1977):

- Soil porosity decreases;
- Impermeable surfaces increase;
- Channels and conveyances are constructed;
- Slopes increase;
- Vegetative cover decreases; and
- Surface roughness decreases.

These changes result in increased runoff volume and velocities, which may lead to increased erosion of streambanks, steep slopes, and unvegetated areas (Novotny, 1991). In addition, destruction of in-stream and riparian habitat, increases in water temperature (Schueler et al., 1992), streambed scouring, and downstream siltation of streambed substrate, riparian areas, estuarine habitat, and reef systems may occur. An example of predicted effects of increased levels of urbanization on runoff volumes is presented in Table 4-4 (USDA-SCS, 1986). Methods are also available to compute peak runoff rates (USDA-SCS, 1986).

The annual TSS loadings can be calculated by adding the TSS loadings that can be expected to be generated during an average 1-year period from precipitation events less than or equal to the 2-year/24-hour storm. The 80 percent standard can be achieved by reducing, over the course of the year, 80 percent of these loadings. EPA recognizes that 80 percent cannot be achieved for each storm event and understands that TSS removal efficiency will fluctuate above and below 80 percent for individual storms.

Management Measures II.A, II.B, and II.C were selected as a system to be used to prevent and mitigate the problems discussed above. In combination, these three management measures applied on-site and throughout watersheds can be used to provide increased watershed protection and help prevent severe erosion, flooding, and increased pollutant loads generally associated with poorly planned development. Implementation of Management Measures II.B and II.C can help achieve the goals of Management Measure II.A.

Structural practices to control urban runoff rely on three basic mechanisms to treat runoff: **infiltration, filtration, and detention.** Table 4-5 lists specific urban runoff control practices that relate to these and includes information on advantages, disadvantages, and costs. Table 4-6 presents site-specific considerations, regional limitations, operation and maintenance burdens, and longevity for these practices.

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[2] Several issues require clarification to fully understand the scope and intent of this management measure. First, this management measure applies only to postdevelopment loadings and not to construction-related loadings. Management measure options II.A.(1)(a) and (b) both apply only to the TSS loadings that are generated after construction has ceased and the site has been properly stabilized using permanent vegetative and/or structural erosion and sediment control practices. Second, for the purposes of this guidance, the term *predevelopment* refers to the sediment loadings and runoff volumes/velocities that exist onsite immediately before the planned land disturbance and development activities occur. Predevelopment is not intended to be interpreted as that period before any human-induced land disturbance activity has occurred. Third, management measure option II.A.(1)(b) is not intended to be used as an alternative to achieving an adequate level of control in cases where high sediment loadings are the result of poor management of developed sites (not "natural" sites), e.g., farmlands where the erosion control components of the USDA conservation management system are not used or sites where land disturbed by previous development was not permanently stabilized.

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Table 4-4. Example Effects of Increased Urbanization on Runoff Volumes (USDA-SCS, 1986)

Development Scenario	Predicted Runoff
100 percent open space	2.81 inches (baseline)
70 percent of the total area divided into ½-acre lots; each lot is 25 percent impervious; 30 percent of the total area is open space	3.28 inches (24 percent increase)
70 percent of the total area is divided into ½-acre lots; each lot is 35 percent impervious; 30 percent of the total area is open space	3.48 inches (24 percent increase)
30 percent of the total area is divided into ½-acre lots - each lot is 25 percent impervious and contiguous; 40 percent is divided into ½-acre lots - each lot is 50 percent impervious and discontinuous; 30 percent of the total area is open space	3.19 inches (14 percent increase)

Infiltration devices, such as infiltration trenches, infiltration basins, filtration basins, and porous and concrete block pavement, rely on absorption of runoff to treat urban runoff discharges. Water is percolated through soils, where filtration and biological action remove pollutants. Systems that rely on soil absorption require deep permeable soils at separation distances of at least 4 feet between the bottom of the structure and seasonal ground water levels. The widespread use of infiltration in a watershed can be useful to maintain or restore predevelopment hydrology, increase dry-weather baseflow, and reduce bankfull flooding frequency. However, infiltration systems may not be appropriate where ground water requires protection. Restrictions may also apply to infiltration systems located above sole source (drinking water) aquifers. Where such designs are selected, they should be incorporated with the recognition that periodic maintenance is necessary for these areas. Long-term effectiveness in most cases will depend on proper operation and maintenance of the entire system.

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NOTE: Infiltration systems, some filtration devices, and sand filters should be installed after construction has been completed and the site has been permanently stabilized. The State of Maryland has observed a high failure rate for infiltration systems. Many of these failures can be attributed to clogging due to sediment loadings generated during the construction process and/or the premature use of the device before proper stabilization of the site has occurred. In cases where construction of the infiltration system is necessary before the cessation of land-disturbing activities, diversions, covers, or other means to prevent sediment-laden runoff from entering and clogging the infiltration system should be used (State of Maryland DNR, personal communication, 1991).

Filtration practices such as filter strips, grassed swales, and sand filters treat sheet flow by using vegetation or sand to filter and settle pollutants. In some cases infiltration and treatment in the subsoil may also occur. After passing through the filtration media, the treated water can be routed into streams, drainage channels, or other waterbodies; evaporated; or percolated into ground water. Sand filters are particularly useful for ground-water protection. The influence of climatic factors must be considered in the process of selecting vegetative systems.

Detention practices temporarily impound runoff to control runoff rates, and settle and retain suspended solids and associated pollutants. Extended detention ponds and wet ponds fall within this category. Constructed urban runoff wetlands and multiple-pond systems also remove pollutants by detaining flows that lead to sedimentation (gravitational settling of suspended solids). Properly designed ponds protect downstream channels by controlling discharge velocities, thereby reducing the frequency of bankfull flooding and resultant bank-cutting erosion. If landscaped and planted with appropriate vegetation, these systems can reduce nutrient loads and also provide terrestrial and aquatic wildlife habitat. When considering the use of these devices, potential negative impacts such as downstream warming, reduced baseflow, trophic shifts, bacterial contamination due to waterfowl, hazards to

Table 4-6. Advantages and Disadvantages of Management Practices

Management Practice	Advantages	Disadvantages	Comparative Cost (Schueler, Kumble, and Heraty, 1992)
Infiltration Basin	• Provides ground-water recharge • Can serve large developments • High removal capability for particulate pollutants and moderate removal for soluble pollutants • When basin works, it can replicate predevelopment hydrology more closely than other BMP options • Basins provide more habitat value than other infiltration systems	• Possible risk of contaminating ground water • Only feasible where soil is permeable and there is sufficient depth to rock and water table • Fairly high failure rate • If not adequately maintained, can be an eyesore, breed mosquitoes, and create undesirable odors • Regular maintenance activities cannot prevent rapid clogging of infiltration basins	Construction cost moderate but rehabilitation cost high
Infiltration Trench	• Provides ground-water recharge • Can serve small drainage areas • Can fit into medians, perimeters, and other unused areas of a development site • Helps replicate predevelopment hydrology, increases dry weather baseflow, and reduces bankfull flooding frequency	• Possible risk of contaminating ground water • Only feasible where soil is permeable and there is sufficient depth to rock and water table • Since not as visible as other BMPs, less likely to be maintained by residents • Requires significant maintenance	Cost-effective on smaller sites. Rehabilitation costs can be considerable.
Vegetated Filter Strip (VFS)	• Low maintenance requirements • Can be used as part of the runoff conveyance system to provide pretreatment • Can effectively reduce particulate pollutant levels in areas where runoff velocity is low to moderate • Provides excellent urban wildlife habitat • Economical	• Often concentrates water, which significantly reduces effectiveness • Ability to remove soluble pollutants highly variable • Limited feasibility in highly urbanized areas where runoff velocities are high and flow is concentrated • Requires periodic repair, regrading, and sediment removal to prevent channelization	Low

Table 4-5. (Continued)

Management Practice	Advantages	Disadvantages	Comparative Cost (Schueler, Kumble, and Heraty, 1992)
Grassed Swale	• Requires minimal land area • Can be used as part of the runoff conveyance system to provide pretreatment • Can provide sufficient runoff control to replace curb and gutter in single-family residential subdivisions and on highway medians • Economical	• Low pollutant removal rates • Leaching from culverts and fertilized lawns may actually increase the presence of trace metals and nutrients	Low compared to curb and gutter
Porous Pavement	• Provides ground-water recharge • Provides water quality control without additional consumption of land • Can provide peak flow control • High removal rates for sediment, nutrients, organic matter, and trace metals • When operating properly can replicate predevelopment hydrology • Eliminates the need for stormwater drainage, conveyance, and treatment systems off-site	• Requires regular maintenance • Possible risk of contaminating ground water • Only feasible where soil is permeable, there is sufficient depth to rock and water table, and there are gentle slopes • Not suitable for areas with high traffic volume • Need extensive feasibility tests, inspections, and very high level of construction workmanship (Schueler, 1987) • High failure rate due to clogging • Not suitable to serve large off-site pervious areas	Cost-effective compared to conventional asphalt when working properly
Concrete Grid Pavement	• Can provide peak flow control • Provides ground-water recharge • Provides water quality control without additional consumption of land	• Requires regular maintenance • Not suitable for area with high traffic volume • Possible risk of contaminating ground water • Only feasible where soil is permeable, there is sufficient depth to rock and water table, and there are gentle slopes	Information not available

Table 4-5. (Continued)

Management Practice	Advantages	Disadvantages	Comparative Cost (Schueler, Kumble, and Heraty, 1992)
Filtration Basin	• Ability to accommodate medium-size development (3-80 acres) • Flexibility to provide or not provide ground-water recharge • Can provide peak volume control	• Requires pretreatment of storm water through sedimentation to prevent filter media from prematurely clogging	Information not available
Water Quality Inlets Catch Basins	• Provide high degree of removal efficiencies for larger particles and debris as pretreatment • Require minimal land area • Flexibility to retrofit existing small drainage areas and applicable to most urban areas	• Not feasible for drainage area greater than 1 acre • Marginal removal of small particles, heavy metals, and organic pollutants • Not effective as water quality control for intense storms • Minimal nutrient removal	Information not available
Water Quality Inlet Catch Basins with Sand Filter	• Provide high removal efficiencies of particulates • Require minimal land area • Flexibility to retrofit existing small drainage areas • Higher removal of nutrient as compared to catch basins and oil/grid separator	• Not feasible for drainage area greater than 5 acres • Only feasible for areas that are stabilized and highly impervious • Not effective as water quality control for intense storms	Information not available
Water Quality Inlet Oil/Grit Separator	• Captures coarse-grained sediments and some hydrocarbons • Requires minimal land area • Flexibility to retrofit existing small drainage areas and applicable to most urban areas • Shows some capacity to trap trash, debris, and other floatables • Can be adapted to all regions of the country	• Not feasible for drainage area greater than 1 acre • Minimal nutrient and organic matter removal • Not effective as water quality control for intense storms • Concern exists over the pollutant toxicity of trapped residuals • Require high maintenance	High, compared to trenches and sand filters

Table 4-6. (Continued)

Management Practice	Advantages	Disadvantages	Comparative Cost (Schueler, Kumble, and Heraty, 1992)
Extended Detention Dry Pond	• Can provide peak flow control • Possible to provide good particulate removal • Can serve large development • Requires less capital cost and land area when compared to wet pond • Does not generally release warm or anoxic water downstream • Provides excellent protection for downstream channel erosion • Can create valuable wetland and meadow habitat when properly landscaped	• Removal rates for soluble pollutants are quite low • Not economical for drainage area less than 10 acres • If not adequately maintained, can be an eyesore, breed mosquitoes, and create undesirable odors	Lowest cost alternative in size range
Wet Pond	• Can provide peak flow control • Can serve large developments; most cost-effective for larger, more intensively developed sites • Enhances aesthetics and provides recreational benefits • Little ground-water discharge • Permanent pool in wet ponds helps to prevent scour and resuspension of sediments • Provides moderate to high removal of both particulate and soluble urban stormwater pollutants	• Not economical for drainage area less than 10 acres • Potential safety hazards if not properly maintained • If not adequately maintained, can be an eyesore, breed mosquitoes, and create undesirable odors • Requires considerable space, which limits use in densely urbanized areas with expensive land and property values • Not suitable for hydrologic soil groups "A" and "B" (SCS classification) • With possible thermal discharge and oxygen depletion, may severely impact downstream aquatic life	Moderate to high compared to conventional storm water detention

Table 4-6. (Continued)

Management Practice	Advantages	Disadvantages	Comparative Cost (Schueler, Kumble, and Heraty, 1992)
Extended Detention Wet Pond	• Can provide peak flow control • Can serve large developments; most cost-effective for larger, more intensively developed sites • Enhances aesthetic and provide recreational benefits • Permanent pool in wet ponds helps to prevent scour and resuspension of sediments • Provides better nutrient removal when compared to wet pond	• Not economical for drainage area less than 10 acres • Potential safety hazards if not properly maintained • If not adequately maintained, can be an eyesore, breed mosquitoes, and create undesirable odors • Requires considerable space, which limits use in densely urbanized areas with expensive land and property values • Not suitable for hydrologic soil groups "A" and "B"(SCS classification) • With possible thermal discharge and oxygen depletion, may severely impact downstream aquatic life	

Table 4-5. (Continued)

Management Practice	Advantages	Disadvantages	Comparative Cost (Schueler, Kumble, and Heraty, 1992)
Constructed Stormwater Wetland	• Can serve large developments; most cost-effective for larger, more intensively developed sites • Provides peak flow control • Enhances aesthetics and provides recreational benefits • The marsh fringe also protects shoreline from erosion • Permanent pool in wet ponds helps to prevent scour and resuspension of sediments • Has high pollutant removal capability	• Not economical for drainage area less than 10 acres • Potential safety hazards if not properly maintained • If not adequately maintained can be an eyesore, breed mosquitoes, and create undesirable odors • Requires considerable space, which limits use in densely urbanized areas with expensive land and property values • With possible thermal discharge and oxygen depletion, may severely impact downstream aquatic life • May contribute to nutrient loadings during die-down periods of vegetation	Marginally higher than wet ponds

Table 4-6. Regional, Site-Specific, and Maintenance Considerations for Structural Practices to Control Sediments in Storm Water Runoff (Schueler et al., 1992)

BMP Option	Size of Drainage Area	Site Requirements	Regional Restrictions	Maintenance Burdens	Longevity
Infiltration basins	Moderate to large	Deep permeable soils	Arid and cold regions	High	Low
Infiltration trenches	Moderate	Same as for infiltration basins			
Vegetated filter strips	Small	Low-density areas with low slopes	Arid and cold regions	Low	Low if poorly maintained
Grassed swales	Small	Low-density areas with <15% slope	Arid and cold regions	Low	High if maintained
Porous pavement	Small	Deep permeable soils, low slopes, and restricted traffic	Arid and cold regions or high wind erosion rates	High	Low
Concrete grid pavement	Small	Same as for porous pavement		Moderate to high	High
Filtration basins and sand filters	Widely applicable	Widely applicable	Arid and cold regions	Moderate	Low to moderate
Water quality inlets	Small	Impervious catchments	Few restrictions	Cleaned twice a year	High
Extended detention ponds	Moderate to large	Deep soils	Few restrictions	Dry ponds have relatively high burdens	High
Wet ponds	Moderate to large	Deep soils	Arid regions	Low	High
Constructed storm water wetlands	Moderate to large	Poorly drained soils, space may be limiting	Arid regions	Annual harvesting of vegetation	High

nearby residents, and nuisance factors such as mosquitoes and odor should be considered. Siting development in wetlands and floodplains should be avoided. Where drainage areas are greater than 250 acres and ponds are being considered, inundation of upstream channels may be of concern.

Constructed wetlands and multiple-pond systems also treat runoff through the processes of adsorption, plant uptake, filtration, volatilization, precipitation, and microbial decomposition (Livingston and McCarron, 1992; Schueler et al., 1992). Multiple-pond systems in particular have shown potential to provide much higher levels of treatment (Schueler et al., 1992). In general, the potential concerns and drawbacks applicable to wet ponds apply to these systems. Many of these systems are currently being designed to include vegetated buffers and deep-water areas to provide habitat for wildlife and aesthetic benefits. Where such designs are selected, they should be incorporated with the recognition that periodic maintenance is necessary. Long-term effectiveness in most cases will depend on proper operation and maintenance of the entire system. Refer to Chapter 7 for additional information on constructed wetlands.

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Water quality inlets, like ponds, rely on gravity settling to remove pollutants before ponds discharge water to the storm sewer or other collection system. Water quality inlets are designed to trap floatable trash and debris. When inlets are coupled with oil/grit separators, hydrocarbon loadings from areas with high traffic/parking volumes can be reduced. However, experience has shown that these devices have limited pollutant-removal effectiveness and should not be used unless coupled with frequent and effective clean-out methods (Schueler et al., 1992). Although no costs are currently available, proper maintenance of water quality inlets must include proper disposal of trapped coarse-grained sediments and hydrocarbons. The costs of clean-out and disposal may be significant when contaminated sediments require proper disposal.

Inadequate maintenance is often cited as one of the major factors influencing the poor effectiveness of structural practices. The cost of long-term maintenance should be evaluated during the selection process. In addition, responsibility for maintenance should be clearly assigned for the life of the system. Typical maintenance requirements include:

- Inspection of basins and ponds after every major storm for the first few months after construction and annually thereafter;
- Mowing of grass filter strips and swales at a frequency to prevent woody growth and promote dense vegetation;
- Removal of litter and debris from dry ponds, forebays, and water quality inlets;
- Revegetation of eroded areas;
- Periodic removal and replacement of filter media from infiltration trenches and filtration ponds;
- Deep tilling of infiltration basins to maintain infiltrative capability;
- Frequent (at least quarterly) vacuuming or jet hosing of porous pavements or concrete grid pavements;
- Quarterly clean-outs of water quality inlets;
- Periodic removal of floatables and debris from catch basins, water quality inlets, and other collection-type controls; and
- Periodic removal and proper disposal of accumulated sediment (applicable to all practices). Sediments in infiltration devices need to be removed frequently enough to prevent premature failure due to clogging.

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Operation and Maintenance

Proper operation and maintenance of structural treatment facilities is critical to their effectiveness in mitigating adverse impacts of urban runoff. The proper installation and maintenance of various BMPs often determines their success or failure (Reinalt, 1992).

During a field study of 51 urban runoff treatment facilities, the Ocean County, New Jersey, planning and engineering departments determined that the major source of urban runoff problems was a failure of the responsible party to provide adequate facility maintenance. The causes of this failure are complex and include factors such as lack of funding, manpower, and equipment; uncertain or irresponsible ownership; unassigned maintenance responsibility; and ignorance or disregard of potential consequences of maintenance neglect (Ocean County, 1989). The analysis of the field data collected during the study indicated the following trends:

- Bottoms, side slopes, trash racks, and low-flow structures were the primary sources of maintenance problems.

- Infiltration facilities seemed to be more prone to maintenance neglect and were generally in the poorest condition overall.
- Retention facilities appeared to receive the greatest amount of maintenance and generally were in the best condition overall.
- Publicly owned facilities were usually better maintained than those that were privately maintained.
- Facilities located at office development sites were better maintained than those at commercial or institutional sites; facilities in residential areas received average maintenance.
- Highly visible urban runoff facilities were generally better maintained that those in more remote, less visible locations (Ocean County, 1989).

The following program elements should be considered to ensure the proper design, implementation, and operation and maintenance of runoff treatment and control devices (adapted from The State of New Jersey Ocean County Demonstration Study's *Storm Water Management Facilities Maintenance Manual*):

- Adoption, promulgation, and implementation of planning and design standards that eliminate, reduce, and/or facilitate facility maintenance; coordination with other regulatory authorities with jurisdiction over runoff facilities;
- Establishment of a comprehensive design review program, which includes training and education to ensure adequate staff competency and expertise;
- Design standards published in a readily understandable format for all permittees and responsible parties including regulatory authorities; the provision of clear requirements to promote the adoption of planning and standards and expedite facility review and approval;
- Publication of specific obligations and responsibilities of the runoff facility owner/operator including procedures for the identification of owners/operators who will have long-term responsibility for the facility;
- Development of a procedure for addressing maintenance default by negligent owner/operators;
- Periodic review and evaluation of the runoff management program to ensure continued program effectiveness and efficiency;
- Runoff facility construction inspection program; and
- Provisions for public assumption of runoff control facilities.

3. Management Measure Selection

This management measure was selected because of the following factors.

(1) Removal of 80 percent of total suspended solids (TSS) is assumed to control heavy metals, phosphorus, and other pollutants.

(2) A number of coastal States, including Delaware and Florida, and the Lower Colorado River Authority (Texas) require and have implemented a TSS removal treatment standard of at least 80 percent for new development.

(3) Analysis has shown that constructed wetlands, wet ponds, and infiltration basins can remove 80 percent of TSS, provided they are designed and maintained properly. Other practices or combinations of practices can be also used to achieve the goal.

(4) The control of postdevelopment volume and peak runoff rates to reduce or prevent streambank erosion and stream scouring and to maintain predevelopment hydrological conditions can be accomplished using a number of water quality and flood control practices. Many States and local governments have implemented requirements that stipulate that, at a minimum, the 2-year/24-hour storm be controlled.

Management Measure II.A.(1)(b) was selected to provide a descriptive alternative to Management Measure II.A.(1)(a). Where preexisting conditions do not already present a water quality problem, preservation of predevelopment TSS loading levels is intended to promote TSS loading reductions that adequately protect surface waters and are equivalent to or greater than the levels achieved by Management Measure option II.A.(1)(a). In some cases, local conditions (e.g., mountainous areas with arid, steep slopes) may preclude the implementation of Management Measure II.A.(1)(a). Where local conditions do not allow the implementation of BMPs such as grassed swales or detention basins, and preconstruction/predevelopment (existing conditions) TSS loadings from the site are significant, it may not be cost-effective or beneficial to require 80 percent TSS postdevelopment loading reductions. Management Measure option II.A.(1)(b) was provided to allow flexibility where such conditions exist. This flexibility will be especially important in cases where loadings from surrounding undeveloped areas dwarf the TSS loadings generated from the new development. (NOTE: Predevelopment is defined, in the context of Management Measure II.A.(1)(b), as the sediment loadings and runoff volumes/velocities that exist onsite immediately before the planned land disturbance and development occur.)

4. Practices

As discussed more fully at the beginning of this chapter and in Chapter 1, the following practices are described for illustrative purposes only. State programs need not require implementation of these practices. However, as a practical matter, EPA anticipates that the management measure set forth above generally will be implemented by applying one or more management practices appropriate to the source, location, and climate. The practices set forth below have been found by EPA to be representative of the types of practices that can be applied successfully to achieve the management measure described above.

Cost and effectiveness information for these practices is shown in Tables 4-7 and 4-8. Many of these practices can be used during site development, but the focus of this section is the abatement of postdevelopment impacts.

a. *Develop training and education programs and materials for public officials, contractors, and others involved with the design, installation, operation, inspection, and maintenance of urban runoff facilities.*

Training programs and educational materials for public officials, contractors, and the public are crucial to implementing effective urban runoff management programs. Contractor certification, inspector training, and competent design review staff are important for program implementation and continuing effectiveness. The State of New Jersey Ocean County Demonstration Study's *Storm Water Management Facilities Maintenance Manual* addresses many of these issues and provides guidance on programmatic elements necessary for the proper operation and maintenance of urban runoff facilities. Several other States and local governments, including Virginia, Maryland, Washington, Delaware, Northeastern Illinois Planning Commission, and the City of Alexandria, Virginia, have developed manuals and training materials to assist in implementation of urban runoff requirements and regulations.

The State of Delaware passed legislation requiring that "all responsible personnel involved in a construction project will have a certificate of attendance at a Departmental sponsored or approved training course for the control of sediment and storm water before initiation of land disturbing activity." The State provides personnel training and educational opportunities for contractors to meet this requirement and has delegated program elements to conservation

Table 4-7. Effectiveness of Management Practices for Control of Runoff From Newly Developed Areas

Management Practice		Removal Efficiency (%)						Factors	References
		TSS	TP	TN	COD	Pb	Zn		
INFILTRATION BASIN	Average:	75	65	60	65	65	65	• Soil percolation rates • Basin surface area • Storage volume	NVPDC, 1979; EPA, 1977; Schueler, 1987; Griffin, et al, 1980; EPA, 1983; Woodward-Clyde, 1986
	Reported Range:	45-100	45-100	45-100	45-100	45-100	45-100		
	Probable Range:[a]								
	SCS Soil Group A	60-100	60-100	60-100	60-100	60-100	60-100		
	SCS Soil Group B	50-80	50-80	50-80	50-80	50-80	50-80		
	No. Values Considered:	7	7	7	4	4	4		
INFILTRATION TRENCH	Average:	75	60	55	65	65	65	• Soil percolation rates • Trench surface area • Storage volume	NVPDC, 1979; EPA, 1977; Schueler, 1987; Griffin, et al, 1980; EPA, 1983; Woodward-Clyde, 1986; Kuo et al., 1988; Lugbill, 1990
	Reported Range:	45-100	40-100	(-10)-100	45-100	45-100	45-100		
	Probable Range:[b]								
	SCS Soil Group A	60-100	60-100	60-100	60-100	60-100	60-100		
	SCS Soil Group B	50-90	50-90	50-90	50-80	50-90	50-90		
	No. Values Considered:	9	9	9	4	4	4		
VEGETATED FILTER STRIP	Average:	65	40	40	40	45	60	• Runoff volume • Slope • Soil infiltration rates • Vegetative cover • Buffer length	IEP, 1991; Casman, 1990; Glick et al., 1991; VADC, 1987; Minnesota PCA, 1989; Schueler, 1987; Hartigan et al., 1989
	Reported Range:	20-80	0-85	0-70	0-80	20-80[e]	30-80[f]		
	Probable Range:[c]	40-80	30-80	20-60	--	30-80	20-50		
	No. Values Considered:	7	4	3	2	3	3		
GRASS SWALE	Average:	60	20	10	25	70	60	• Runoff volume • Slope • Soil infiltration rates • Vegetative cover • Swale length • Swale geometry	Yousef et al., 1985; Dupuis, 1985; Washington State, 1988; Schueler, 1987; British Columbia Res. Corp., 1991; EPA, 1983; Whalen, et al., 1988; Pitt, 1986; Casman, 1990
	Reported Range:	0-100	0-100	0-40	25	3-100[g]	50-60[h]		
	Probable Range:[d]	20-40	20-40	10-30	--	10-20	10-20		
	No. Values Considered:	10	8	4	1	10	7		

Table 4-7. (Continued)

Management Practice		Removal Efficiency (%) TSS	TP	TN	COD	Pb	Zn	Factors	References
POROUS PAVEMENT	Average:	90	65	85	80	100	100	• Percolation rates • Storage volume	Schueler, 1987
	Reported Range:	80-95	65	80-85	80	100	100		
	Probable Range:	60-90	60-90	60-90	60-90	60-90	60-90		
	No. Values Considered:	2	2	2	2	2	2		
CONCRETE GRID PAVEMENT	Average:	90	90	90	90	90	90	• Percolation rates	Day, 1981; Smith, et al, 1981; Schueler, 1987
	Reported Range:	65-100	65-100	65-100	65-100	65-100	65-100		
	Probable Range:	60-90	60-90	60-90	60-90	60-90	60-90		
	No. Values Considered:	2	2	2	2	2	2		
SAND FILTER/FILTRATION BASIN	Average:	80	80	35	55	80	65	• Treatment volume • Filtration media	City of Austin, 1988; Environmental and Conservation Service Department, 1990
	Reported Range:	60-95	0-80	20-40	45-70	30-90	50-80		
	Probable Range:	60-90	0-80	20-40	40-70	40-80	40-80		
	No. Values Considered:	10	6	7	3	5	5		
WATER QUALITY INLET[a]	Average:	35	5	20	5	15	5	• Maintenance • Sedimentation storage volume	Pitt, 1986; Field, 1985; Schueler, 1987
	Reported Range:	0-95	5-10	5-55	5-10	10-25	5-10		
	Probable Range:	10-25	5-10	5-10	5-10	10-25	5-10		
	No. Values Considered:	3	1	2	1	2	1		

Table 4-7. (Continued)

Management Practice		TSS	TP	TN	COD	Pb	Zn	Factors	References
		Removal Efficiency (%)							
WATER QUALITY INLET WITH SAND FILTER[e]	Average:	80	NA	35	55	80	65	• Sedimentation storage volume	Shaver, 1991
	Reported Range:	75-85	NA	30-45	45-70	70-90	50-80	• Depth of filter media	
	Probable Range:	70-90	–	30-40	40-70	70-90	50-80		
	No. Values Considered:	1	0	1	1	1	1		
OIL/GRIT SEPARATOR[e]	Average:	15	5	5	5	15	5	• Sedimentation storage volume	Pitt, 1985; Schueler, 1987
	Reported Range:	0-25	5-10	5-10	5-10	10-25	5-10	• Outlet configurations	
	Probable Range:	10-25	5-10	5-10	5-10	10-25	5-10		
	Number of References	2	1	1	1	1	1		
EXTENDED DETENTION DRY POND	Average:	45	25	30	20	50	20	• Storage volume • Detention time • Pond shape	MWCOG, 1983; City of Austin, 1990; Schueler and Helfrich, 1988; Pope and Hess, 1989; OWML, 1987; Wolinski and Stack, 1990
	Reported Range:	5-90	10-55	20-60	0-40	25-65	(-40)-65		
	Probable Range:[e]	70-90	10-60	20-60	30-40	20-60	40-60		
	No. Values Considered:	6	6	4	5	4	5		
WET POND	Average:	60	45	35	40	75	60	• Pool volume • Pond shape	Wotzka and Oberts, 1988; Yousef et al., 1986; Cullum, 1985; Driscoll, 1983; Driscoll, 1986; MWCOG, 1983; OWML, 1983; Yu and Benemouffok, 1988; Holler, 1989; Martin, 1988; Dorman et al., 1989; OWML, 1982; City of Austin, 1990
	Reported Range:	(-30)-91	10-85	5-85	5-90	10-95	10-95		
	Probable Range:	50-90	20-90	10-90	10-90	10-95	20-95		
	No. Values Considered:	18	18	9	7	13	13		

Table 4-7. (Continued)

Management Practice		Removal Efficiency (%) TSS	TP	TN	COD	Pb	Zn	Factors	References
EXTENDED DETENTION WET POND	Average:	80	65	55	NA	40	20	• Pool volume • Pond shape • Detention time	Ontario Ministry of the Environment, 1991, cited in Schueler et al., 1992
	Reported Range:	50-100	50-80	55	NA	40	20		
	Probable Range:	50-95	50-90	10-90	10-90	10-95	20-95		
	No. Values Considered:	3	3	1	0	1	1		
CONSTRUCTED STORMWATER WETLANDS	Average:	65	25	20	50	65	35	• Storage volume • Detention time • Pool shape • Wetland's biota • Seasonal variation	Harper et al., 1986; Brown, 1985; Wotzka and Obert, 1988; Hickock et al., 1977; Barten, 1987; Meiorin, 1986; Morris et al., 1981; Sherberger and Davis, 1982; ABAG, 1979; Oberts et al., 1989; Rushton and Dye, 1990; Hey and Barrett, 1991; Martin and Smoot, 1986, Reinelt et al., 1990, cited in Woodward-Clyde, 1991
	Reported Range:	(-20)-100	(-120)-100	(-15)-40	20-80	30-95	(-30)-80		
	Probable Range[f]:	50-90	(-5)-80	0-40	—	30-95	—		
	No. Values Considered:	23	24	8	2	10	8		

NA - Not available.

[a] Design criteria: storage volume equals 90% avg runoff volume, which completely drains in 72 hours; maximum depth = 8 ft; minimum depth = 2 ft.

[b] Design criteria: storage volume equals 90% avg runoff volume, which completely drains in 72 hours; maximum depth = 8 ft; minimum depth = 3 ft; storage volume = 40% excavated trench volume.

[c] Design criteria: flow depth < 0.3 ft, travel time > 5 min.

[d] Design criteria: low slope and adequate length.

[e] Design criteria: min. ED time 12 hours.

[f] Design criteria: minimum area of wetland equal 1% of drainage area.

[g] No information was available on the effectiveness of removing grease or oil.

[h] Also reported as 90% TSS removed.

[i] Also reported as 60% TSS removed.

Table 4-8. Cost of Management Practices for Control of Runoff from Newly Developed Areas

Practice	Land requirement	Construction cost	Useful life	Annual O&M	Total annual cost	References
Infiltration Basin	High	Average: $0.5/ ft^3 storage Probable Cost: $0.4 - $0.7/ft^3 Reported Range: $0.2 - $1.2/ ft^3	25[a]	Average: 7% of capital cost Reported Range: 3% - 13% of capital cost	$0.03 - $0.05/ ft^3	Wiegand, et al, 1986; SWRPC, 1991
Infiltration Trench	Low	Average: $4.0/ ft^3 storage Probable Cost: $2.5 - $7.5/ft^3 Reported Range: $0.9 - $9.2/ ft^3	10[a]	Average: 9% of capital cost Reported Range: 5% - 15% of capital cost	$0.3 - $0.9/ft^3	Wiegand, et al, 1986; Macal, et al, 1987; SWRPC, 1991; Kuo, et al, 1988
Vegetative Filter Strip	Varies	Established from existing vegetation- Average: $0 Reported Range: $0 Established from seed- Average: $400/ acre Reported Range: $200 - $1,000/ acre Established from seed and mulch- Average: $1,500/ acre Reported Range: $800 - $3,500/ acre Established from sod- Average: $11,300/ acre Reported Range: $4,500 - $48,000/ acre	50[b]	Natural succession allowed to occur- Average: $100/ acre Reported Range: $50 - $200/ acre Natural succession not allowed to occur- Average: $800/ acre Reported Range: $700 - $900/ acre	Natural succession allowed to occur- Established from- Natural vegetation: $100/ acre Seed: $125/ acre Seed & mulch: $200/ acre Sod: $700/ acre Natural succession not allowed to occur- Established from: natural vegetation: $800/acre Seed: $825/acre Seed & mulch: $900/acre Sod: $1,400/acre	Schueler, 1987; SWRPC, 1991

Table 4-8 (continued)

Practice	Land requirement	Construction cost	Useful life	Annual O&M	Total annual cost	References
Grass Swales	Low	Established from seed: Average: $8.5/ lin ft Reported Range: $4.5 - $8.5/ lin ft Established from sod: Average: $20/ lin ft Reported Range: $8 - $50/ lin ft	50 [b]	Established from seed or sod- Average: $0.75/ lin ft Reported Range: $0.5 - $1.0/ lin ft	Established from seed: $1/lin ft Established from sod: $2/lin ft	Schueler, 1987; SWRPC, 1991
Porous Pavement	None	Average: $1.5/ ft^2 [e] Reported Range: $1 - $2/ ft^2 [e]	10 [d]	Average: $0.01/ ft^2 [e] Reported Range: $0.01/ ft^2 [e]	0.15/ ft^2 [e]	SWRPC, 1991; Schueler, 1987
Concrete Grid Pavement	None	Average: $1/ ft^2 [e] Reported Range: $1 - $2/ ft^2 [e]	20	Average: (-$0.04)/ ft^2 [e] Reported Range: (-$0.04)/ ft^2 [e]	0.05/ ft^2 [e]	Smith, 1981
Sand Filter/ Filtration Basin	High	Average: $5/ ft^3 Probable Cost: $2 - $9/ ft^3 Reported Range: $1 - $11/ ft^3	25 [d]	Average: Not Available Probable Cost: 7% of construction cost Reported Range: Not Available	$0.1 - $0.8/ ft^3	Tull, 1990
Water Quality Inlet	None	Average: $2,000/ each Reported Range: $1,100 - $3,000/ each	50	Average: $30/each [f] Reported Range: $20-40/each [f]	$150/ each	SWRPC, 1991
Water Quality Inlet with Sand Filters	None	Average: $10,000/ drainage acre Reported Range: $10,000/ drainage acre	50	Average: Not Available Probable Cost: $100/ drainage acre Reported Range: Not Available	$700/ drainage acre	Shaver, 1991
Oil/Grit Separator	None	Average: $18,000/ drainage acre Reported Range: $15,000 - $20,000/ drainage acre	50	Average: $20/ drainage acre [f] Reported Range: $5 - $40/ drainage acre [f]	$1,000/ drainage acre	Schueler, 1987

Table 4-8 (continued)

Practice	Land requirement	Construction cost	Useful life	Annual O&M	Total annual cost	References
Extended Detention Dry Pond	High	Average $0.5/ ft³ storage Probable Cost: $0.09 - $5/ft³ Reported Range: $0.05 - $3.2/ ft³	50	Average: 4% of capital cost Reported Range: 3% - 5% of capital cost	$0.007 - $0.3/ft³	APWA Res. Foundation
Wet Pond and Extended Detention Wet Pond	High	Storage Volume < 1,000,000 ft³: Average: $0.5/ ft³ storage Probable Cost: $0.5 - $1/ft³ Reported Range: $0.05 - $1.0/ ft³ Storage Volume > 1,000,000 ft³: Average: $0.25/ ft³ storage Probable Cost: $0.1 - $0.5/ft³ Reported Range: $0.05 - $0.5/ft³	50	Average: 3% of capital cost Probable Cost: <100,000 ft³ = 5% of capital cost >100,000 & <1,000,000 ft³ = 3% of capital cost >1,000,000 ft³ = 1% of capital cost Reported Range: 0.1% - 5% of capital cost	$0.008 - $0.07/ft³	APWA Res. Foundation; Wiegand, et al, 1986; Schueler, 1987; SWRPC, 1991
Stormwater Wetlands	High	Average: Not available Reported Range: Not available	50[b]	Average: Not Available Reported Range: Not Available	Not available	

[a] References indicate the useful life for infiltration basins and infiltration trenches at 25-50 and 10-15 years, respectively. Because of the high failure rate, infiltration basins are assumed to have useful life span of 25 years and infiltration trenches are assumed to have useful life span of 10 years.
[b] Useful life taken as life of project, assumed to be 50 years.
[c] Incremental cost, i.e., cost beyond that required for conventional asphalt pavement.
[d] Since no information was available for useful life of porous pavement, it was assumed to be similar to that of infiltration trenches.
[e] Since no information was available for useful life of filtration basins it was assumed to be similar to that of infiltration basins.
[f] Frequency of cleaning assumed 2 times per year.

districts, counties, and other agencies. The program has been well received and from February 1991 to July 1991, over 1,100 individuals from 300 companies and organizations participated in the program (Shaver and Piorko, 1992).

b. *Ensure that all urban runoff facilities are operated and maintained properly.*

Once an urban runoff facility is installed, it should receive thorough maintenance in order to function properly and not pose a health or safety threat. Maintenance should occur at regular intervals, be performed by one or more individuals trained in proper inspection and maintenance of urban runoff facilities, and be performed in accordance with the adopted standards of the State or local government (Ocean County, undated). It is more effective and efficient to perform preventative maintenance on a regular basis than to undertake major remedial or corrective action on an as needed basis (Ocean County, undated).

c. *Infiltration Basins*

Infiltration basins are impoundments in which incoming urban runoff is temporarily stored until it gradually infiltrates into the soil surrounding the basin. Infiltration basins should drain within 72 hours to maintain aerobic conditions, which favor bacteria that aid in pollutant removal, and to ensure that the basin is ready to receive the next storm (Schueler, 1987). The runoff entering the basin is pretreated to remove coarse sediment that may clog the surface soil pore on the basin floor. Concentrated runoff should flow through a sediment trap, or a vegetated filter strip may be used for sheet flow.

d. *Infiltration Trenches*

Infiltration trenches are shallow excavated ditches that have been backfilled with stone to form an underground reservoir. Urban runoff diverted into the trench gradually infiltrates from the bottom of the trench into the subsoil and eventually into the ground water. Variations in the design of infiltration trenches include dry wells, pits designed to control small volumes of runoff (such as the runoff from a rooftop), and enhanced infiltration trenches, which are equipped with extensive pretreatment systems to remove sediment and oil. Depending on the quality of the runoff, pretreatment will generally be necessary to lower the failure rate of the trench. More costly than pond systems in terms of cost per unit of runoff treated, infiltration trenches are suited best for drainage areas of less than 5 to 10 acres or where ponds cannot be applied (Schueler et al., 1992).

e. *Vegetated Filter Strips*

Vegetated filter strips are areas of land with vegetative cover that are designed to accept runoff as overland sheet flow from upstream development. They may closely resemble many natural ecotones, such as grassy meadows or riparian forests. Dense vegetative cover facilitates sediment attenuation and pollutant removal. Vegetated filter strips do not effectively treat high-velocity flows and are therefore generally recommended for use in agriculture and low-density development and other situations where runoff does not tend to be concentrated. Unlike grassed swales, vegetated filter strips are effective only for overland sheet flow and provide little treatment for concentrated flows. Grading and level spreaders can be used to create a uniformly sloping area that distributes the runoff evenly across the filter strip (Dillaha et al., 1987). Vegetated filter strips are often used as pretreatment for other structural practices, such as infiltration basins and infiltration trenches. Refer to Chapter 7 of this guidance for additional information.

Filter strips are less effective on slopes of over 15 percent. Periodic inspection, repair, and regrading are required to prevent channelization (Schueler et al., 1992). Inspection is especially important following major storm events. Excessive use of pesticides, fertilizers, and other chemicals should be avoided. To minimize soil compaction, vehicular traffic and excessive pedestrian traffic should be avoided.

A berm of sediment that must be periodically removed may form at the upper edge of grassed filter strips. Mowing of grassed filter strips at a minimum of two to three times per year will maintain a thicker vegetative cover, providing better sediment retention. To avoid impacts on ground-nesting birds, mowing should be limited to spring or fall (USEPA, undated). Harvesting of mowed vegetation will allow for thicker growth and promotes the retention of nutrients that are released during decomposition (Dillaha et al., 1989).

Forested areas directly adjacent to waterbodies should be left undisturbed except for the removal of trees presenting unusual hazards and the removal of small debris near the stream that may be refloated by high water. Periodic harvesting of some trees not directly adjacent to waterbodies removes sequestered nutrients (Lowrance, Leonard, and Sheridan, 1985) and maintains an efficient filter through vigorous vegetation (USEPA, undated). Exposure of forested filter strip soil to direct radiation should be avoided to keep the temperature of water entering waterbodies low, and moist conditions conducive to microbial activities in filter strip soil should be maintained (Nutter and Gaskin, 1989).

f. Grassed Swales

A grassed swale is an infiltration/filtration method that is usually used to provide pretreatment before runoff is discharged to treatment systems. Grassed swales are typically shallow, vegetated, man-made ditches designed so that the bottom elevation is above the water table to allow runoff to infiltrate into ground water. The vegetation or turf prevents erosion, filters sediment, and provides some nutrient uptake (USDA-SCS, 1988). Grassed swales can also serve as conveyance systems for urban runoff and provide similar benefits.

The swale should be mowed at least twice each year to stimulate vegetative growth, control weeds, and maintain the capacity of the system. It should never be mowed shorter than 3 to 4 inches. The established width should be maintained to ensure the continued effectiveness and capacity of the system (Bassler, undated).

g. Porous Pavement and Permeable Surfaces

Porous pavement, an alternative to conventional pavement, reduces much of the need for urban runoff drainage conveyance and treatment off-site. Instead, runoff is diverted through a porous asphalt layer into an underground stone reservoir. The stored runoff gradually exfiltrates out of the stone reservoir into the subsoil. Many States no longer promote the use of porous pavement because it tends to clog with fine sediments (Washington Department of Ecology, 1991). A vacuum-type street sweeper should be used to maintain porous pavement.

Permeable paving surfaces such as modular pavers, grassed parking areas, and permeable pavements may also be employed to reduce runoff volumes and trap vehicle-generated pollutants (Pitt, 1990; Smith, 1981); however, care should be taken when selecting such alternatives. The potential for ground-water contamination, compaction, or clogging due to sedimentation should be evaluated during the selection process. (NOTE: These practices should be selected only in cases where proper operation and maintenance can be guaranteed due to high failure rates without proper upkeep.)

h. Concrete Grid Pavement

Concrete grid pavement consists of concrete blocks with regularly interdispersed void areas that are filled with pervious materials, such as gravel, sand, or grass. The blocks are typically placed on a sand or gravel base and designed to provide a load-bearing surface that is adequate to support vehicles, while allowing infiltration of surface water into the underlying soil.

i. Water Quality Inlets

Water quality inlets are underground retention systems designed to remove settleable solids. Several designs of water quality inlets exist. In their simplest form, catch basins are single-chambered urban runoff inlets in which the bottom has been lowered to provide 2 to 4 feet of additional space between the outlet pipe and the structure bottom for collection of sediment. Some water quality inlets include a second chamber with a sand filter to provide additional removal of finer suspended solids by filtration. The first chamber provides effective removal of coarse particles and helps prevent premature clogging of the filter media. Other water quality inlets include an oil/grit separator. Typical oil/grit separators consist of three chambers. The first chamber removes coarse material and debris; the second chamber provides separation of oil, grease, and gasoline; and the third chamber provides safety relief should blockage occur (NVPDC, 1980). While water quality inlets have the potential to perform effectively, they are not recommended. Maintenance and disposal of trapped residuals and hydrocarbons must occur regularly for these devices to work. No acceptable clean-out and disposal techniques currently exist (Schueler et al., 1992).

j. Extended Detention Ponds

Extended detention (ED) ponds temporarily detain a portion of urban runoff for up to 24 hours after a storm, using a fixed orifice to regulate outflow at a specified rate, allowing solids and associated pollutants the required time to settle out. The ED ponds are normally "dry" between storm events and do not have any permanent standing water. These basins are typically composed of two stages: an upper stage, which remains dry except for larger storms, and a lower stage, which is designed for typical storms. Enhanced ponds are equipped with plunge pools near the inlet, a micropool at the outlet, and an adjustable reverse-sloped pipe as the ED control device (orifice) (NVPDC, 1980; Schueler et al., 1992). Temporary and most permanent ED ponds use a riser with an antivortex trash rack on top to control trash.

k. Wet Ponds

Wet ponds are basins designed to maintain a permanent pool of water and temporarily store urban runoff until it is released at a controlled rate. Enhanced designs include a forebay to trap incoming sediment where it can easily be removed. A fringe wetland can also be established around the perimeter of the pond.

l. Constructed Wetlands

Constructed wetlands are engineered systems designed to simulate the water quality improvement functions of natural wetlands to treat and contain surface water runoff pollutants and decrease loadings to surface waters. Where site-specific conditions allow, constructed wetlands or sediment retention basins should be located to have a minimal impact on the surrounding areas. (The State of Washington requires that constructed wetlands be located in uplands (Washington Department of Ecology, 1992).) In addition, constructed urban runoff wetlands differ from artificial wetlands created to comply with mitigation requirements in that they do not replicate all of the ecological functions of natural wetlands. Enhanced designs may include a forebay, complex microtopography, and pondscaping with multiple species of wetland trees, shrubs, and plants. Additional information on constructed wetlands is provided in Chapter 7.

m. Filtration Basins and Sand Filters

Filtration basins are impoundments lined with filter media, such as sand or gravel. Urban runoff drains through the filter media and perforated pipes into the subsoil. Detention time is typically 4 to 6 hours. Sediment-trapping structures are typically used to prevent premature clogging of the filter media (NVPDC, 1980; Schueler et al., 1992).

Sand filters are a self-contained bed of sand to which the first flush of runoff water is diverted. The runoff percolates through the sand, where colloidal and particulate materials are strained out by the cake of solids that forms, or is placed, on the surface of the media. Water leaving the filter is collected in underground pipes and returned to the stream or channel. A layer of peat, limestone, and/or topsoil may be added to improve removal efficiency.

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■ ***n. Educate the public about the importance of runoff management facilities.***

"... the value of a comprehensive public information and education program cannot be overemphasized. Such a program must explain the basis, purpose, and details of the proposal and must convince the public and their elected officials that it is both necessary to implement and beneficial to their interests. It must also explain the fundamentals of storm water management facilities, the vital role they play in our lives, and their need for regular maintenance. This information can be presented through flyers, brochures, posters, and other educational aids. Work sessions and field trips can also be conducted. Signs at facility sites can also be erected. Finally, presentations to planning boards, municipal councils and committees, and county freeholders by storm water management experts can also be of great assistance" (New Jersey, undated).

5. Effectiveness and Cost Information

The box and whisker plot in Figure 4-3 summarizes efficiencies for selected structural TSS removal practices, as reported by Schueler et al., 1992. The whiskers of each box represent the range of reported TSS removal efficiencies. The box ends delimit the 25th and 75th percentiles. The horizontal line represents the median, or 50th percentile. Circles represent outliers. Figure 4-3 and Table 4-7 illustrate the range of removal efficiencies, based on monitoring and modeling studies, for total suspended solids for several of the structural practices. The reviewed literature reported a median TSS removal efficiency above 80 percent for three practices—constructed wetlands, wet ponds, and filtration basins. However, it has been reported that the other practices are capable of achieving 80 percent TSS removal efficiency when properly designed, sited, operated, and maintained. More detailed information on the removal efficiencies of the practices and factors influencing the removal efficiencies is presented in Table 4-7. Costs of the practices are shown in Table 4-8.

In many cases, a systems approach to best management practice (BMP) design and implementation may be more effective. By applying multiple practices, enhanced runoff attenuation, conveyance, pretreatment, and treatment may be attained (Schueler et al., 1992). In addition, regionalization of systems (installing and maintaining a BMP or BMPs for more than one development site) may prove more efficient and cost-effective due to the economies of scale of operating one large system versus several smaller systems.

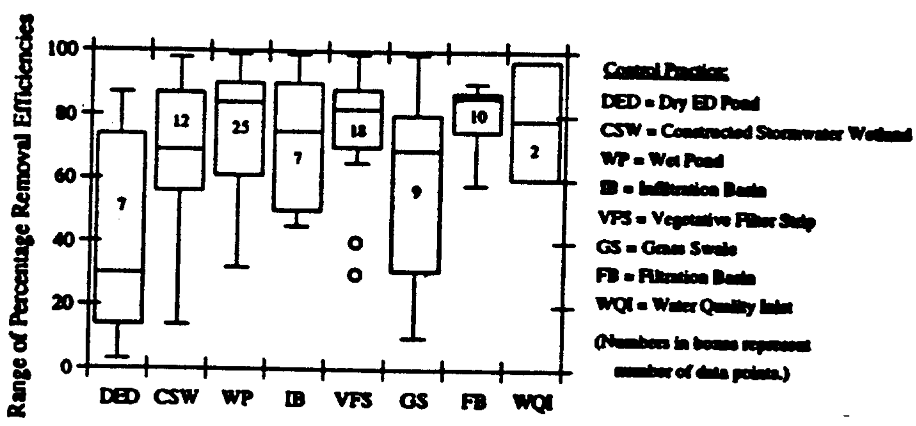

Figure 4-3. Removal efficiencies of selected urban runoff controls for TSS (adapted from Schueler et al., 1992).

Watershed Protection Management Measure

Develop a watershed protection program to:

(1) Avoid conversion, to the extent practicable, of areas that are particularly susceptible to erosion and sediment loss;

(2) Preserve areas that provide important water quality benefits and/or are necessary to maintain riparian and aquatic biota; and

(3) Site development, including roads, highways, and bridges, to protect to the extent practicable the natural integrity of waterbodies and natural drainage systems.

1. Applicability

This management measure is intended to be applied by States to new development or redevelopment including construction of new and relocated roads, highways, and bridges that generate nonpoint source pollutants. Under the Coastal Zone Act Reauthorization Amendments of 1990, States are subject to a number of requirements as they develop coastal nonpoint source programs in conformity with this management measure and will have flexibility in doing so. The application of management measures by States is described more fully in *Coastal Nonpoint Pollution Control Program: Program Development and Approval Guidance*, published by the U.S. Environmental Protection Agency (EPA) and the National Oceanic and Atmospheric Administration (NOAA) of the U.S. Department of Commerce.

2. Description

The purpose of this management measure is to reduce the generation of nonpoint source pollutants and to mitigate the impacts of urban runoff and associated pollutants that result from new development or redevelopment, including the construction of new and relocated roads, highways, and bridges. The measure is intended to provide general goals for States and local governments to use in developing comprehensive programs for guiding future development and land use activities in a manner that will prevent and mitigate the effects of nonpoint source pollution.

A watershed is a geographic region where water drains into a particular receiving waterbody. As discussed in the introduction, comprehensive planning is an effective nonstructural tool available to control nonpoint source pollution. Where possible, growth should be directed toward areas where it can be sustained with a minimal impact on the natural environment (Meeks, 1990). Poorly planned growth and development have the potential to degrade and destroy entire natural drainage systems and surface waters (Mantel et al., 1990). Defined land use designations and zoning direct development away from areas where land disturbance activities or pollutant loadings from subsequent development would severely impact surface waters. Defined land use designations and zoning also protect environmentally sensitive areas such as riparian areas, wetlands, and vegetative buffers that serve as filters and trap sediments, nutrients, and chemical pollutants. Refer to Chapter 7 for a thorough description of the benefits of wetlands and vegetative buffers.

Areas such as streamside buffers and wetlands may also have the added benefit of providing long-term pollutant removal capabilities without the comparatively high costs usually associated with structural controls. Conservation or preservation of these areas is important to water quality protection. Land acquisition programs help to preserve areas critical to maintaining surface water quality. Buffer strips along streambanks provide protection for stream ecosystems and help to stabilize the stream and prevent streambank erosion (Holler, 1989). Buffer strips protect and maintain near-stream vegetation that attenuates the release of sediment into stream channels and prevent excessive loadings. Levels of suspended solids increase at a slower rate in stream channel sections with well-developed riparian vegetation (Holler, 1989).

The availability of infrastructure specifically sewage treatment facilities, is also a factor in watershed planning. If centralized sewage treatment is not available, onsite disposal systems (OSDS) most likely will be used for sewage treatment. Because of potential ground-water and surface water contamination from OSDS, density restrictions may be needed in areas where OSDS will be used for sewage treatment. Section VI of this chapter contains a more detailed discussion of siting densities for OSDS.

3. Management Measure Selection and Effectiveness Information

This measure was selected for the following reasons:

(1) Watershed protection is a technique to provide long-term water quality benefits, and many States and local communities already use this practice. Numerous State and local governments have already legislated and implemented detailed watershed planning controls that are consistent with this management measure. For example, Oregon, New Jersey, Delaware, and Florida have passed legislation that requires county and municipal governments to adopt comprehensive plans, including requirements to direct future development away from sensitive areas. Several municipalities and regions, in addition to those in these States, have adopted land use and growth controls, including Amherst, Massachusetts, the Cape Cod region, Norwood, Massachusetts, and Narragansett, Rhode Island.

(2) Setting general water quality objectives oriented toward protection of environmentally sensitive areas and areas that provide water quality benefits allows States flexibility in the pursuit of widely differing water quality priorities and reduces potential conflicts that may arise due to existing State or local program goals and requirements. Although public comments on the May 1991 draft guidance suggested that much more specific criteria should be required, such as minimum setbacks from waterbodies, prohibitions on development on slopes in excess of 45 degrees, and bans on development in floodplains, such prescriptive measures are deemed unreasonable given the need for State and local determination of priorities and program direction.

(3) This measure is effective in producing long-term water quality benefits and lacks the high operation and maintenance costs associated with structural controls.

By protecting those areas necessary for maintaining surface water quality in a natural or near natural state, adverse impacts can be reduced. To illustrate the effectiveness of this management measure, two case studies are presented.

CASE STUDY 1 - RHODE RIVER ESTUARY, CHESAPEAKE BAY, MARYLAND

An evaluation of the impact of the Maryland Critical Area Act on nonpoint source pollution (nutrients and sediment) in surface runoff was completed by modeling three land use scenarios and determining the relative change in nonpoint loadings from the Rhode River Critical Area. Research findings suggest that the implementation of the Act will reduce nonpoint source nutrient and sediment loading by mandating agricultural and urban best management practices (BMPs) and limiting development in forested lands. Figure 4-4 illustrates the predicted nitrogen and phosphorus loadings from various land uses within the watershed under various development scenarios. These predictions are based on the assumption that no structural BMPs are in place.

New development allowed by the Critical Area Act is required to minimize impervious surfaces and reduce nonpoint source pollution through urban BMPs. Results from this study indicate that by limiting the impervious portion of a building site to 15 percent in the Rhode River Estuary, nutrient loadings could be reduced by one-third when compared to similar development without this practice (Houlihan, 1990).

CASE STUDY 2 - ALAMEDA COUNTY, CALIFORNIA

Pollutant loading estimates can be used to evaluate the effectiveness of land planning on controlling nonpoint source pollution. For example, Alameda County, California, has estimated seven pollutant loadings for seven parameters by type of land use, as shown in Table 4-9. By leaving larger areas in open space—through easements, buffers, clustering, or preserves—the potential pollutant loading to San Francisco Bay can be reduced. For example, it is estimated that if 50 percent of a 100-acre parcel designated for residential development is preserved in open space, pollutant loadings for zinc and total suspended solids can be reduced by 50.24 percent and 49.76 percent, respectively, when compared to residential development of the entire 100-acre parcel.

Table 4-9. Load Estimates for Six Land Uses in Alameda County, California (based on average wet weather load, lb/acre; adapted from Woodward-Clyde, 1991)

Land Use	Cadmium	Chromium	Copper	Lead	Nickel	Zinc	Total Suspended Solids
Open	N/A	N/A	N/A	N/A	N/A	0.002	0.75
Residential	0.002	0.036	0.088	0.134	0.037	0.424	82.16
Commercial	0.002	0.038	0.094	0.094	0.083	0.685	511.76
Transportation	0.003	0.080	0.112	0.269	0.071	0.274	883.23
Industrial	0.003	0.044	0.087	0.171	0.028		251.43
Industrial Park	0.002	0.038	0.067	0.101	0.017	0.479	148.89

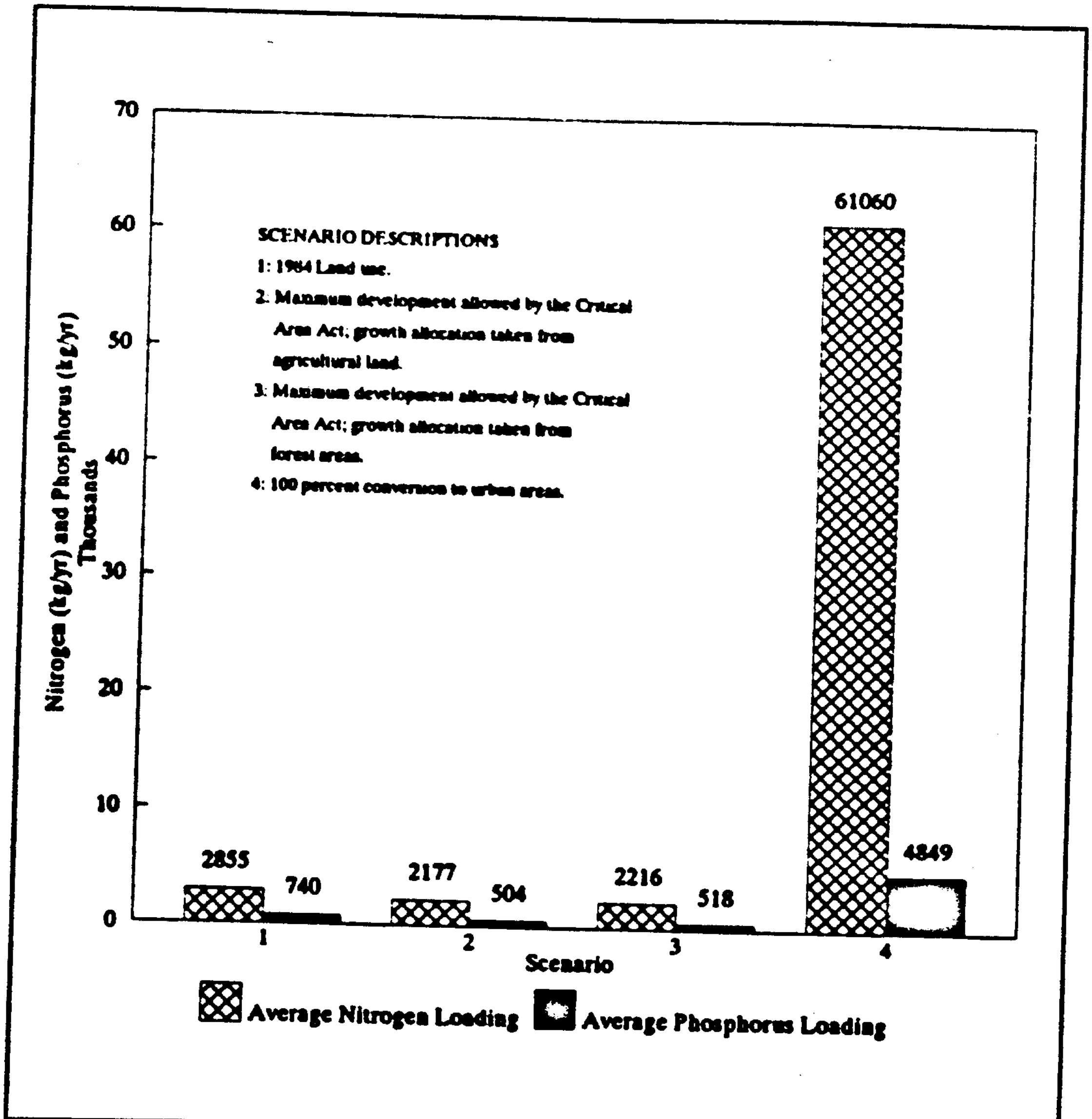

Figure 4-4. Predicted total nitrogen and phosphorus loadings in surface water after runoff from the Rhode River Critical Area under different land use scenarios (Houlihan, 1990).

Considerable uncertainty is associated with the ability to quantify load reductions from various nonstructural practices for controlling nonpoint source pollution (USEPA, 1990). Table 4-10 illustrates the general effectiveness of various planning and site design practices. Many are described in the practices section of this management measure and the Site Development Management Measure.

Table 4-10. General Effectiveness of Various Nonstructural Control Practices (Metropolitan Washington Council of Governments, 1991)

	Nutrient Control	Shellfish	Estuarine Habitat Protection	Sedimentation	Sediment Toxics	Stormwater Control	Flexibility in Coastal Areas	Maintenance Burdens	Longevity	Community Acceptance	Secondary Environmental Impacts	Cost to Developers	Cost to Local Governments	Difficulty in Local Implementation	Site Data Required	Water Dependent Use
I. COASTAL DENSITY ZONES																
Intense Zones	○	○	○	○	○	○	●	■	■	○	○	○	●	○	◉	
Rural Zones	○	●	●	●	●	●	●	■	■	○	●	◉	◉	○	◉	
Protection Zones	●	●	●	●	●	●	●	■	■	○	●	●	◉	○	○	
Overlay Zones	●	●	●	●	◉	◉	●	■	■	○	●	◉	◉	◉	○	
Performance Zoning	●	●	●	●	◉	●	●	■	■	○	◉	◉	◉	◉	○	
II. ENVIRONMENTAL RESERVES																
Stream Buffers	●	●	●	●	○	○	●	●	●	●	●	◉	●	◉	●	○
Wetland Buffers	●	○	●	●	○	○	●	●	●	●	●	○	●	◉	●	●
Coastal Buffers	●	●	●	●	○	○	●	●	●	●	●	○	◉	○	●	●
Expanded Buffers	●	●	●	●	○	○	●	●	●	●	●	◉	●	○	○	◉
Floodplain Limits	◉	○	●	○	○	●	●	●	●	◉	●	◉	●	◉	◉	○
Steep Soils Limits	○	○	●	●	○	◉	●	●	●	◉	●	◉	●	◉	●	◉
Septic Limits	◉	●	○	○	○	■	●	●	●	●	●	○	◉	○	◉	◉
Wetland Protection	◉	●	●	●	○	◉	●	●	●	●	◉	◉	◉	●	○	●
Forest Protection	○	◉	●	◉	○	○	●	●	●	●	◉	○	◉	◉	◉	●
Habitat Protection	○	○	●	○	○	○	●	●	●	●	◉	◉	◉	◉	○	◉
Open Space Protection	○	○	●	○	○	○	●	●	●	●	●	○	●	◉	◉	●
Key	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

Table 4-10 (continued)

	Nutrient Control	Shellfish	Estuarine Habitat Protection	Sedimentation	Sediment Toxics	Stormwater Control	Feasibility in Coastal Areas	Maintenance Burdens	Longevity	Community Acceptance	Secondary Environmental Impacts	Cost to Developers	Cost to Local Governments	Difficulty in Local Implementation	Site Data Required	Water Dependent Use
III. SITE PLANNING																
Cluster	○	●	○	○	○	○	●	●	●	●	●	●	●	○	◍	●
Performance Criteria	●	●	●	●	●	●	●	○	○	○	○	○	○	○	○	●
Minimize Imperviousness	○		○	○	○	●	●									
EROSION & SEDIMENT CONTROL		○														
Time/Area Disturbance	●	○	●	●	■	○	●	●	●	●	●	●	●	●	○	●
V. POST DEVELOPMENT																
Urban Housekeeping	○	●	○	●	●	■	●	●	○	●	●		●	●	●	●
Fertilizer Control	●	○	■	■	■	■	●	○	○	●	●		●	◍	◍	◍
Septic Maintenance	◍	●	○	■	■	■	●	○	●	●	◍		◍	◍	○	◍
Household Hazardous Waste	○	■	○	■	●	■	●	○	○	●	◍		●	●	○	◍
	[illegible] ●●○■	[illegible] ●●○■	[illegible] ●●○■	[illegible] ●●○■	[illegible] ●●○■	[illegible] ●●○■	[illegible] ●●○■	[illegible] ●●○■	[illegible] ●●○■	[illegible] ●●○■	[illegible] ●●○■	[illegible] ●●○■	[illegible] ●●○■	[illegible] ●●○■	[illegible] ●●○■	[illegible] ●●○■

4. Watershed Protection Practices and Cost Information

As discussed more fully at the beginning of this chapter and in Chapter 1, the following practices are described for illustrative purposes only. State programs need not require implementation of these practices. However, as a practical matter, EPA anticipates that the management measure set forth above generally will be implemented by applying one or more management practices appropriate to the source, location, and climate. The practices set forth below have been found by EPA to be representative of the types of practices that can be applied successfully to achieve the management measure described above.

The most effective way to achieve this management measure is to develop a comprehensive program that incorporates protection of surface waters with programs and plans for guiding growth and development. Planning is an orderly process, and each step builds upon preceding steps. The following practices are part of the process and can be modified to meet the needs of the community. Many of the practices can be incorporated into existing activities being carried out by a local government, such as land planning, zoning, and site plan review. Other activities, such as land acquisition programs, may have to be developed. Where cost and effectiveness information was available, it was included in the discussion of the examples. The general cost and effectiveness of planning programs are described after the practices.

a. *Resource Inventory and Information Analysis*

Before a comprehensive program can be developed, define the watershed boundaries, target areas, and pollutants of concern, and conduct resource inventory and information analysis. These activities can be done by using best available information or collecting primary data, depending on funding availability and the quality of available data. Activities pursued under this process include: assessment of ground-water and surface water hydrology; evaluation of soil type and ground cover; identification of areas with water quality impairments; and identification of environmentally sensitive areas, such as steep or erodible uplands, wetlands, riparian areas, floodplains, aquifer recharge areas, drainage ways, and unique geologic formations. Once environmentally sensitive areas are identified, areas that are integral to the protection of surface waters and the prevention of nonpoint source pollution can be protected.

The following are examples of resource inventory and information analysis programs:

LOCATION	PROGRAM	COST
City of Virginia Beach, Virginia	Three-phase natural areas inventory to help planners and public officials develop practices for resource protection	Phase I (data collection) $13,867; Phase II (field inventory) $54,624; and Phase III (final report) $15,225 (Jenkins, 1991).
Richmond County, Virginia	The Richmond County Resource Information System (RIS) was developed to provide a basis for responsible planning and development of shoreline areas. The compilation and mapping of resource information are part of the county's planning and zoning program.	In 1990, the program was supported by a $39,000 Federal Coastal Zone Management Grant, $45,000 from the Chesapeake Bay Foundation through a Virginia Environmental Endowment Grant, and $96,000 from the county's comprehensive plan budget (Jenkins, 1991).

b. *Development of Watershed Management Plan*

The resource inventory and information analysis component provides the basis for a watershed management plan. A watershed management plan is a comprehensive approach to addressing the needs of a watershed, including land use, urban runoff control practices, pollutant reduction strategies, and pollution prevention techniques.

For a watershed management plan to be effective, it should have measurable goals describing desired outcomes and methods for achieving the goals. Goals, such as reducing pollutant loads to surface water by 25 percent, can be articulated in a watershed management plan. Development and implementation of urban runoff practices, both structural and nonstructural, can be incorporated as methods for achieving the goal. Table 4-11 describes the general steps for developing a watershed management plan.

Table 4-11. Watershed Management: A Step-by-Step Guide (Livingston and McCarron, 1992)

1. **Delineate and map watershed boundary and sub-basins within the watershed.**

2. **Inventory and map natural storm water conveyance and storage systems.**

3. **Inventory and map man-made storm water conveyance and storage system.**
   This includes all ditches, swales, storm sewers, detention ponds, and retention areas and includes information such as size, storage capacity, and age.

4. **Inventory and map land use by sub-basin.**

5. **Inventory and map detailed soils by sub-basin.**

6. **Establish a clear understanding of water resources in the watershed.**
   Analyze water quality, sediment, and biological data. Analyze subjective information on problems (such as citizen complaints). Evaluate waterbody use impairment–frequency, timing, seasonality of problem. Conduct water quantity assessment–low flows, seasonality.

7. **Inventory pollution sources in the watershed.**
   Point sources—location, pollutants, loadings, flow, capacity, etc. Nonpoint sources—type, location, pollutants, loading, etc.
   - land use/loading rate analysis for storm water;
   - sanitary survey for septic tanks;
   - dry flow monitoring to locate illicit discharges

8. **Identify and map future land use by sub-basin.**
   Conduct land use loading rate analyses to assess potential effects of various land use scenarios.

9. **Identify planned infrastructure improvements—5-year, 20-year.**
   Stormwater management deficiencies should be coordinated and scheduled with other infrastructure or development projects.

10. **Analysis.**
    Determine infrastructure and natural resources management needs within each watershed.

11. **Set resource management goals and objectives.**
    Before corrective actions can be taken, a resource management target must be set. The target can be defined in terms of water quality standards; attainment and preservation of beneficial uses; or other local resource management objectives.

12. **Determine pollutant reduction (for existing and future land uses) needed to achieve water quality goals.**

13. **Select appropriate management practices (point source, nonpoint source) that can be used to achieve the goal.**
    Evaluate pollutant removal effectiveness, land owner acceptance, financial incentives and costs, availability of land operation and maintenance needs, feasibility, and availability of technical assistance.

14. **Develop watershed management Plan.**
    Since the problems in each watershed will be unique, each watershed management plan will be specific. However, all watershed plans will include elements such as:
    - existing and future land use plan;
    - master storm water management plan that addresses existing and future needs;
    - wastewater management plan including septic tank maintenance programs;
    - infrastructure and capital improvements plan

Development of a watershed management plan may involve establishing general land use designations that define allowable activities on a parcel of land. For example, land designated for low-density residential use would be limited to a density of two houses per acre, provided that all other regulations and requirements are met. All development activities allowed in a use category should be defined. By guiding uses within the planning areas, impacts to surface waters from urban runoff can be controlled. Those areas identified in the resource inventory and information analysis phase as environmentally sensitive and important to maintaining water quality can be preserved through various measures supported by State or local goals, objectives, and policies.

The following are examples of plan development:

LOCATION	PROGRAM	COST
Florida	• Local governments (counties and incorporated municipalities) were required to develop comprehensive plans based on existing information to guide growth and development in the short term (5 years) and long term (20 to 25 years). • Local plans must be consistent with the State plan and the State Growth Management law. • Each plan must identify environmentally sensitive areas and areas with water quality problems.	Cost information specific to those parts of the plans relating to NPS pollution was not available.
Fairfax County, Virginia	• The Environmental Quality Corridor (EQC) System was established to preserve floodplains, wetlands, shoreline areas, and steep valley slopes. • EQCs are defined in the county's comprehensive plan and identified on the county land use map. • If a parcel of land subject to a zoning or land use designation change contains an EQC, it is set aside by the developer as part of development approval. Since its initiation, tens of thousands of acres have been set aside through the EQC program.	The cost of implementing the program is part of the operating budget of the County Planning Department (Fairfax County Planning Department, personal communication, 1991).
Howard County, Maryland	• A Land Preservation and Recreation Plan was developed as part of the county comprehensive plan. • Open space resources are purchased for preservation and recreation.	The annual cost to update the plan, $25,000, is funded by the State. In FY 1990, the county received $1.14 million in State funds to update the plan and to acquire land (Jenkins, 1991).

c. Plan Implementation

Once critical areas have been identified, land use designations have been defined, and goals have been established to guide activities in the watershed, implementation strategies can be developed. At this point, the requirements of future development are defined. These requirements include, but are not limited to, permitted uses, construction techniques, and protective maintenance measures. Land development regulations may also prescribe natural performance standards; for example, "rates of runoff or soil loss should be no greater than predevelopment

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conditions" (USEPA, 1977). Listed below are examples of the types of development regulations and other implementation tools that have been successful at controlling nonpoint source pollution.

- *Development of ordinances or regulations requiring NPS pollution controls for new development and redevelopment.*

  These ordinances or regulations should address, at a minimum:

  (1) Control of off-site urban runoff discharges (to control potential impacts of flooding);

  (2) The use of source control BMPs and treatment BMPs;

  (3) The performance expectations of BMPs, specifying design storm size, frequency, and minimum removal effectiveness, as specified by the State or local government;

  (4) The protection of stream channels, natural drainage ways, and wetlands;

  (5) Erosion and sediment control requirements for new construction and redevelopment; and

  (6) Treatment BMP operation and maintenance requirements and designation of responsible parties.

- *Infrastructure planning*

  Infrastructure planning is the multiyear scheduling and implementation of public physical improvements (infrastructure), such as roads, sewers, potable water delivery, landfills, public transportation, and urban runoff management facilities. Infrastructure planning can be an effective practice to help guide development patterns away from areas that provide water quality benefits, are susceptible to erosion, or are sensitive to disturbance or pollutant loadings. Where possible, long-term comprehensive plans to prevent the conversion of these areas to more intensive land uses should be drafted and adopted. Infrastructure should be planned for and sited in areas that have the capacity to sustain environmentally sound development. Development tends to occur in response to infrastructure availability, both existing and planned. New development should be targeted for areas that have adequate infrastructure to support growth in order to promote infill development, prevent urban sprawl, and discourage the use of septic tanks where they are inappropriate (International City Management Association, 1979). Infill development may have the added advantage of municipal cost savings.

  To discourage development in the environmentally sensitive East Everglades area, Dade County, Florida, has developed an urban services boundary (USB). In areas outside the USB, the county will not provide infrastructure and has kept land use densities very low. This strategy was selected to prevent urban sprawl, protect the Everglades wetlands (outside of Everglades National Park), and minimize the costs of providing services countywide. The area is defined in the county comprehensive plan, and restrictions have been implemented through the land development regulations (Metro-Dade Comprehensive Development Master Plan, 1988).

  Congress has enacted similar legislation for the protection of coastal barrier islands. In 1981, the availability of Federal flood insurance for new construction on barrier islands was discontinued. In 1982, Congress passed the Coastal Barriers Resources Act, establishing the Coastal Barrier Resource System (CBRS), and terminated a variety of Federal assistance programs for designated coastal barriers, including grants for new water, sewage, and transportation systems. In 1988, similar legislation was passed for the Great Lakes area, adding 112 Great Lakes barrier islands. Additions to the CBRS in 1990 included parts of the Florida Keys, the U.S. Virgin Islands, Puerto Rico, and the Great Lakes (Simmons, 1991).

The result of the legislation and subsequent additions to the CBRS has been the establishment of 1,394,059 acres of barriers that are ineligible for Federal assistance for infrastructure and flood insurance (Simmons, 1991). This Act has helped to guide development away from these sensitive coastal areas to more suitable locations.

- *Local ordinances*

Zoning is the division of a municipality or county into districts for the purpose of regulating land use. Usually defined on a map, the allowable uses within each zone are described in an official document, such as a zoning ordinance. Zoning is enacted for a variety of reasons, including preservation of environmentally sensitive areas and areas necessary to maintain the environmental integrity of an area (International City Management Association, 1979).

Within zoning ordinances, subdivision regulations govern the process by which individual lots of land are created out of larger tracts. Subdivision regulations are intended to ensure that subdivisions are appropriately related to their surroundings. General site design standards, such as preservation of environmentally sensitive areas, are one example of subdivision regulations (International City Management Association, 1979).

Farmland preservation ordinances are another measure that can be implemented to provide open space retention, habitat protection, and watershed protection. Farmland protection may be a less costly means of controlling pollutant loadings than the implementation of urban runoff structural control practices. Much of the farmland currently being converted has soils that are stable and not highly erodible. Conversion of these farmlands often displaces farming activities to less productive, more erodible areas that may require increased nutrient and pesticide applications.

- *Limits on impervious surfaces, encouragement of open space, and promotion of cluster development*

As described earlier, urban runoff contains high concentrations of pollutants washed off impervious surfaces (roadways, parking lots, loading docks, etc.). By retaining the greatest area of pervious surface and maximizing open space, nonpoint source pollution due to runoff from impervious surfaces can be kept to a minimum.

The following are examples of open space requirements and cluster development:

LOCATION	PROGRAM	COST
Brunswick, Maine	• Recently adopted an allowable impervious area threshold of 5 percent of the site to be developed in the defined Coastal Protection Zone. • The remaining 95 percent must be left natural or landscaped.	Accomplished with a $28,000 grant (Brunswick Planning Department, personal communication, 1991).
Commonwealth of Virginia	• Provides general guidance with regard to minimum open space/maximum impervious areas to local governments within the Chesapeake Bay watershed. • While specific requirements are not associated with the guidance, local government plans must contain criteria and must be approved by the Chesapeake Bay Local Assistance Board.	Cost information specific to those parts of the guidance relating to NPS pollution was not available.

LOCATION	PROGRAM	COST
Carroll County, Maryland	• Amended its zoning ordinance to encourage cluster development and preserve open space. • This requirement has been applied to three subdivisions in the county and has resulted in the protection of more than 200 acres of wetlands (Carroll County Planning Department, personal communication, 1991).	Developed using existing county staff and funding.
State of Maryland	• Adopted the Forest Conservation Act of 1991. • Requires all public agency and private landowner submitting a subdivision plan or application for a sediment control permit for an area greater than 40,000 square feet to develop a forest conservation plan for retention of existing forest cover on the site. • Clearing essential to site development is allowed. • The Act also established a forest conservation fund for reforestation projects.	Not available.
Broward County, Florida	• Implements an open space program and encourages cluster development to reduce the amount of impervious surface, to protect water quality, and to enhance aquifer recharge (Broward County, Florida, Land Development Code, 1990).	Developed using existing county staff and funding.
New Hampshire	• Model shoreland protection ordinance. • Encourages grouping of residential units provided a minimum of 50 percent of the total parcel remains as open space.	Not available.

One way to increase open space while allowing reasonable development of land is to encourage cluster development. Clustering entails decreasing the allowable lot size while maintaining the number of allowable units on a site. Such policies provide planners the flexibility to site buildings on more suitable areas of the property and leave environmentally sensitive areas undeveloped. Criteria can be varied.

- *Setback (buffer zone) standards*

In coastal areas, setbacks or buffer zones adjacent to surface waterbodies, such as rivers, estuaries, or wetlands, provide a transition between upland development and waterbodies. The use of setbacks or buffer zones may prevent direct flow of urban runoff from impervious areas into adjoining surface waters and provide pollutant removal, sediment attenuation, and infiltration. Riparian forest buffers function as filters to remove sediment and attached pollutants, as transformers that alter the chemical composition of compounds, as sinks that store nutrients for an extended period of time, and as a source of energy for aquatic life (USEPA, 1992). Setbacks or buffer zones are commonly used to protect coastal vegetation and wildlife corridors, reduce exposure to flood hazards, and protect surface waters by reducing and cleansing urban runoff (Mantell et al., 1990). The types of development allowed in these areas are usually limited to nonhabitable structures and those necessary to allow reasonable use of the property (docks, nonenclosed gazebos, etc.).

Factors for delineating setbacks and buffer zones vary with location and environment and include seasonal water levels, the nature and extent of wetlands and floodplains, the steepness of adjacent topography, the type of riparian vegetation, and wildlife values.

EPA recommends that no habitat-disturbing activities should occur within tidal or nontidal wetlands. In addition, a buffer area should be established that is adequate to protect the identified wetland values. Minimum widths for buffers should be 50 feet for low-order headwater streams with expansion to as much as 200 feet or more for larger streams. In coastal areas, a 100-foot minimum buffer of natural vegetation landward from the mean high tide line helps to remove or reduce sediment, nutrients, and toxic substances entering surface waters (MWCOG, 1991).

Examples of setback or buffer requirements include the following:

LOCATION	PROGRAM	COST
Monroe County, Florida	• Requires a setback of 20 feet from high water on man-made or lawfully altered shorelines for all enclosed structures and 50 feet from the landward extent of mangroves or mean high tide line for natural waterbodies with unaltered shorelines (Monroe County, Florida, Code, Section 9.5-286).	Developed using existing county staff and funding.
Town of Brunswick, Maine	• Requires a buffer of 125 to 300 feet from mean high water within the Coastal Protection Zone (Section 315 of the Brunswick Zoning Ordinance), depending on the slope of the buffer, as designated on the land use map.	Developed using a $28,000 grant (Brunswick Planning Department, personal communication, 1991).
Queen Annes County, Maryland	• Established a standard shore buffer of 300 feet from the edge of tidal water or wetland, 50 percent of which must be forested.	Developed using existing county staff and funding; a bond of surety to cover the cost of implementation is required prior to development (Jenkins, 1991).
Maryland Critical Areas Regulations	• Requires a 25-foot buffer around nontidal wetlands and 100 feet landward of mean high water in tidal areas. • Allowable uses within the setback area are defined in the regulations (Chesapeake Bay Critical Areas Commission, 1988).	Developed as part of the Chesapeake Bay Critical Areas program.
City of Alexandria, Virginia	• Buffers are required as part of the city's Chesapeake Bay Preservation Ordinance. • Applies to all designated Resource Protection Areas (RPAs). • The buffer must achieve 75 percent reduction of sediments and 40 percent reduction of nutrients (100-foot-wide buffer is considered adequate to achieve this standard; smaller widths may be allowed if they are proven to meet the sediment and nutrient removal requirements). • Indigenous vegetation removal is limited to that necessary to provide reasonable sight lines, access paths, general woodlot management, and BMP implementation.	Not available.

LOCATION	PROGRAM	COST
Northeastern Illinois Planning Commission	• Model ordinance • Suggests 75-foot setback from the ordinary high watermark of streams, lakes, ponds, and edge of wetlands or the boundary of the 100-year floodplain (as defined by FEMA), whichever is greater. • Suggests a minimum 25-foot-wide natural vegetation strip from the ordinary highwater mark of perennial and intermittent streams, lakes, ponds, and the edge of wetlands.	Not available

- ***Slope restrictions***

Slope restrictions can be effective tools to control erosion and sediment transport. Erosion rates depend on several site-specific factors including soil type, vegetative cover, and rainfall intensity. In general, as slope increases, there is a corresponding increase in runoff water velocity, which may result in increased erosion and sediment transport to surface waters (Schwab et al., 1981; Dunn and Leopold, 1978). The Maryland Chesapeake Bay Critical Areas Program prohibits clearing on slopes greater than 25 percent (Chesapeake Bay Critical Areas Commission, 1988).

- ***Site plan reviews and approval***

A site plan review involves review of specific development proposals for consistency with the laws and regulations of the local government of jurisdiction. To ensure that natural resources necessary for protecting surface water quality are preserved, inspection of a potential development site should occur. Inspection ensures that the information presented in any application for development approval is accurate and that sensitive areas are noted for preservation. Inspections should also be conducted during and after development to ensure compliance with development conditions. Depending on the size of the local government and the amount of new development occurring, this inspection could be incorporated into the duties of existing staff at minimal additional cost to the local government or could require the addition of staff to conduct onsite inspections and monitoring. The effectiveness of such a program depends on the ability of the inspectors to evaluate property for its natural resource value and the practices used to protect areas necessary for the preservation of water quality.

Development approvals should contain conditions requiring steps to be taken to maintain the environmental integrity of the area and prevent degradation due to nonpoint source pollution, consistent with the goals, objectives, and policies of the comprehensive program and the requirements of the land development regulations. The criteria for new development are outlined as part of a development permit. Examples include the following:

- Areas for preservation or mitigation may be identified, similar to the Fairfax County Environmental Quality Corridor System (page 44).

- The use of nonstructural and structural best management practices described in this chapter for controlling nonpoint source pollution may be a condition of development approval.

- Setbacks and limits on impervious areas may be clearly defined in a condition for development approval, as is being done in the programs discussed earlier such as Monroe County, Florida, Queen Annes County, Maryland, State of Maryland Critical Areas Program, Town of Brunswick, Maine, and the Northeastern Illinois Planning Commission (pages 48 and 49).

- Reduce the use of pesticides and fertilizers on landscaped areas by encouraging the use of vegetation that is adaptable to the environment and requires minimal maintenance. (Xeriscaping is described later in this chapter.)

- *Designation of an entity or individual who is responsible for maintaining the infrastructure, including the urban runoff management systems*

  The responsible party should be trained in the maintenance and management of urban runoff management systems. If desired, the local government could be designated to maintain urban runoff systems, with financial compensation from the developer. Because they are not usually trained in infrastructure maintenance, homeowners groups are not the best entity for monitoring infrastructure for adequacy, especially urban runoff management systems. This responsibility should belong to a responsible party who understands the complexity of urban runoff management systems, can determine when such systems are not functioning properly, and has the resources to correct the problem. Again, this is a duty that the local government can assume, with either existing staff or additional staff, depending on the size of the local government and the amount of new development occurring. The amount of funding needed depends on the size of the local government.

- *Official mapping*

  Official maps can be used to designate and/or protect environmentally sensitive areas, zoning districts, identified land uses, or other areas that provide water quality benefits. When approved by the local governing body, these maps can be used as legal instruments to make land use decisions related to nonpoint source pollution.

- *Environmental impact assessment statements*

  To evaluate the impact that proposed development may have on the natural resources of an area, some counties and municipalities require an environmental assessment as part of the development approval processes. These assessments can be incorporated into the land development regulation process. Areas to be covered include geology, slopes, vegetation, historical features, wildlife, and infrastructure needs (International City Management Association, 1979).

d. Cost of Planning Programs

Cost information was provided for several of the practices discussed in this section. The cost of planning programs depends on a variety of factors, including the level of effort needed to complete and implement a program. As discussed earlier, many of the practices described in this section can be incorporated into ongoing activities of a State or local government.

The Florida legislature funded the development of comprehensive programs and land development regulations required by the Local Government Comprehensive Planning and Land Development Regulation Act (1985). Distribution of funds was based on population according to formulas used for determining funding for the plan and land development regulations. A base amount was given to all counties that requested it. The balance of the monies was allocated to each county in an amount proportionate to its share of the total unincorporated population of all the counties. A similar distribution process was used for local governments. A total of $2.1 million was allocated for plan development; however, not all components of the plans address NPS issues.

The effect of planning programs depends on many variables, including implementation of programs and monitoring of conformance with conditions of development approval.

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5. Land or Development Rights Acquisition Practices and Cost Information

As discussed more fully at the beginning of this chapter and in Chapter 1, the following practices are described for illustrative purposes only. State programs need not require implementation of these practices. However, as a practical matter, EPA anticipates that the management measure set forth above generally will be implemented by applying one or more management practices appropriate to the source, location, and climate. The practices set forth below have been found by EPA to be representative of the types of practices that can be applied successfully to achieve the management measure described above.

An effective way to preserve land necessary for protecting the environmental integrity of an area is to acquire it outright or to limit development rights. The following practices can be used to protect beneficial uses.

■ a. *Fee Simple Acquisition/Conservation Easements*

The most direct way to protect land for preservation purposes and associated nonpoint source control functions is fee simple acquisition, through either purchase or donation. Once a suitable area is identified for preservation, the area may be acquired along with the development rights. The more development rights that are associated with a piece of property, the more expensive the property. Many State and local governments and private organizations have programs for purchasing land.

Conservation easements are restrictions put on property that legally restrict the present and future use of the land. For preservation purposes, the easement holder is usually not the owner of the property and is able to control property rights that a landowner could use that might cause adverse impacts to resources on the property. In effect, the property owner gives up development rights within the easement while retaining fee ownership of the property (Mantell et al., 1990; Barrett and Livermore, 1983).

■ b. *Transfer of Development Rights*

The principle of transfer of development rights (TDR) is based on the concept that ownership of real property includes the ownership of a bundle of rights that goes with it. These rights may include densities granted by a certain use designation, environmental permits, zoning approvals, and others. Certain properties have a bigger bundle of rights than others, depending on what approvals have been received by the owner. The TDR system takes all or some of the rights on one piece of property and moves them to another parcel. The purpose of TDRs is to shift future development potential from an area that is determined to be unsuitable for development (sending site) to an area deemed more suitable (receiving site). The development potential can be measured in a variety of ways, including number of dwelling units, square footage, acres, or number of parking spaces. Most TDR systems require a legal restriction for future development on the sending site. TDR programs can be either fixed so that there are only a certain number of sending and receiving sites in an area or flexible so that a sender and receiver can be matched as the situation allows (Mantell et al., 1990; Barrett and Livermore, 1983).

This system is useful for the preservation of those areas thought necessary for maintaining the quality of surface waters in that development rights associated with the environmentally sensitive areas can be transferred to less sensitive areas. There are several examples in the United States where TDRs have been used. Some of the more successful projects involve preservation of the New Jersey Pine Barrens and the Santa Monica Mountains in California. For the TDR concept to work, receiving and sending sites should be identified and evaluated, a program that is simple and flexible should be developed, and the use of the program should be promoted and facilitated (Mantell et al., 1990).

■ c. *Purchase of Development Rights*

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In this process, the rights of development are purchased while the remaining rights remain with the fee title holder. Restrictions in the deed make it clear that the land cannot be developed based on the rights that have been purchased (Mantell et al., 1990).

Howard County, Maryland, has the goal of preserving 20,000 acres of farmland. Development rights are acquired in perpetuity with one-fourth of one percent of the local land transfer tax used as funding. There is no cap on the percent of assessed value that may be considered development value, and payment for development rights may be spread over 30 years to ease the capital gains tax burden on the landowner (Jenkins, 1991).

d. Land Trusts

Land trusts may be established as publicly or privately sponsored nonprofit organizations with the goal of holding lands or conservation easements for the protection of habitat, water quality, recreation, or scenic value or for agricultural preservation. A land trust may also preacquire properties that are conservation priorities if the land trust enters the development market when government funds are not immediately available by acquiring bank funding with the government as guarantor (Jenkins, 1991).

e. Agricultural and Forest Districts

Agricultural or forest districting is an alternative to acquisition of land or development rights. Jurisdictions may choose to allow landowners to apply for designation of land as an Agricultural or Forest District. Tax benefits are received in exchange for a commitment to maintain the land in agriculture, forest, or open space.

Fairfax County, Virginia, taxes land designated as Agricultural or Forest District based on the present use valuation rather than the usual potential use valuation. A commitment to agricultural or forestry activities must be shown, and sound land management practices must be used. The districts are established and renewed for 8-year periods (Jenkins, 1991).

f. Cost and Effectiveness of Land Acquisition Programs

The cost associated with land acquisition programs varies, depending on the desired outcome. If land is to be purchased, the cost will vary depending on the value of the land. An additional cost to be considered is the maintenance of the property once it is in public ownership. Easements and development rights are less expensive, and maintenance of the property is retained by the owner. Depending on the size of the local government, implementation of these programs is usually part of the operating budget of the appropriate agency (planning department or parks and recreation department, for example) and additional operational funding for implementation is dependent on the size of the local government.

The effectiveness of a land acquisition program is determined by the size of the parcel and the difference between predevelopment and potential postdevelopment pollutant loading rates. In addition, wetlands and riparian areas have been shown to reduce pollutant loadings. The acquisition and preservation of these areas can be extremely important to water quality protection and decrease the cost of implementing structural BMPs. However, the use of wetlands for urban runoff treatment, in general, should be discouraged. Where no other alternative exists, States and local governments can target upland areas for acquisition to minimize the impacts to wetlands and preserve the function of wetlands. One option for acquiring land is a public/private partnership. Several examples of such partnerships exist throughout the country. Harford County, Maryland, has targeted areas for purchase of conservation easements. The county staff is working jointly with a local land trust to acquire conservation easements and to educate people in environmentally sound land use practices. The estimated cost for the program is $60,000 per year (Jenkins, 1991). To aid in the establishment of two local land trusts, Anne Arundel County, Maryland, provided $350,000 in seed money for capital expenditures such as land and easement procurement. The county also gives staff assistance to volunteers; additional support comes from contributions of money or land, grants, and fundraisers (Jenkins 1991).

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C. Site Development Management Measure

Plan, design, and develop sites to:

(1) Protect areas that provide important water quality benefits and/or are particularly susceptible to erosion and sediment loss;

(2) Limit increases of impervious areas, except where necessary;

(3) Limit land disturbance activities such as clearing and grading, and cut and fill to reduce erosion and sediment loss; and

(4) Limit disturbance of natural drainage features and vegetation.

1. Applicability

This management measure is intended to be applied by States to all site development activities including those associated with roads, highways, and bridges. Under the Coastal Zone Act Reauthorization Amendments of 1990, States are subject to a number of requirements as they develop coastal NPS programs in conformity with this management measure and will have flexibility in doing so. The application of management measures by States is described more fully in *Coastal Nonpoint Pollution Control Program: Program Development and Approval Guidance*, published jointly by the U.S. Environmental Protection Agency (EPA) and the National Oceanic and Atmospheric Administration (NOAA) of the U.S. Department of Commerce.

2. Description

The goal of this management measure is to reduce the generation of nonpoint source pollution and to mitigate the impacts of urban runoff and associated pollutants from all site development, including activities associated with roads, highways, and bridges. Management Measure II.C is intended to provide guidance for controlling nonpoint source pollution through the proper design and development of individual sites. This management measures differs from Management Measure II.A, which applies to postdevelopment runoff, in that Management Measure II.C is intended to provide controls and policies that are to be applied during the site planning and review process. These controls and policies are necessary to ensure that development occurs so that nonpoint source concerns are incorporated during the site selection and the project design and review phases. While the goals of the Watershed Protection Management Measure (II.B) are similar, Management Measure II.C is intended to apply to individual sites rather than watershed basins or regional drainage basins. The goals of both the Site Development and Watershed Protection Management Measures are, however, intended to be complementary and the measures should be used within a comprehensive framework to reduce nonpoint source pollution.

Programs designed to control nonpoint source pollution resulting from site development, both during and after construction, should be developed to include provisions for:

- Site plan review and conditioned approval to ensure that the integrity of environmentally sensitive areas and areas necessary for maintaining surface water quality will not be lost;

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- Requirements for erosion and sediment control plan review and approval prior to issuance of appropriate development permits; and
- Guidance on appropriate pollution prevention practices to be incorporated into site development and use.

In addition to the preceding provisions, where applicable, the following objectives should be incorporated into the site development process:

- During site development, disturb the smallest area necessary to perform current activities to reduce erosion and offsite transport of sediment;
- Avoid disturbance of unstable soils or soils particularly susceptible to erosion and sediment loss, and favor sites where development will minimize erosion and sediment loss;
- Where appropriate, protect and retain indigenous vegetation to decrease concentrated flows and to maintain site hydrology;
- Minimize, to the extent practicable, the percentage of impervious area on-site;
- Properly manage all maintained landscapes to avoid water quality impacts;
- Avoid alteration, modification, or destruction of natural drainage features on-site; and
- Design sites so that natural buffers adjacent to coastal waterbodies and their tributaries are preserved.

The use of site planning and evaluation can significantly reduce the cost of providing structural controls to retain sediment on the development site. Long-term maintenance burdens may also be reduced. Good site planning not only can attenuate runoff from development, but also can improve the effectiveness of the conveyance and treatment components of an urban runoff management system (MWCOG, 1991).

During the site design process, planners should further identify sensitive areas and land forms that may provide water quality protection. These areas should be targeted for preservation or conservation and incorporated into site design. Highly erodible soils should be avoided. By siting development away from erodible soils, it is possible to significantly reduce the amount of erosion, although soil type, topography, vegetation, and climatological conditions affect the degree of erosion resulting from land disturbance activities both during and after construction. In the United States, it has been estimated that human activity causes the transport of nearly 4 billion tons of sediment annually, one-fourth of which eventually reaches the ocean. Sediment loads from developing areas where new construction is occurring can be 5 to 500 times greater than loadings from undeveloped rural areas (Gray, 1972). Natural erosion rates from forested areas or well-sodded prairies are in the range of 0.1 to 1.0 ton of soil per acre per year (Washington Department of Ecology, 1989). Because many nonpoint source pollutants, including heavy metals and nutrients, adsorb to sediments, it is important to limit the volume of sediment leaving a site and entering surface waters.

The Maryland State Highway Administration has developed initiatives to protect sensitive habitats as part of the governor's program to clean up and preserve the Chesapeake Bay. A selection of these initiatives include the following:

- Use of turbidity curtains to protect sensitive sections of a waterway during construction;
- Inspection and maintenance of runoff controls after every storm event;
- Immediate notification of noncompliance and follow-up inspection, when noncompliance occurs;

- A 72-hour stabilization requirement;
- Oversizing of sediment traps and basins depending on right-of-way constraints;
- Innovative scheduling for paving versus vegetative stabilization and implementation of infiltration practices to reduce thermal impacts;
- Minimal clearing of forest areas; and
- Installation of traps and basins prior to grading (Maryland State Highway Administration, 1990).

3. Management Measure Selection

This management measure was selected because the components of the measure have already been implemented, to varying degrees, by State and local governments. For example, the States of California, Maryland, Delaware, and Florida and the local governments of Montgomery, Prince Georges, and Anne Arundel counties in Maryland have implemented these concepts in State or local ordinances and in erosion and sediment control regulations. This measure is intended to provide States and local governments with general guidance on nonpoint source pollution objectives that can be integrated into the site planning process. The components of the management measure were selected to represent the minimum provisions that State and local governments must implement.

This approach was adopted to use existing programs and staff, thereby reducing administrative burdens and implementation costs as much as possible. A significant number of local governments have programs to oversee and review the site development process. In many communities, the costs of implementing this measure within the scope of existing programs may be nominal.

4. Practices and Cost Information for Control of Erosion During Site Development

As discussed more fully at the beginning of this chapter and in Chapter 1, the following practices are described for illustrative purposes only. State programs need not require implementation of these practices. However, as a practical matter, EPA anticipates that the management measure set forth above generally will be implemented by applying one or more management practices appropriate to the source, location, and climate. The practices set forth below have been found by EPA to be representative of the types of practices that can be applied successfully to achieve the management measure described above.

a. *Erosion and Sediment Control Plans and Programs*

Structural control measures for reducing impacts from erosion during site construction are discussed in the Construction Management Measure. These practices can be implemented as part of plans established in erosion and sediment control ordinances by local government or State laws. A well-thought-out plan for urban runoff management on construction sites can control erosion, retain sediments on the site, and reduce the environmental effects of runoff. In addition to a plan for BMP use, contractors should develop schedules that minimize the area of exposed soil at any given time, particularly during times of heavy or frequent rains. Table 4-12 lists items that should be considered in an erosion and sediment control (ESC) plan. Table 4-13 contains examples of sediment and erosion control requirements implemented at the State and local levels. All temporary erosion and sediment control practices that will be used during the construction phase should be detailed in architectural or engineering drawings to ensure that they are properly implemented. Inclusion of temporary pollution control practices on construction drawings also ensures that their costs are included in the pricing and bidding process (USEPA, 1973).

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Table 4-12. Items to Consider in Developing an Erosion and Sediment Control Plan (Adapted from Goldman, 1986)

Item	Description
Schedule grading and construction to minimize soil exposure.	• Schedule projects so clearing and grading are done during the dry season or the time of minimum erosion potential. Many parts of the country have a time of year when erosion potential is relatively low and carefully planned construction scheduling could be very effective. • Stage construction so that one area can be stabilized before another is disturbed. This practice reduces the time that an area is left unstabilized.
Retain existing vegetation wherever feasible.	• Clear only those areas that are essential for completing site construction. • Avoid disturbing vegetation on steep slopes or other critical areas and locate material stockpiles, borrow areas, and access roads away from critical areas. • Route construction traffic to avoid existing or newly planted vegetation. • Physically mark off limits of land disturbance with tape, signs, or barriers. This ensures that the bulldozer operator knows the proposed limits of clearing. • Protect natural vegetation with fencing, tree armoring, retaining walls, or tree walls.
Stabilize all denuded areas within 15 calendar days after final grading. Disturbed areas that are inactive and will be exposed to rain for 30 days or more should also be temporarily stabilized.	• During favorable seeding dates and in areas where vegetation can be established, the following should be implemented: - Use seeding and fertilizing in very flat, nonsensitive areas with favorable soils. - Use seeding and mulching for less erosive soil or on moderately steep slopes with moderately erosive soils in relatively sensitive areas. - Use seeding with multiple mulching treatments or sodding for highly erosive soil, very steep slopes, or sensitive areas with highly erosive soils. • If stabilization is required during the time of year that vegetation cannot be established, implement the following practices: - On moderate slopes or soil that is not highly erodible, mulching should be employed. - On steep slopes or highly erodible soils, multiple mulching treatments should be used. • If in high elevation or desert site where grasses cannot survive due to harsh environment, at a minimum, plant native shrubs. • Before stabilizing an area, make sure necessary controls (e.g., diversion of runoff) are in place. • Where practical, stockpile topsoil and reapply to revegetate site. • Cover or stabilize topsoil stockpiles. • For high potential for wind-blown sediment transport, prior to stabilization protect with dust controls such as wind barriers, mulching, tillage, or sprinkling.
Divert runoff away from denuded areas or newly seeded slopes.	• Above disturbed areas, construct dike or swale or install pipe slope drain to intercept runoff and convey it to a permanent channel or storm drain.
Minimize length and steepness of slopes.	• On long or steep disturbed or man-made slopes, construct benches, terraces, or ditches at regular intervals to intercept runoff.

Table 4-12. (Continued)

Item	Description
Prepare drainageways and outlets to handle concentrated or increased runoff.	• Provide lining for any existing or newly constructed channel on-site or off-site so the 2-year storm channel velocity does not cause erosion. • Check dams should be installed on temporary swales that have erosive velocity but due to their short service life cannot support a vegetative lining.
Trap sediment onsite (sediment controls).	• In areas where greater than 5 acres drain to a point, sediment basin should be installed. • In areas where less than 5 acres of concentrated flow leaves the site, silt traps should be installed. • In areas where sheet flow leaves the site and the drainage area is less than 0.5 ac/100 ft of flow, filter fabric fence should be installed. • In areas where sheet flow leaves the site and the drainage area is greater than 0.5 ac/100 ft of flow, perimeter dikes should be installed and flow should be diverted to a sediment trap or sediment basin. • Install inlet protection around all storm drain inlets. • Install construction entrance (gravel pad to collect mud and sediment from wheels) and route all traffic leaving the site to the construction entrance. • Install all sediment controls prior to grading.
Inspect and maintain control measures.	• Remove sediment from sediment traps and filter fence when silted to half capacity. • Inspect and repair, as needed, all controls after each storm event.

NOTE: These are recommendations only and are not intended to be all-inclusive.

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Table 4-13. State and Local Construction Site Erosion and Sediment Control Plan Requirements

State or Local Government	General Requirements
Delaware	State law requires erosion and sediment control plans as part of site development approval on construction sites over 5,000 square feet. The State has adopted an ESC handbook. Temporary or permanent stabilization must occur within 14 calendar days of disturbance.
Florida	State law requires erosion and sediment control plans on all construction sites requiring a storm water management permit.
Maine	State law requires ESC plans for construction sitos adjacent to a wetland or waterbody. Measures should ensure that soil is stabilized to prevent erosion of shoreline and siltation of the waterbody. The ESC must prevent the wash of materials into surface waters. Sites must be stabilized at completion of construction or if there is no activity for 7 calendar days. If temporary stabilization is used, permanent stabilization must occur within 30 calendar days; if not, permanent stabilization is required upon completion of construction.
Maryland	State law requires ESC plans for all construction sites over 5,000 square feet. If there is no activity on a construction site for 14 calendar days, the site must be seeded. Permanent stabilization must occur within 7 calendar days.
Michigan	State law requires ESC plans for sites over 1 acre or within 500 feet of a waterbody. Permanent stabilization must occur within 15 calendar days of final grading. Temporary stabilization is required within 30 days if construction activity ceases.
New Jersey	State law requires ESC plans for sites over 5,000 square feet.
North Carolina	State law requires ESC plans on construction sites over 1 acre. Controls must be sufficient to retain the sediment generated by land disturbance activities. Stabilization must occur within 30 working days of completion of any phase of development.
Ohio	State law requires ESC plans for sites larger than 5 acres. Permanent stabilization must occur within 7 calendar days of final grading or when there has been no construction activity on the site for 45 days.
Pennsylvania	State law requires ESC plans for all development; however, the State reviews only plans for sites greater than 25 acres. Sites must be stabilized as soon as possible after grading. Temporary stabilization is required within 70 days if the site will be inactive for more than 30 days. Permanent stabilization is required if the site will be inactive for more than 1 year.
South Carolina	State law requires an ESC plan for all residential, commercial, industrial, or institutional land use, unless specifically exempted. Perimeter controls must be installed, and temporary or permanent stabilization is required for topsoil stockpiles and all other disturbed areas within 7 calendar days of site disturbance.
Virginia	For areas within the jurisdiction of the Chesapeake Bay Preservation Act, no more land is to be disturbed than is necessary to provide for the allowed development. Indigenous vegetation must be preserved to the greatest extent possible.
Washington	State law mandated development of a State storm water management plan, including erosion control provisions. In response, the Department of Ecology is to develop construction activity regulations.

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Table 4-13. (Continued)

State or Local Government	General Requirements
King County, WA	King County Code requires submission of a comprehensive plan in accordance with BMPs in King County Conservation District's publication, *Construction and Water Quality: A Guide to Recommended Construction Practices for the Control of Erosion and Sedimentation in King County.*
City of Bellevue, WA	A Temporary Erosion/Sedimentation Control Plan is required for any construction requiring a storm water detention facility or a Clearing and Grading Permit.
Puget Sound Basin, WA	Program Implementation Guidance requires all exposed and unworked soils to be stabilized by suitable application of BMPs. From October 1 to April 30, no soils shall remain unstabilized for more than 2 days. From May 1 to September 30, no soils shall remain unstabilized for more than 7 days. Prior to leaving the site, stormwater runoff shall pass through a sediment pond or sediment trap, or other appropriate BMPs.
Wisconsin	State law requires ESC plans for sites over 4,000 square feet. Permanent or temporary stabilization is required within 7 days.
Colleton County, SC	The county Development Standards Ordinance requires that BMPs be used during development or land-disturbing activity affecting greater than 1 acre. The State's guidelines for BMPs are adopted by reference.
Birmingham, AL	Through the city's Soil and Erosion Sediment Control Code, a clearing and earthwork permit is required for most construction sites over 10,000 square feet. The disturbed area must be stabilized as quickly as practicable.

b. *Phasing and Limiting Areas of Disturbance*

This practice reduces the potential for erosion and can be accomplished by prohibiting clearing and grading from all postdevelopment buffer zones, configuring the site plan to retain high amounts of open space, and using phased construction sequencing to limit the amount of disturbed area at any given time.

c. *Require vegetative stabilization.*

Rapid establishment of a grass or mulch cover on a cleared or graded area at construction sites can reduce suspended sediment levels to surface waters by up to sixfold. Mandatory temporary stabilization of areas left undisturbed for 7 to 14 days is recommended, unless conditions indicate otherwise. Section III.A contains detailed information regarding vegetative stabilization practices.

d. *Minimum Disturbance/Minimum Maintenance*

Minimum disturbance/minimum maintenance is an approach to site development in which clearing and site grading are allowed only within a carefully prescribed building area, preserving and protecting the existing natural vegetation. Landscapes that demand significant amounts of chemical treatment should be avoided. Minimum disturbance/minimum maintenance strategies help minimize nonpoint source impacts associated with the application of fertilizers, pesticides, and herbicides that result from new land development. The retention of existing vegetation may also help maintain predevelopment runoff volumes and peak rates of discharge and thus reduce erosion.

Translation of a concept such as minimum disturbance/minimum maintenance into straightforward numerical standards and criteria is difficult. A certain level of interpretation and judgment is often necessary. Nevertheless, basic standards can be established. Assuming that land use categories have been established through the local land use plans or zoning ordinances, vegetation mapping can be used to illustrate where the proposed development can be constructed with minimal impact on existing vegetation. The area to be disturbed should be identified for all buildings, structures, roads, walkways, and activity areas. The exact dimensions of this disturbance will be subjective and will depend on factors such as lot size and site-specific conditions. For example, a single-family residential development can be constructed with a narrower zone of disturbance than a mall or office park that may require larger construction equipment with greater maneuverability. In general, an extremely conservative zone width would be 10 feet beyond the roof line of a structure or dwelling unit; a more moderate criterion might be 25 feet. Mall sites and large residential developments are typically mass-graded. Limits of Disturbance (LOD) are usually required on all erosion and sediment control plans and are always a function of grading requirements.

Program Implementation Costs

The annual costs of establishing and implementing a minimum disturbance/minimum maintenance (MD/MM) program are estimated below. In some cases, the MD/MM tasks can be incorporated within the framework of the existing land development review process and implementation costs would only be additive. A new program, however, would need trained staff responsible for ensuring that developers properly integrate the requirements for the MD/MM into their respective site plans. The need to inspect sites during construction would also result in additional costs. The annual operating costs of implementing such a program will vary depending on the size of the community and the degree of new development. For a typical program, estimated costs may be approximately $110,000 for one professional staffperson and can be divided as follows:

Professional staff	$ 60,000
Support staff	$ 30,000
Office space	$ 15,000
Office expenses	$ 5,000
Total	$110,000 per year

These figures are based on approximate average salaries and expenses for similar programs.

The manner by which a turf management or landscape control ordinance is developed or implemented varies to some extent, county by county, State by State. The process would reflect county size, the framework of existing government agencies, techniques of governance, and numerous other factors. Costs would vary as well. These specific aspects of the program would be established by any initial studies and establishment of program requirements, as discussed above. Also, as experience is gained by the staff and the minimum disturbance/minimum maintenance concept is better understood by the development community, the need for services might be expected to decrease as the result of increased program operation efficiency.

5. Site Planning Practices

As discussed more fully at the beginning of this chapter and in Chapter 1, the following practices are described for illustrative purposes only. State programs need not require implementation of these practices. However, as a practical matter, EPA anticipates that the management measure set forth above generally will be implemented by applying one or more management practices appropriate to the source, location, and climate. The practices set forth below have been found by EPA to be representative of the types of practices that can be applied successfully to achieve the management measure described above.

a. *Clustering*

Clustering development is used to concentrate development and construction activity on a limited portion of a site, leaving the remaining portion undisturbed. This allows for the design of more effective erosion and sediment control and urban runoff management plans for the sites, as described in Section II.A. It also provides a mechanism for preserving environmentally sensitive areas and reducing road lengths and impervious parking areas.

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NOTE: A common belief is that low-density development is more environmentally sound because it results in increased open space. Minimum lot size requirements can result in suburban sprawl. Many of these areas are heavily landscaped and therefore have the potential to contribute significant loadings of nutrients and pesticides to surface waters. In many cases, clustering and infill development may be more environmentally sound strategies. They may also result in a cost savings for municipalities because clustering and infill development usually require less infrastructure, including urban runoff treatment systems. The imposition of density controls may preclude clustering. While minimum lot size requirements are useful in some instances, such as farmland preservation, zoning ordinances should not preclude the implementation of clustered development as an alternative to traditional suburban development.

b. Performance Criteria

Performance criteria for site development contain certain built-in safeguards to protect natural features. Performance criteria often apply not to individual zoning districts but to the site being regulated or protected and set fixed protection levels for specific resources that are not based on general zoning definitions.

c. Site Fingerprinting

The total amount of disturbed area within a site can be reduced by fingerprinting development. Fingerprinting places development away from environmentally sensitive areas (wetlands, steep slopes, etc.), future open spaces, tree save areas, future restoration areas, and temporary and permanent vegetative forest buffer zones. At a subdivision or lot level, ground disturbance is confined to areas where structures, roads, and rights of way will exist after construction is complete.

d. Preserving Natural Drainage Features and Natural Depressional Storage Areas

As discussed in the Watershed Protection Management Measure, natural drainage features should be preserved as development occurs. This can be done at the site planning stage as well as the watershed planning stage and is desirable because of the ability of natural drainage features to infiltrate and attenuate flows and filter pollutants. Depressional storage areas, commonly found as ponded areas in fields during the wet season or large runoff events, serve the purpose of reducing runoff volumes and trapping pollutants. These areas are usually filled and graded as a site is developed. Cluster development can be used to preserve natural drainage features and depressional storage areas and allow for incorporation of these features into a site design (Dreher and Price, 1992).

e. Minimizing Imperviousness

Through the use of various incentives, such as those found in the Maryland Chesapeake Bay Critical Areas 10 Percent Rule, a general strategy of minimizing paved areas can be implemented at the site planning level. Methods used to meet this goal include:

- Reduced sidewalk widths, especially in low-traffic neighborhoods;
- Use of permeable materials for sidewalk construction;
- Mandatory open space requirements;
- Use of porous, permeable, or gritted pavement, where appropriate;
- Reduced building setbacks, which reduces the lengths of driveways and entry walks; and
- Reduced street widths by elimination of onstreet parking (where such action does not pose a safety hazard).

f. Reducing the Hydraulic Connectivity of Impervious Surfaces

Pollutant loading from impervious surfaces may be reduced if the impervious area does not connect directly to an impervious conveyance system. This can be done in at least four ways:

- Route runoff over lawn areas to increase infiltration;

- Discourage the direct connection of downspouts to storm sewers or the discharge of downspouts to driveways or parking lots;

- Substitute swale and pond systems to increase infiltration; and

- Reduce the use of storm sewers to drain streets, parking lots, and back yards (NIPC, 1992)

g. Xeriscape Programs

Xeriscaping is a landscaping concept that maximizes the conservation of water by the use of site-appropriate plants and an efficient watering system and involves the use of landscaping plants that need minimal watering, fertilization, and pesticide application. Xeriscaping can reduce the contribution of landscaped areas to coastal nonpoint source pollution. Xeriscape designs can reduce landscape maintenance by as much as 50 percent, primarily as a result of the following:

- Reduction of water loss and soil erosion through careful planning, design, and implementation;
- Reduction of mowing by limiting lawn areas and using proper fertilization techniques; and
- Reduction of fertilization through soil preparation (Clemson University, 1991).

In 1991, the Florida Legislature adopted a xeriscape law that requires State agencies to adopt and implement xeriscaping programs. The law requires that rules and guidelines for implementation of xeriscaping along highway rights-of-way and on public property associated with publicly owned buildings constructed after July 1, 1992, be adopted. Local governments are to determine whether xeriscaping is a cost-effective measure for conserving water. If so, local governments are to work with the water management districts in developing their xeriscape guidelines. Water management districts will provide financial incentives to local governments for developing xeriscape plans and ordinances. These plans must include:

- Landscape design, installation, and maintenance standards;
- Identification of prohibited plant species (invasive exotic plants);
- Identification of controlled plant species and conditions for their use;
- Specifications for maximum percentage of turf and impervious surfaces allowed in a xeriscaped area;
- Specifications for land clearing and requirements for the conservation of existing native vegetation; and
- Monitoring programs for ordinance implementation and compliance.

There is also a provision in the law requiring local governments and water management districts to promote the use of xeriscape practices in already developed areas through public education programs. California has passed a law requiring all municipalities to consider enacting water-efficient landscape requirements.

III. CONSTRUCTION ACTIVITIES

[illegible]

(1) Reduce erosion and, to the extent practicable, retain sediment onsite during and after construction, and

(2) Prior to land disturbance, prepare and implement an approved erosion and sediment control plan or similar administrative document that contains erosion and sediment control provisions.

1. Applicability

This management measure is intended to be applied by States to all construction activities on sites less than 5 acres in areas that do not have an NPDES permit[3] in order to control erosion and sediment loss from those sites. This management measure does not apply to: (1) construction of a detached single family home on a site of 1/2 acre or more or (2) construction that does not disturb over 5,000 square feet of land on a site. (NOTE: All construction activities, including clearing, grading, and excavation, that result in the disturbance of areas greater than or equal to 5 acres or are a part of a larger development plan are covered by the NPDES regulations and are thus excluded from these requirements.) Under the Coastal Zone Act Reauthorization Amendments of 1990, States are subject to a number of requirements as they develop coastal NPS programs in conformity with this management measure and will have flexibility in doing so. The application of management measures by States is described more fully in *Coastal Nonpoint Pollution Control Program: Program Development and Approval Guidance*, published jointly by the U.S. Environmental Protection Agency (EPA) and the National Oceanic and Atmospheric Administration (NOAA) of the U.S. Department of Commerce.

2. Description

The goal of this management measure is to reduce the sediment loadings from construction sites in coastal areas that enter surface waterbodies. This measure requires that coastal States establish new or enhance existing State erosion and sediment control (ESC) programs and/or require ESC programs at the local level. It is intended to be part of a comprehensive land use or watershed management program, as previously detailed in the Watershed and Site Development Management Measures. It is expected that State and local programs will establish criteria determined by local conditions (e.g., soil types, climate, meteorology) that reduce erosion and sediment transport from construction sites.

Runoff from construction sites is by far the largest source of sediment in urban areas under development (York County Soil and Water Conservation District, 1990). Soil erosion removes over 90 percent of sediment by tonnage in urbanizing areas where most construction activities occur (Canning, 1988). Table 4-14 illustrates some of the

[3] On May 27, 1992, the United States Court of Appeals for the Ninth Circuit invalidated EPA's exemption of construction sites smaller than 5 acres from the storm water permit program in *Natural Resources Defense Council* v. *EPA*, 965 F.2d 759 (9th Cir. 1992). EPA is conducting further rulemaking proceedings on this issue and will not require permit applications for construction activities under 5 acres until further rulemaking has been completed.

measured sediment loading rates associated with construction activities found across the United States. As seen in Table 4-14, erosion rates from natural areas such as undisturbed forested lands are typically less than one ton/acre/year, while erosion from construction sites ranges from 7.2 to over 1,000 tons/acre/year.

Table 4-14. Erosion and Sediment Problems Associated With Construction

Location	Problem	Reference
United States	Sediment loading rates vary from 36.5 to 1,000 ton/ac/yr. These are 5 to 500 times greater than those from undeveloped land. Approximately 600 million tons of soil erodes from developed sites each year. Construction site sediment in runoff can be 10 to 20 times greater than that from agricultural lands.	York County Soil and Water Conservation District, 1990
Franklin County, FL	Sediment yield (ton/ac/yr): forest < 0.5 rangeland < 0.5 tilled 1.4 construction site 30 established urban < 0.5	Franklin County, FL
Wisconsin	Erosion rates range from 30 to 200 ton/ac/yr (10 to 20 times those of cropland).	Wisconsin Legislative Council, 1991
Washington, DC	Erosion rates range from 35 to 45 ton/ac/yr (10 to 100 times greater than agriculture and stabilized urban land uses).	MWCOG, 1987
Anacostia River Basin, VA, MD, DC	Sediment yields from portions of the Anacostia Basin have been estimated at 75,000 to 132,000 ton/yr.	U.S. Army Corps of Engineers, 1990
Washington	Erosion rates range from 50 to 500 ton/ac/yr. Natural erosion rates from forests or well-sodded prairies are 0.01 to 1.0 ton/ac/yr.	Washington Department of Ecology, 1989
Anacostia River Basin, VA, MD, DC	Erosion rates range from 7.2 to 100.8 ton/ac/yr.	USGS, 1978
Alabama North Carolina Louisiana Oklahoma Georgia Texas Tennessee Pennsylvania Ohio Kentucky	1.4 million tons eroded per year. 6.7 million tons eroded per year. 5.1 million tons eroded per year. 4.2 million tons eroded per year. 3.8 million tons eroded per year. 3.5 million tons eroded per year. 3.3 million tons eroded per year. 3.1 million tons eroded per year. 3.0 million tons eroded per year. 3.0 million tons eroded per year.	Woodward-Clyde, 1991

Eroded sediment from construction sites creates many problems in coastal areas including adverse impacts on water quality, critical habitats, submerged aquatic vegetation (SAV) beds, recreational activities, and navigation (APWA, 1991). For example, the Miami River in Florida has been severely affected by pollution associated with upland erosion. This watershed has undergone extensive urbanization, which has included the construction of many commercial and residential buildings over the past 50 years. Sediment deposited in the Miami River channel contributes to the severe water quality and navigation problems of this once-thriving waterway, as well as Biscayne Bay (SFWMD, 1988).

ESC plans are important for controlling the adverse impacts of construction and land development and have been required by many State and local governments, as shown in Table 4-13 (in the Site Development section of this chapter). An ESC plan is a document that explains and illustrates the measures to be taken to control erosion and sediment problems on construction sites (Connecticut Council on Soil and Water Conservation, 1988). It is intended that existing State and local erosion and sediment control plans may be used to fulfill the requirements of this management measure. Where existing ESC plans do not meet the management measure criteria, inadequate plans may be enhanced to meet the management measure guidelines.

Typically, an ESC plan is part of a larger site plan and includes the following elements:

- Description of predominant soil types;
- Details of site grading including existing and proposed contours;
- Design details and locations for structural controls;
- Provisions to preserve topsoil and limit disturbance;
- Details of temporary and permanent stabilization measures; and
- Description of the sequence of construction.

ESC plans ensure that provisions for control measures are incorporated into the site planning stage of development and provide for the reduction of erosion and sediment problems and accountability if a problem occurs (York County Soil and Water Conservation District, 1990). An effective plan for urban runoff management on construction sites will control erosion, retain sediments on site, to the extent practicable, and reduce the adverse effects of runoff. Climate, topography, soils, drainage patterns, and vegetation will affect how erosion and sediment should be controlled on a site (Washington State Department of Ecology, 1989). An effective ESC plan includes both structural and nonstructural controls. Nonstructural controls address erosion control by decreasing erosion potential, whereas structural controls are both preventive and mitigative because they control both erosion and sediment movement.

Typical nonstructural erosion controls include (APWA, 1991; York County Soil and Water Conservation District, 1990):

- Planning and designing the development within the natural constraints of the site;
- Minimizing the area of bare soil exposed at one time (phased grading);
- Providing for stream crossing areas for natural and man-made areas; and
- Stabilizing cut-and-fill slopes caused by construction activities.

Structural controls include:

- Perimeter controls;
- Mulching and seeding exposed areas;
- Sediment basins and traps; and
- Filter fabric, or silt fences.

Some erosion and soil loss are unavoidable during land-disturbing activities. While proper siting and design will help prevent areas prone to erosion from being developed, construction activities will invariably produce conditions where erosion may occur. To reduce the adverse impacts associated with construction, the construction management measure suggests a system of nonstructural and structural erosion and sediment controls for incorporation into an

ESC plan. Erosion controls have distinct advantages over sediment controls. Erosion controls reduce the amount of sediment transported off-site, thereby reducing the need for sediment controls. When erosion controls are used in conjunction with sediment controls, the size of the sediment control structures and associated maintenance may be reduced, decreasing the overall treatment costs (SWRPC, 1991).

3. Management Measure Selection

This management measure was selected to minimize sediment being transported outside the perimeter of a construction site through two broad performance goals: (1) reduce erosion and (2) retain sediment onsite, to the extent practicable. These performance goals were chosen to allow States and local governments flexibility in specifying practices appropriate for local conditions.

While several commentors responding to the draft (May 1991) guidance expressed the need to define "more measurable, enforceable ways" to control sediment loadings, other commentors stressed the need to draft management measures that do not conflict with existing State programs and allow States and local governments to determine appropriate practices and design standards for their communities. These management measures were selected because virtually all coastal States control construction activities to prevent erosion and sediment loss.

The measures were specifically written for the following reasons:

(1) Predevelopment loadings may vary greatly, and some sediment loss is usually inevitable;

(2) Current practice is built on the use of systems of practices selected based on site-specific conditions; and

(3) The combined effectiveness of erosion and sediment controls in systems is not easily quantified.

4. Erosion Control Practices

As discussed more fully at the beginning of this chapter and in Chapter 1, the following practices are described for illustrative purposes only. State programs need not require implementation of these practices. However, as a practical matter, EPA anticipates that the management measure set forth above generally will be implemented by applying one or more management practices appropriate to the source, location, and climate. The practices set forth below have been found by EPA to be representative of the types of practices that can be applied successfully to achieve the management measure described above.

Erosion controls are used to reduce the amount of sediment that is detached during construction and to prevent sediment from entering runoff. Erosion control is based on two main concepts: (1) disturb the smallest area of land possible for the shortest period of time, and (2) stabilize disturbed soils to prevent erosion from occurring.

■ a. *Schedule projects so clearing and grading are done during the time of minimum erosion potential.*

Often a project can be scheduled during the time of year that the erosion potential of the site is relatively low. In many parts of the country, there is a certain period of the year when erosion potential is relatively low and construction scheduling could be very effective. For example, in the Pacific region if construction can be completed during the 6-month dry season (May 1 - October 31), temporary erosion and sediment controls may not be needed. In addition, in some parts of the country erosion potential is very high during certain parts of the year such as the spring thaw in northern areas. During this time of year, melting snowfall generates a constant runoff that can erode soil. In addition, construction vehicles can easily turn the soft, wet ground into mud, which is more easily washed offsite. Therefore, in the north, limitations should be placed on grading during the spring thaw (Goldman et al., 1986).

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b. Stage construction.

Avoid areawide clearance of construction sites. Plan and stage land disturbance activities so that only the area currently under construction is exposed. As soon as the grading and construction in an area are complete, the area should be stabilized.

By clearing only those areas immediately essential for completing site construction, buffer zones are preserved and soil remains undisturbed until construction begins. Physical markers, such as tape, signs, or barriers, indicating the limits of land disturbance, can ensure that equipment operators know the proposed limits of clearing. The area of the watershed that is exposed to construction is important for determining the net amount of erosion. Reducing the extent of the disturbed area will ultimately reduce sediment loads to surface waters. Existing or newly planted vegetation that has been planted to stabilize disturbed areas should be protected by routing construction traffic around and protecting natural vegetation with fencing, tree armoring, retaining walls, or tree wells.

c. Clear only areas essential for construction.

Often areas of a construction site are unnecessarily cleared. Only those areas essential for completing construction activities should be cleared, and other areas should remain undisturbed. Additionally, the proposed limits of land disturbance should be physically marked off to ensure that only the required land area is cleared. Avoid disturbing vegetation on steep slopes or other critical areas.

d. Locate potential nonpoint pollutant sources away from steep slopes, waterbodies, and critical areas.

Material stockpiles, borrow areas, access roads, and other land-disturbing activities can often be located away from critical areas such as steep slopes, highly erodible soils, and areas that drain directly into sensitive waterbodies.

e. Route construction traffic to avoid existing or newly planted vegetation.

Where possible, construction traffic should travel over areas that must be disturbed for other construction activity. This practice will reduce the area that is cleared and susceptible to erosion.

f. Protect natural vegetation with fencing, tree armoring, and retaining walls or tree wells.

Tree armoring protects tree trunks from being damaged by construction equipment. Fencing can also protect tree trunks, but should be placed at the tree's drip line so that construction equipment is kept away from the tree. The tree drip line is the minimum area around a tree in which the tree's root system should not be disturbed by cut, fill, or soil compaction caused by heavy equipment. When cutting or filling must be done near a tree, a retaining wall or tree well should be used to minimize the cutting of the tree's roots or the quantity of fill placed over the tree's roots.

g. Stockpile topsoil and reapply to revegetate site.

Because of the high organic content of topsoil, it cannot be used as fill material or under pavement. After a site is cleared, the topsoil is typically removed. Since topsoil is essential to establish new vegetation, it should be stockpiled and then reapplied to the site for revegetation, if appropriate. Although topsoil salvaged from the existing site can often be used, it must meet certain standards and topsoil may need to be imported onto the site if the existing topsoil is not adequate for establishing new vegetation.

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h. Cover or stabilize topsoil stockpiles.

Unprotected stockpiles are very prone to erosion and therefore stockpiles must be protected. Small stockpiles can be covered with a tarp to prevent erosion. Large stockpiles should be stabilized by erosion blankets, seeding, and/or mulching.

i. Use wind erosion controls.

Wind erosion controls limit the movement of dust from disturbed soil surfaces and include many different practices. Wind barriers block air currents and are effective in controlling soil blowing. Many different materials can be used as wind barriers, including solid board fence, snow fences, and bales of hay. Sprinkling moistens the soil surface with water and must be repeated as needed to be effective for preventing wind erosion (Delaware DNREC, 1989); however, applications must be monitored to prevent excessive runoff and erosion.

j. Intercept runoff above disturbed slopes and convey it to a permanent channel or storm drain.

Earth dikes, perimeter dikes or swales, or diversions can be used to intercept and convey runoff above disturbed areas. An earth dike is a temporary berm or ridge of compacted soil that channels water to a desired location. A perimeter dike/swale or diversion is a swale with a supporting ridge on the lower side that is constructed from the soil excavated from the adjoining swale (Delaware DNREC, 1989). These practices should be used to intercept flow from denuded areas or newly seeded areas to keep the disturbed areas from being eroded from the uphill runoff. The structures should be stabilized within 14 days of installation. A pipe slope drain, also known as a pipe drop structure, is a temporary pipe placed from the top of a slope to the bottom of the slope to convey concentrated runoff down the slope without causing erosion (Delaware DNREC, 1989).

k. On long or steep, disturbed, or man-made slopes, construct benches, terraces, or ditches at regular intervals to intercept runoff.

Benches, terraces, or ditches break up a slope by providing areas of low slope in the reverse direction. This keeps water from proceeding down the slope at increasing volume and velocity. Instead, the flow is directed to a suitable outlet, such as a sediment basin or trap. The frequency of benches, terraces, or ditches will depend on the erodibility of the soils, steepness and length of the slope, and rock outcrops. This practice should be used if there is a potential for erosion along the slope.

l. Use retaining walls.

Often retaining walls can be used to decrease the steepness of a slope. If the steepness of a slope is reduced, the runoff velocity is decreased and, therefore, the erosion potential is decreased.

m. Provide linings for urban runoff conveyance channels.

Often construction increases the velocity and volume of runoff, which causes erosion in newly constructed or existing urban runoff conveyance channels. If the runoff during or after construction will cause erosion in a channel, the channel should be lined or flow control BMPs installed. The first choice of lining should be grass or sod since this reduces runoff velocities and provides water quality benefits through filtration and infiltration. If the velocity in the channel would erode the grass or sod, then riprap, concrete, or gabions can be used.

n. Use check dams.

Check dams are small, temporary dams constructed across a swale or channel. They can be constructed using gravel or straw bales. They are used to reduce the velocity of concentrated flow and, therefore, to reduce the erosion in

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a swale or channel. Check dams should be used when a swale or channel will be used for a short time and therefore it is not feasible or practical to line the channel or implement flow control BMPs (Delaware DNREC, 1989).

o. Seed and fertilize.

Seeding establishes a vegetative cover on disturbed areas. Seeding is very effective in controlling soil erosion once a dense vegetative cover has been established. However, often seeding and fertilizing do not produce as thick a vegetative cover as do seed and mulch or netting. Newly established vegetation does not have as extensive a root system as existing vegetation and therefore is more prone to erosion, especially on steep slopes. Care should be taken when fertilizing to avoid untimely or excessive application. Since the practice of seeding and fertilizing does not provide any protection during the time of vegetative establishment, it should be used only on favorable soils in very flat areas and not in sensitive areas.

p. Use seeding and mulch/mats.

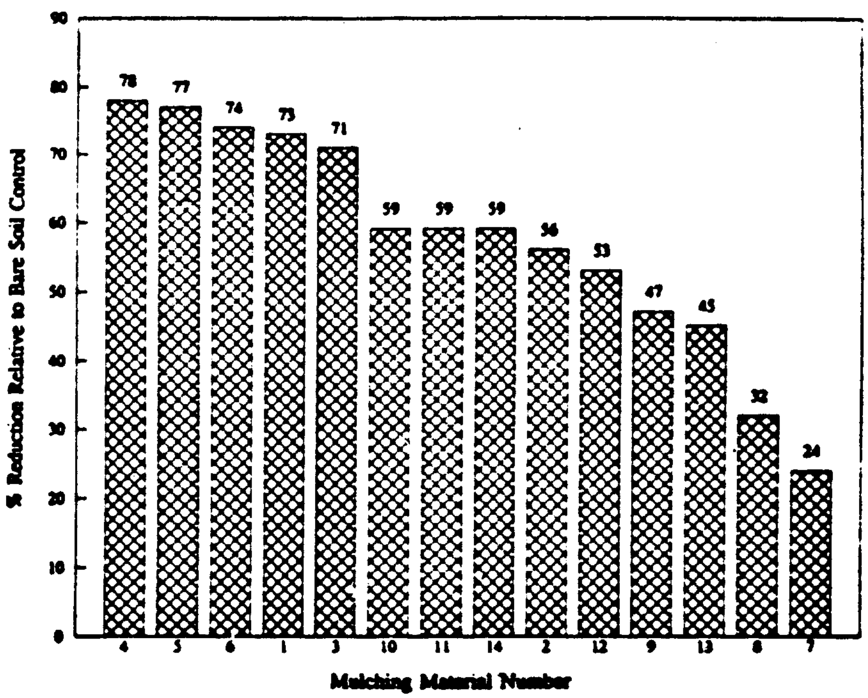
Seeding establishes a vegetative cover on disturbed areas. Seeding is very effective in controlling soil erosion once the vegetative cover has been established. The mulching/mats protect the disturbed area while the vegetation becomes established.

The management of land by using ground cover reduces erosion by reducing the flow rate of runoff and the raindrop impact. Bare soils should be seeded or otherwise stabilized within 15 calendar days after final grading. Denuded areas that are inactive and will be exposed to rain for 30 days or more should also be temporarily stabilized, usually by planting seeds and establishing vegetation during favorable seasons in areas where vegetation can be established. In very flat, non-sensitive areas with favorable soils, stabilization may involve simply seeding and fertilizing. Mulching and/or sodding may be necessary as slopes become moderate to steep, as soils become more erosive, and as areas become more sensitive.

q. Use mulch/mats.

Mulching involves applying plant residues or other suitable materials on disturbed soil surfaces. Mulchs/mats used include tacked straw, wood chips, and jute netting and are often covered by blankets or netting. Mulching alone should be used only for temporary protection of the soil surface or when permanent seeding is not feasible. The useful life of mulch varies with the material used and the amount of precipitation, but is approximately 2 to 6 months. Figure 4-5 shows water velocity reductions that could be expected using various mulching techniques. Similarly, Figure 4-6 shows reductions in soil loss achievable using various mulching techniques. During times of year when vegetation cannot be established, soil mulching should be applied to moderate slopes and soils that are not highly erodible. On steep slopes or highly erodible soils, multiple mulching treatments should be used. On a high-elevation or desert site where grasses cannot survive the harsh environment, native shrubs may be planted. Interlocking ceramic materials, filter fabric, and netting are available for this purpose. Before stabilizing an area, it is important to have installed all sediment controls and diverted runoff away from the area to be planted. Runoff may be diverted away from denuded areas or newly planted areas using dikes, swales, or pipe slope drains to intercept runoff and convey it to a permanent channel or storm drain. Reserved topsoil may be used to revegetate a site if the stockpile has been covered and stabilized.

Consideration should be given to maintenance when designing mulching and matting schemes. Plastic nets are often used to cover the mulch or mats; however, they can foul lawn mower blades if the area requires mowing.



Mulch Material	Characteristics
1	100% wheat straw/top net
2	100% wheat straw/two nets
3	70% wheat straw/30% coconut fiber
4	70% wheat straw/30% coconut fiber
5	100% coconut fiber
6	Nylon monofilament/two nets
7	Nylon monofilament/rigid/bonded
8	Vinyl monofilament/flexible/bonded
9	Curled wood fibers/top net
10	Curled wood fibers/two nets
11	Antiwash netting (jute)
12	Interwoven paper and thread
13	Uncrimped wheat straw – 2,242 kg/ha
14	Uncrimped wheat straw – 4,484 kg/ha

Figure 4-5. Water velocity reductions for different mulch treatments (adapted from Harding, 1990).

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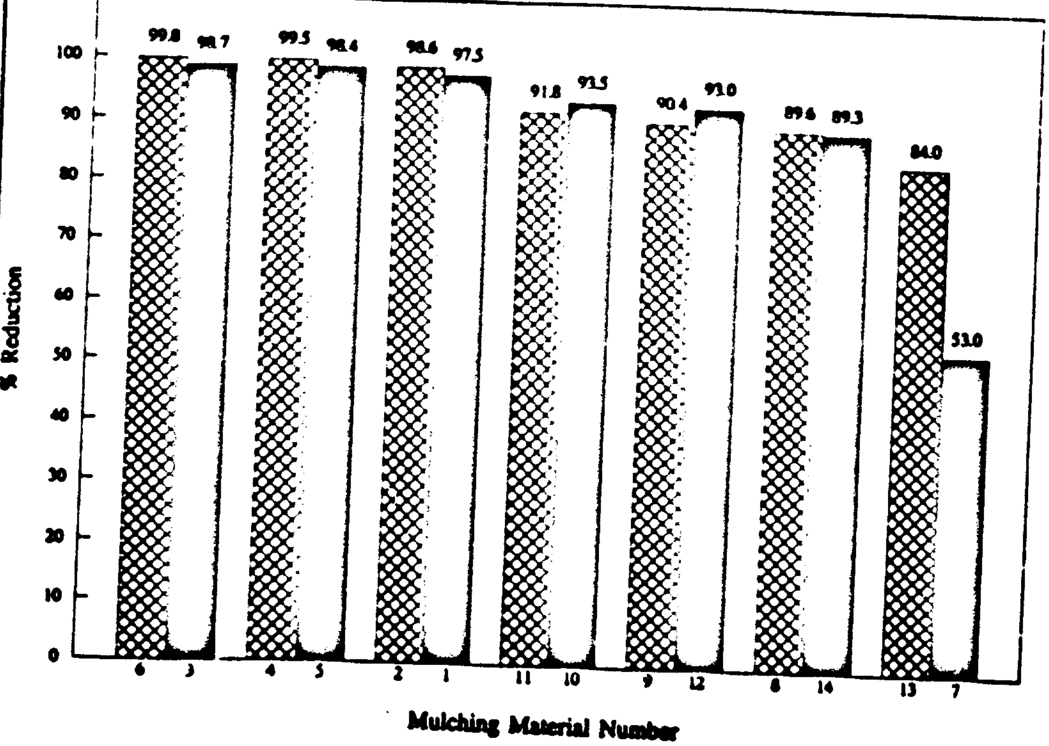

Mulch Material	Characteristics
1	100% wheat straw/top net
2	100% wheat straw/two nets
3	70% wheat straw/30% coconut fiber
4	70% wheat straw/30% coconut fiber
5	100% coconut fiber
6	Nylon monofilament/two nets
7	Nylon monofilament/rigid/bonded
8	Vinyl monofilament/flexible/bonded
9	Curled wood fibers/top net
10	Curled wood fibers/two nets
11	Antiwash netting (jute)
12	Interwoven paper and thread
13	Uncrimped wheat straw – 2,242 kg/ha
14	Uncrimped wheat straw – 4,484 kg/ha

Figure 4-6. Actual soil loss reductions for different mulch treatments (adapted from Harding, 1990).

r. Use sodding.

Sodding permanently stabilizes an area. Sodding provides immediate stabilization of an area and should be used in critical areas or where establishment of permanent vegetation by seeding and mulching would be difficult. Sodding is also a preferred option when there is a high erosion potential during the period of vegetative establishment from seeding.

s. Use wildflower cover.

Because of the hardy drought-resistant nature of wildflowers, they may be more beneficial as an erosion control practice than turf grass. While not as dense as turfgrass, wildflower thatches and associated grasses are expected to be as effective in erosion control and contaminant absorption. Because thatches of wildflowers do not need fertilizers, pesticides, or herbicides, and watering is minimal, implementation of this practice may result in a cost savings (Brash et al., undated). In 1987, Howard County, Maryland, spent $690.00 per acre to maintain turfgrass areas, compared to only $31.00 per acre for wildflower meadows (Wilson, 1990).

A wildflower stand requires several years to become established; maintenance requirements are minimal once the area is established (Brash et al., undated).

5. Sediment Control Practices[4]

As discussed more fully at the beginning of this chapter and in Chapter 1, the following practices are described for illustrative purposes only. State programs need not require implementation of these practices. However, as a practical matter, EPA anticipates that the management measure set forth above generally will be implemented by applying one or more management practices appropriate to the source, location, and climate. The practices set forth below have been found by EPA to be representative of the types of practices that can be applied successfully to achieve the management measure described above.

Sediment controls capture sediment that is transported in runoff. Filtration and detention (gravitational settling) are the main processes used to remove sediment from urban runoff.

a. Sediment Basins

Sediment basins, also known as silt basins, are engineered impoundment structures that allow sediment to settle out of the urban runoff. They are installed prior to full-scale grading and remain in place until the disturbed portions of the drainage area are fully stabilized. They are generally located at the low point of sites, away from construction traffic, where they will be able to trap sediment-laden runoff.

Sediment basins are typically used for drainage areas between 5 and 100 acres. They can be classified as either temporary or permanent structures, depending on the length of service of the structure. If they are designed to function for less than 36 months, they are classified as "temporary"; otherwise, they are considered permanent structures. Temporary sediment basins can also be converted into permanent urban runoff management ponds. When sediment basins are designed as permanent structures, they must meet all standards for wet ponds.

b. Sediment Trap

Sediment traps are small impoundments that allow sediment to settle out of runoff water. Sediment traps are typically installed in a drainageway or other point of discharge from a disturbed area. Temporary diversions can be

[4]Adapted from Goldman (1986).

used to direct runoff to the sediment trap. Sediment traps should not be used for drainage areas greater than 5 acres and typically have a useful life of approximately 18 to 24 months.

c. Filter Fabric Fence

Filter fabric fence is available from many manufacturers and in several mesh sizes. Sediment is filtered out as urban runoff flows through the fabric. Such fences should be used only where there is sheet flow (i.e., no concentrated flow), and the maximum drainage area to the fence should be 0.5 acre or less per 100 feet of fence. Filter fabric fences have a useful life of approximately 6 to 12 months.

d. Straw Bale Barrier

A straw bale barrier is a row of anchored straw bales that detain and filter urban runoff. Straw bales are less effective than filter fabric, which can usually be used in place of straw bales. However, straw bales have been effectively used as temporary check dams in channels. As with filter fabric fences, straw bale barriers should be used only where there is sheet flow. The maximum drainage area to the barrier should be 0.25 acre or less per 100 feet of barrier. The useful life of straw bales is approximately 3 months.

e. Inlet Protection

Inlet protection consists of a barrier placed around a storm drain drop inlet, which traps sediment before it enters the storm sewer system. Filter fabric, straw bales, gravel, or sand bags are often used for inlet protection.

f. Construction Entrance

A construction entrance is a pad of gravel over filter cloth located where traffic leaves a construction site. As vehicles drive over the gravel, mud, and sediment are collected from the vehicles' wheels and offsite transport of sediment is reduced.

g. Vegetated Filter Strips

Vegetated filter strips are low-gradient vegetated areas that filter overland sheet flow. Runoff must be evenly distributed across the filter strip. Channelized flows decrease the effectiveness of filter strips. Level spreading devices are often used to distribute the runoff evenly across the strip (Dillaha et al., 1989).

Vegetated filter strips should have relatively low slopes and adequate length and should be planted with erosion-resistant plant species. The main factors that influence the removal efficiency are the vegetation type, soil infiltration rate, and flow depth and travel time. These factors are dependent on the contributing drainage area, slope of strip, degree and type of vegetative cover, and strip length. Maintenance requirements for vegetated filter strips include sediment removal and inspections to ensure that dense, vigorous vegetation is established and concentrated flows do not occur. Maintenance of these structures is discussed in Section II.A of this chapter.

6. Effectiveness and Cost Information

a. Erosion Control Practices

The effectiveness of erosion control practices can vary based on land slope, the size of the disturbed area, rainfall frequency and intensity, wind conditions, soil type, use of heavy machinery, length of time soils are exposed and unprotected, and other factors. In general, a system of erosion and sediment control practices can more effectively reduce offsite sediment transport than can a single system. Numerous nonstructural measures such as protecting natural or newly planted vegetation, minimizing the disturbance of vegetation on steep slopes and other highly erodible areas, maximizing the distance eroded material must travel before reaching the drainage system, and locating roads away from sensitive areas may be used to reduce erosion.

Table 4-15 contains the available cost and effectiveness data for some of the erosion controls listed above. Information on the effectiveness of individual nonstructural controls was not available. All reported effectiveness data assume that controls are properly designed, constructed, and maintained. Costs have been broken down into annual capital costs, annual maintenance costs, and total annual costs (including annualization of the capital costs).

b. Sediment Control Practices

Regular inspection and maintenance are needed for most erosion control practices to remain effective. The effectiveness of sediment controls will depend on the size of the construction site and the nature of the runoff flows. Sediment basins are most appropriate for drainage areas of 5 acres or greater. In smaller areas with concentrated flows, silt traps may suffice. Where concentrated flow leaves the site and the drainage area is less than 0.5 ac/100 ft of flow, filter fabric fences may be effective. In areas where sheet flow leaves the site and the drainage area is greater than 0.5 acre/100 ft of flow, perimeter dikes may be used to divert the flow to a sediment trap or sediment basin. Urban runoff inlets may be protected using straw bales or diversions to filter or route runoff away from the inlets.

Table 4-16 describes the general cost and effectiveness of some common sediment control practices.

c. Comparisons

Figure 4-7 illustrates the estimated TSS loading reductions from Maryland construction sites possible using a combination of erosion and sediment controls in contrast to using only sediment controls. Figure 4-8 shows a comparison of the cost and effectiveness of various erosion control practices. As can be seen in Figure 4-8, seeding or seeding and mulching provide the highest levels of control at the lowest cost.

Table 4-15. ESC Quantitative Effectiveness and Cost Summary

Practice	Design Constraints or Purpose	Percent Removal of TSS	Useful Life (years)[a]	Construction Cost	Annual Maintenance Cost (as % construction cost)	Total Annual Cost
Sod	Immediate erosion protection where there is high erosion potential during vegetative establishment.	Average: 99% Observed range: 98% - 99% References: Minnesota Pollution Control Agency, 1989; Pennsylvania, 1983 cited in USEPA, 1991	2	Average: $0.2 per ft^2 [$11,300 per acre] Range: $0.1 - $1.1 References: SWRPC, 1991; Schueler, 1987; Virginia, 1980	Average: 5% Range: 5% Reference: SWRPC, 1991	$0.20 per ft^2 $7,500 per acre
Seed	Establish vegetation on disturbed area.	After vegetation established- Average: 90% Observed range: 50% - 100% References: SCS, 1985 cited in EPA, 1991; Minnesota Pollution Control Agency, 1989; Oberts, 1984 cited in City of Austin, 1988; Delaware Department of Natural Resources, 1989	2	Average: $400 per acre Range: $200 - $1000 per acre References: Wisconsin DOT cited in SWRPC, 1991; SWRPC, 1991; Goldman, 1986; Virginia, 1980	Average: 20% Range: 15% - 25% References: Wisconsin DOT cited in SWRPC, 1991; SWRPC, 1991	$300 per acre
Seed and Mulch	Establish vegetation on disturbed area.	After vegetation established- Average: 90% Observed range: 50% - 100% References: SCS, 1985 cited in EPA, 1991; Minnesota Pollution Control Agency, 1989; Oberts, 1984 cited in City of Austin, 1988; Delaware Department of Natural Resources, 1989	2	Average: $1,500 per acre Range: $800 - $3,500 per acre References: Goldman, 1986; Washington DOT, 1990; NC State, 1990; Schueler, 1987; Virginia, 1980; SWRPC, 1991	Average: NA[b] Range: NA References: None	$1,100 per acre

Table 4-15. (Continued)

Practice	Design Constraints or Purpose	Percent Removal of TSS	Useful Life (years)[a]	Construction Cost	Annual Maintenance Cost (as % construction cost)	Total Annual Cost
Mulch	Temporary stabilization of disturbed area.	Observed range: sand: 20% slope / 50% slope wood fiber ● 1500 lb/ac 50-60% / 0-20% wood fiber ● 3000 lb/ac 50-85% / 50-70% straw ● 3000 lb/ac 90-100% / 95%	Straw mulch: 0.25	Straw mulch: Average: $1,700 per acre Range: $500 - $5,000 per acre References: Wisconsin DOT cited in SWRPC, 1991; Washington DOT, 1990; Virginia, 1980	Average: NA[b] Range: NA References: None	Straw mulch: $7,500 per acre
		Silt-loam: 20% slope / 50% slope wood fiber ● 1500 lb/ac 20-60% / 40-60% wood fiber ● 3000 lb/ac 60-90% / 60-70% straw ● 3000 lb/ac 80-95% / 70-90%	Wood fiber mulch: 0.33	Wood fiber mulch: Average: $1,000 per acre Range: $100 - $2,300 per acre References: Washington DOT, 1990; Virginia, 1980		Wood fiber mulch: $3,500 per acre
		Silt-clay-loam: 10-30% slope / 30-50% slope wood fiber ● 1500 lb/ac 5% / – wood fiber ● 3000 lb/ac 40% / – jute netting 30-60% / 30%	Jute netting: 0.33	Jute netting: Average: $3,700 per acre Range: $3,500-$4,100 per acre References: Washington DOT, 1990; Virginia, 1980		Jute netting: $12,500 per acre
		straw ● 3000 lb/ac 40-70% / 20-40% wood chips ● 10,000 lb/ac 60-80% / 50-60% mulch blanket 60-80% / 50-60% excelsior blanket 60-80% / 50-60% multiple treatment (straw and jute) 90% / 90%	Straw and jute: 0.33	Straw and jute: Average: $5,400 per acre Range: $4,000-$9,100 per acre References: Washington DOT, 1990; Virginia, 1980		Straw and jute: $18,000 per acre
		References: Minnesota Pollution Control Agency, 1989; Kay, 1983 cited in Goldman, 1986				

Table 4-15. (Continued)

Practice	Design Constraints or Purpose	Percent Removal of TSS	Useful Life (years)[a]	Construction Cost	Annual Maintenance Cost (as % construction cost)	Total Annual Cost
Terraces	Break up long or steep slopes.	Observed range: Land Slope — Reduction in Erosion 1-12% — 70% 12-18% — 60% 18-24% — 55% Additionally, if the slope steepness is halved, while other factors are held constant, the soil loss potential decreases 2-1/2 times. If both the slope and length are halved, the soil loss potential is decreased 4 times. References: Goldman, 1986; Beasley, 1972	2	Average: $5 per lin ft Range: $1 - $12 References: SWRPC, 1991; Goldman, 1986; Virginia, 1991	Average: 20% Range: 20% Reference: SWRPC, 1991	$4 per lin ft
All Erosion Controls	Reduce amount of sediment entering runoff.	Average: 85% Observed range: 85% Reference: Schueler, 1990	--	Varies but typically low	Varies but typically low	Varies but typically low

NA - Not available.
[a] Useful life estimated as length of construction project (assumed to be 2 years).
[b] For Total Annual Cost, assume Annual Maintenance Cost = 2% of construction cost.

Table 4-16. ESC Quantitative Effectiveness and Cost Summary for Sediment Control Practices

Practice	Design Constraints or Purpose	Percent Removal of TSS	Useful Life (years)[a]	Construction Cost	Annual Maintenance Cost (as % construction cost)	Total Annual Cost
Sediment basin	Minimum drainage area = 5 acres, maximum drainage area = 100 acres	Average: 70% Observed range: 55% - 100% References: Schueler, 1990; Engle, BW and Jarrett, AR, 1990; Baumann, 1990	2	Less than 50,000 ft^3 storage Average: $0.60 per ft^3 storage ($1,100 per drainage acre[c]) Range: $0.20 - $1.30 per ft^3	Average: 25% Range: 25% References: Denver COG cited in SWRPC, 1991; SWRPC, 1991	Less than 50,000 ft^3 storage $0.40 per ft^3 storage $700 per drainage acre[b]
				Greater than 50,000 ft^3 storage Average: $0.3 per ft^3 storage ($550 per drainage acre[c]) Range: $0.10 - $0.40 per ft^3 References: SWRPC, 1991		Greater than 50,000 ft^3 storage $0.20 per ft^3 storage $900 per drainage acre[c]
Sediment trap	Maximum drainage area = 5 acres	Average: 60% Observed range: (-7%) - 100% References: Schueler, et al., 1990; Tahoe Regional Planning Agency, 1989; Baumann, 1990	1.5	Average: $0.60 per ft^3 storage ($1,100 per drainage acre[c]) Range: $0.20 - $2.00 per ft^3 References: Denver COG cited in SWRPC, 1991; SWRPC, 1991; Goldman, 1986	Average: 20% Range: 20% References: Denver COG cited in SWRPC, 1991; SWRPC, 1991	$0.70 per ft^3 storage $1,300 per drainage acre[c]
Filter Fabric Fence	Maximum drainage area = 0.5 acre per 100 feet of fence. Not to be used in concentrated flow areas.	Average: 70% Observed range: 0% - 100% sand: 80% - 99% silt-loam: 50% - 80% silt-clay-loam: 0% - 20% References: Munson, 1991; Fisher et al., 1984; Minnesota Pollution Control Agency, 1989	0.5	Average: $3 per lin ft ($700 per drainage acre[c] Range: $1 - $8 per lin ft References: Wisconsin DOT cited in SWRPC, 1991; SWRPC, 1991; Goldman, 1986; Virginia, 1991; NC State, 1990	Average: 100% Range: 100% References: SWRPC, 1991	$7 per lin ft $850 per drainage acre[c]

Table 4-16. (Continued)

Practice	Design Constraints or Purpose	Percent Removal of TSS	Useful Life (years)[a]	Construction Cost	Annual Maintenance Cost (as % construction cost)	Total Annual Cost
Straw Bale Barrier	Maximum drainage area = 0.25 acre per 100 feet of barrier. Not to be used in concentrated flow areas.	Average: 70% Observed Range: 70% References: Virginia, 1980 cited in EPA, 1991	0.25	Average: $4 per lin ft ($1,600 per drainage acre[d] Range: $2 - $6 per lin ft References: Goldman, 1986; Virginia, 1991	Average: 100% Range: 100% References: SWRPC, 1991	$17 per lin ft $6,800 per drainage acre[d]
Inlet Protection	Protect storm drain inlet.	Average: NA Observed Range: NA References: None	1	Average: $100 per inlet Range: $50 - $150 References: SWRPC, 1991; Denver COG cited in SWRPC, 1991; Virginia, 1991; EPA cited in SWRPC, 1991	Average: 60% Range: 20% - 100% References: SWRPC, 1991; Denver COG cited in SWRPC, 1991	$150 per inlet
Construction Entrance	Removes sediment from vehicles wheels.	Average: NA Observed Range: NA References: None	2	Average: $2,000 each Range: $1,000 - $4,000 References: Goldman, 1986; NC State, 1990	Average: NA[e] Range: NA References: None	$1,500 each
				With washrack: Average: $3,000 each Range: $1,000 - $5,000 References: Virginia, 1991		$2,200 each

Table 4-16. (Continued)

Practice	Design Constraints or Purpose	Percent Removal of TSS	Useful Life (years)[a]	Construction Cost	Annual Maintenance Cost (as % construction cost)	Total Annual Cost
Vegetative Filter Strip	Must have sheet flow.	Average: 70% Observed Range: 20% - 80% References: Hayes and Hairston, 1983 cited in Casman, 1990; Dillaha et al., 1989, cited in Glick et al., 1991; Virginia Department of Conservation, 1987; Nonpoint Source Control Task Force, 1983 cited in Minnesota PCA, 1989; Schueler, 1987	2	Established from existing vegetation- Average: $0 Range: $0 References: Schueler, 1987 Established from sod- Average: $11,300 per acre Range: $4,500 - $48,000 per acre References: Schueler, 1987; SWRPC, 1991	Average: NA Range: NA References: None	NA

NA - Not available.
[a] Useful life estimated as length of construction project (assumed to be 2 years)
[e] For Total Annual Cost, assume Annual Maintenance Cost=20% of construction cost.
[b] Assumes trap volume = 1800 cf/ac (0.5 inches runoff per acre).
[c] Assumes drainage area of 0.5 acre per 100 feet of fence (maximum allowed).
[d] Assumes drainage area of 0.25 acre per 100 feet of barrier (maximum allowed).

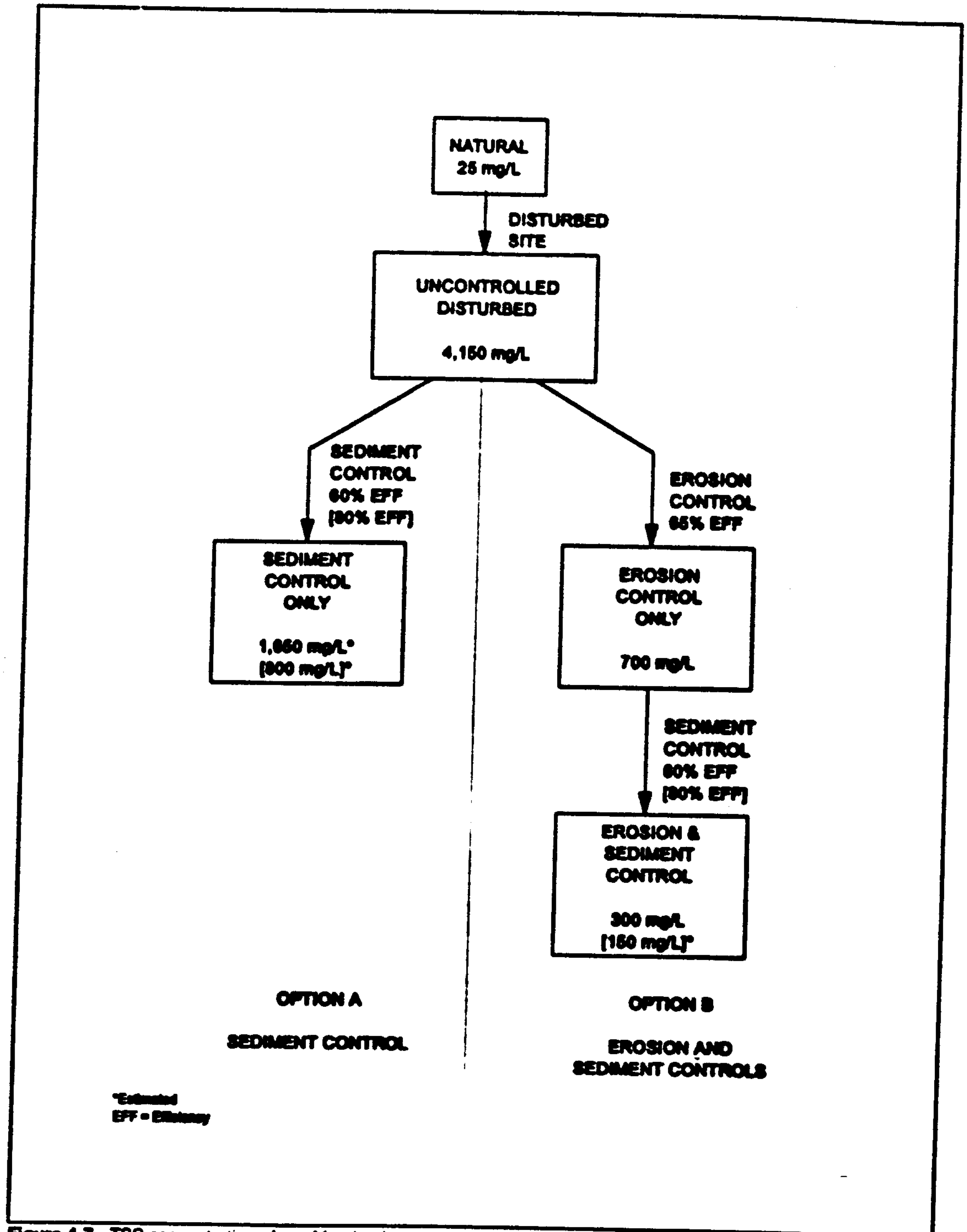

Figure 4-7. TSS concentrations from Maryland construction sites (Schueler, 1987).

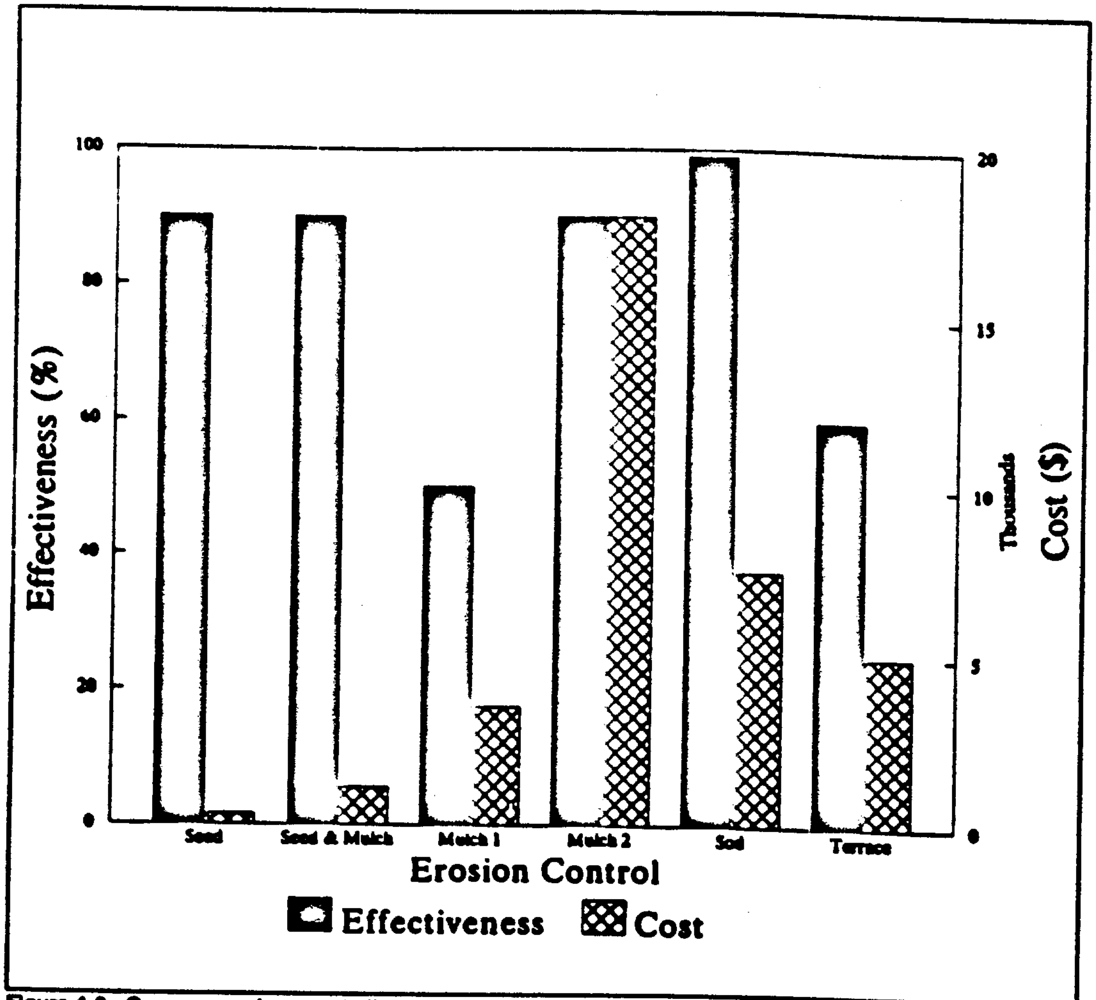

Figure 4-8. Comparison of cost and effectiveness for erosion control practices (based on information in Tables 4-15 and 4-16).

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(1) Limit application, generation, and migration of toxic substances;

(2) Ensure the proper storage and disposal of toxic materials; and

(3) Apply nutrients at rates necessary to establish and maintain vegetation without causing significant nutrient runoff to surface waters.

1. Applicability

This management measure is intended to be applied by States to all construction sites less than 5 acres in area and to new, resurfaced, restored, and reconstructed road, highway, and bridge construction projects. This management measure does not apply to: (1) construction of a detached single family home on a site of 1/2 acre or more or (2) construction that does not disturb over 5,000 square feet of land on a site. (NOTE: All construction activities, including clearing, grading, and excavation, that result in the disturbance of areas greater than or equal to 5 acres or are a part of a larger development plan are covered by the NPDES regulations and are thus excluded from these requirements.) Under the Coastal Zone Act Reauthorization Amendments of 1990, States are subject to a number of requirements as they develop coastal NPS programs in conformance with this management measure and will have flexibility in doing so. The application of management measures by States is described more fully in *Coastal Nonpoint Pollution Control Program: Program Development and Approval Guidance*, published jointly by the U.S. Environmental Protection Agency (EPA) and the National Oceanic and Atmospheric Administration (NOAA) of the U.S. Department of Commerce.

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2. Description

The purpose of this management measure is to prevent the generation of nonpoint source pollution from construction sites due to improper handling and usage of nutrients and toxic substances, and to prevent the movement of toxic substances from the construction site.

Many potential pollutants other than sediment are associated with construction activities. These pollutants include pesticides (insecticides, fungicides, herbicides, and rodenticides); fertilizers used for vegetative stabilization; petrochemicals (oils, gasoline, and asphalt degreasers); construction chemicals such as concrete products, sealers, and paints; wash water associated with these products; paper; wood; garbage; and sanitary wastes (Washington State Department of Ecology, 1991).

The variety of pollutants present and the severity of their effects are dependent on a number of factors:

(1) **The nature of the construction activity.** For example, potential pollution associated with fertilizer usage may be greater along a highway or at a housing development than it would be at a shopping center development because highways and housing developments usually have greater landscaping requirements.

(2) **The physical characteristics of the construction site.** The majority of all pollutants generated at construction sites are carried to surface waters via runoff. Therefore, the factors affecting runoff volume,

such as the amount, intensity, and frequency of rainfall; soil infiltration rates; surface roughness; slope length and steepness; and area denuded, all contribute to pollutant loadings.

(3) **The proximity of surface waters to the nonpoint pollutant source.** As the distance separating pollutant-generating activities from surface waters decreases, the likelihood of water quality impacts increases.

a. Pesticides

Insecticides, rodenticides, and herbicides are used on construction sites to provide safe and healthy conditions, reduce maintenance and fire hazards, and curb weeds and woody plants. Rodenticides are also used to control rodents attracted to construction sites. Common insecticides employed include synthetic, relatively water-insoluble chlorinated hydrocarbons, organophosphates, carbamates, and pyrethrins.

b. Petroleum Products

Petroleum products used during construction include fuels and lubricants for vehicles, for power tools, and for general equipment maintenance. Specific petroleum pollutants include gasoline, diesel oil, kerosene, lubricating oils, and grease. Asphalt paving also can be particularly harmful since it releases various oils for a considerable time period after application. Asphalt overloads might be dumped and covered without inspection. However, many of these pollutants adhere to soil particles and other surfaces and can therefore be more easily controlled.

c. Nutrients

Fertilizers are used on construction sites when revegetating graded or disturbed areas. Fertilizers contain nitrogen and phosphorus, which in large doses can adversely affect surface waters, causing eutrophication.

d. Solid Wastes

Solid wastes on construction sites are generated from trees and shrubs removed during land clearing and structure installation. Other wastes include wood and paper from packaging and building materials, scrap metals, sanitary wastes, rubber, plastic and glass, and masonry and asphalt products. Food containers, cigarette packages, leftover food, and aluminum foil also contribute solid wastes to the construction site.

e. Construction Chemicals

Chemical pollutants, such as paints, acids for cleaning masonry surfaces, cleaning solvents, asphalt products, soil additives used for stabilization, and concrete-curing compounds, may also be used on construction sites and carried in runoff.

f. Other Pollutants

Other pollutants, such as wash water from concrete mixers, acid and alkaline solutions from exposed soil or rock, and alkaline-forming natural elements, may also be present and contribute to nonpoint source pollution.

Revegetation of disturbed areas may require the use of fertilizers and pesticides, which, if not applied properly, may become nonpoint source pollutants. Many pesticides are restricted by Federal and/or State regulations.

Hydroseeding operations, in which seed, fertilizers, and lime are applied to the ground surface in a one-step operation, are more conducive to nutrient pollution than are the conventional seedbed-preparation operations, in which fertilizers and lime are tilled into the soil. Use of fertilizers containing little or no phosphorus may be required by local authorities if the development is near sensitive waterbodies. The addition of lime can also affect the pH of sensitive waters, making them more alkaline.

Improper fueling and servicing of vehicles can lead to significant quantities of petroleum products being dumped onto the ground. These pollutants can then be washed off site in urban runoff, even when proper erosion and sediment controls are in place. Pollutants carried in solution in runoff water, or fixed with sediment crystalline structures, may not be adequately controlled by erosion and sediment control practices (Washington Department of Ecology, 1991). Oils, waxes, and water-insoluble pesticides can form surface films on water and solid particles. Oil films can also concentrate water-soluble insecticides. These pollutants can be nearly impossible to control once present in runoff other than by the use of very costly water-treatment facilities (Washington Department of Ecology, 1991).

After spill prevention, one of the best methods to control petroleum pollutants is to retain sediments containing oil on the construction site through use of erosion and sediment control practices. Improved maintenance and safe storage facilities will reduce the chance of contaminating a construction site. One of the greatest concerns related to use of petroleum products is the method for waste disposal. The dumping of petroleum product wastes into sewers and other drainage channels is illegal and could result in fines or job shutdown.

The primary control method for solid wastes is to provide adequate disposal facilities. Erosion and sediment control structures usually capture much of the solid waste from construction sites. Periodic removal of litter from these structures will reduce solid waste accumulations. Collected solid waste should be removed and disposed of at authorized disposal areas.

Improperly stored construction materials, such as pressure-treated lumber or solvents, may lead to leaching of toxics to surface water and ground water. Disposal of construction chemicals should follow all applicable State and local laws that may require disposal by a licensed waste management firm.

3. Management Measure Selection

This management measure was selected based on the potential for many construction activities to contribute to nutrient and toxic NPS pollution.

This management measure was selected because (1) construction activities have the potential to contribute to increased loadings of toxic substances and nutrients to waterbodies; (2) various States and local governments regulate the control of chemicals on construction sites through spill prevention plans, erosion and sediment control plans, or other administrative devices; (3) the practices described are commonly used and presented in a number of best management practice handbooks and guidance manuals for construction sites; and (4) the practices selected are the most economical and effective.

4. Practices

As discussed more fully at the beginning of this chapter and in Chapter 1, the following practices are described for illustrative purposes only. State programs need not require implementation of these practices. However, as a practical matter, EPA anticipates that the management measure set forth above generally will be implemented by applying one or more management practices appropriate to the source, location, and climate. The practices set forth below have been found by EPA to be representative of the types of practices that can be applied successfully to achieve the management measure described above.

■ a. *Properly store, handle, apply, and dispose of pesticides.*

Pesticide storage areas on construction sites should be protected from the elements. Warning signs should be placed in areas recently sprayed or treated. Persons mixing and applying these chemicals should wear suitable protective clothing, in accordance with the law.

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Application rates should conform to registered label directions. Disposal of excess pesticides and pesticide-related wastes should conform to registered label directions for the disposal and storage of pesticides and pesticide containers set forth in applicable Federal, State, and local regulations that govern their usage, handling, storage, and disposal. Pesticides and herbicides should be used only in conjunction with Integrated Pest Management (IPM) (see Chapter 2). Pesticides should be the tool of last resort; methods that are the least disruptive to the environment and human health should be used first.

Pesticides should be disposed of through either a licensed waste management firm or a treatment, storage, and disposal (TSD) facility. Containers should be triple-rinsed before disposal, and rinse waters should be reused as product.

Other practices include setting aside a locked storage area, tightly closing lids, storing in a cool, dry place, checking containers periodically for leaks or deterioration, maintaining a list of products in storage, using plastic sheeting to line the storage area, and notifying neighboring property owners prior to spraying.

■ b. *Properly store, handle, use, and dispose of petroleum products.*

When storing petroleum products, follow these guidelines:

- Create a shelter around the area with cover and wind protection;
- Line the storage area with a double layer of plastic sheeting or similar material;
- Create an impervious berm around the perimeter with a capacity 110 percent greater than that of the largest container;
- Clearly label all products;
- Keep tanks off the ground; and
- Keep lids securely fastened.

Oil and oily wastes such as crankcase oil, cans, rags, and paper dropped into oils and lubricants should be disposed of in proper receptacles or recycled. Waste oil for recycling should not be mixed with degreasers, solvents, antifreeze, or brake fluid.

■ c. *Establish fuel and vehicle maintenance staging areas located away from all drainage courses, and design these areas to control runoff.*

Proper maintenance of equipment and installation of proper stream crossings will further reduce pollution of water by these sources. Stream crossings should be minimized through proper planning of access roads. Refer to Chapter 3 for additional information on stream crossings.

■ d. *Provide sanitary facilities for constructions workers.*

■ e. *Store, cover, and isolate construction materials, including topsoil and chemicals, to prevent runoff of pollutants and contamination of ground water.*

■ f. *Develop and implement a spill prevention and control plan. Agencies, contractors, and other commercial entities that store, handle, or transport fuel, oil, or hazardous materials should develop a spill response plan.*

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Post spill procedure information and have persons trained in spill handling on site or on call at all times. Materials for cleaning up spills should be kept on site and easily available. Spills should be cleaned up immediately and the contaminated material properly disposed of. Spill control plan components should include:

- Stop the source of the spill.
- Contain any liquid.
- Cover the spill with absorbent material such as kitty litter or sawdust, but do not use straw. Dispose of the used absorbent properly.

g. Maintain and wash equipment and machinery in confined areas specifically designed to control runoff.

Thinners or solvents should not be discharged into sanitary or storm sewer systems when cleaning machinery. Use alternative methods for cleaning larger equipment parts, such as high-pressure, high-temperature water washes, or steam cleaning. Equipment-washing detergents can be used, and wash water may be discharged into sanitary sewers if solids are removed from the solution first. (This practice should be verified with the local sewer authority.) Small parts can be cleaned with degreasing solvents, which can then be reused or recycled. Do not discharge any solvents into sewers.

Washout from concrete trucks should be disposed of into:

- A designated area that will later be backfilled;
- An area where the concrete wash can harden, can be broken up, and then can be placed in a dumpster; or
- A location not subject to urban runoff and more than 50 feet away from a storm drain, open ditch, or surface water.

Never dump washout into a sanitary sewer or storm drain, or onto soil or pavement that carries urban runoff.

h. Develop and implement nutrient management plans.

Properly time applications, and work fertilizers and liming materials into the soil to depths of 4 to 6 inches. Using soil tests to determine specific nutrient needs at the site can greatly decrease the amount of nutrients applied.

i. Provide adequate disposal facilities for solid waste, including excess asphalt, produced during construction.

j. Educate construction workers about proper materials handling and spill response procedures. Distribute or post informational material regarding chemical control.

IV. EXISTING DEVELOPMENT

A. Existing Development Management Measure

Develop and implement watershed management programs to reduce runoff pollutant concentrations and volumes from existing development:

(1) Identify priority local and/or regional watershed pollutant reduction opportunities, e.g., improvements to existing urban runoff control structures;

(2) Contain a schedule for implementing appropriate controls;

(3) Limit destruction of natural conveyance systems; and

(4) Where appropriate, preserve, enhance, or establish buffers along surface waterbodies and their tributaries.

1. Applicability

This management measure is intended to be applied by States to all urban areas and existing development in order to reduce surface water runoff pollutant loadings from such areas. Under the Coastal Zone Act Reauthorization Amendments of 1990, States are subject to a number of requirements as they develop coastal NPS programs in conformity with this management measure and will have flexibility in doing so. The application of management measures by States is described more fully in *Coastal Nonpoint Pollution Control Program: Program Development and Approval Guidance*, published jointly by the U.S. Environmental Protection Agency (EPA) and the National Oceanic and Atmospheric Administration (NOAA).

2. Description

The purpose of this management measure is to protect or improve surface water quality by the development and implementation of watershed management programs that pursue the following objectives:

(1) Reduce surface water runoff pollution loadings from areas where development has already occurred;

(2) Limit surface water runoff volumes in order to minimize sediment loadings resulting from the erosion of streambanks and other natural conveyance systems; and

(3) Preserve, enhance, or establish buffers that provide water quality benefits along waterbodies and their tributaries.

Maintenance of water quality becomes increasingly difficult as areas of impervious surface increase and urbanization occurs. For the purpose of this guidance, urbanized areas are those areas where the presence of "man-made" impervious surfaces results in increased peak runoff volumes and pollutant loadings that permanently alter one or more of the following:[5] stream channels, natural drainageways, and in-stream and adjacent riparian habitat so that predevelopment aquatic flora and fauna are eliminated or reduced to unsustainable levels and predevelopment water quality has been degraded. Increased bank cutting, streambed scouring, siltation damaging to aquatic flora and fauna, increases in water temperature, decreases in dissolved oxygen, changes to the natural structure and flow of the stream or river, and the presence of anthropogenic pollutants that are not generated from agricultural activities, in general, are indications of urbanization.

The effects of urbanization have been well described in the introduction to this chapter. Protection of water quality in urbanized areas is difficult because of a range of factors. These factors include diverse pollutant loadings, large runoff volumes, limited areas suitable for surface water runoff treatment systems, high implementation costs associated with structural controls, and the destruction or absence of buffer zones that can filter pollutants and prevent the destabilization of streambanks and shorelines.

As discussed in Section II.B of this chapter, comprehensive watershed planning facilitates integration of source reduction activities and treatment strategies to mitigate the effects of urban runoff. Through the use of watershed management, States and local governments can identify local water quality objectives and focus resources on control of specific pollutants and sources. Watershed plans typically incorporate a combination of nonstructural and structural practices.

An important nonstructural component of many watershed management plans is the identification and preservation of buffers and natural systems. These areas help to maintain and improve surface water quality by filtering and infiltrating urban runoff. In areas of existing development, natural buffers and conveyance systems may have been altered as urbanization occurred. Where possible and appropriate, additional impacts to these areas should be minimized and if degraded, the functions of these areas restored. The preservation, enhancement, or establishment of buffers along waterbodies is generally recommended throughout the section 6217 management area as an important tool for reducing NPS impacts. The establishment and protection of buffers, however, is most appropriate along surface waterbodies and their tributaries where water quality and the biological integrity of the waterbody is dependent on the presence of an adequate buffer/riparian area. Buffers may be necessary where the buffer/riparian area (1) reduces significant NPS pollutant loadings, (2) provides habitat necessary to maintain the biological integrity of the receiving water, and (3) reduces undesirable thermal impacts to the waterbody. For a discussion of protection and restoration of wetlands and riparian areas, refer to Chapter 7.

Institutional controls, such as permits, inspection, and operation and maintenance requirements, are also essential components of a watershed management program. The effectiveness of many of the practices described in this chapter is dependent on administrative controls such as inspections. Without effective compliance mechanisms and operation and maintenance requirements, many of these practices will not perform satisfactorily.

Where existing development precludes the use of effective nonstructural controls, structural practices may be the only suitable option to decrease the NPS pollution loads generated from developed areas. In such situations, a watershed plan can be used to integrate the construction of new surface water runoff treatment structures and the retrofit of existing surface water runoff management systems.

Retrofitting is a process that involves the modification of existing surface water runoff control structures or surface water runoff conveyance systems, which were initially designed to control flooding, not to serve a water quality improvement function. By enlarging existing surface water runoff structures, changing the inflow and outflow characteristics of the device, and increasing detention times of the runoff, sediment and associated pollutants can be removed from the runoff. Retrofit of structural controls, however, is often the only feasible alternative for improving water quality in developed areas. Where the presence of existing development or financial constraints limits treatment options, targeting may be necessary to identify priority pollutants and select the most appropriate retrofits.

[5] Changes resulting from dam building and "acts of God" such as earthquakes, hurricanes, and unusual natural events (e.g., a 100-year storm), as well as natural predevelopment riverine behavior that results in stream meander and deposition of sediments in sandbars or similar formations, are excluded from consideration in this definition. For additional information, refer to Chapter 6.

Once key pollutants have been identified, an achievable water quality target for the receiving water should be set to improve current levels based on an identified objective or to prevent degradation of current water quality. Extensive site evaluations should then be performed to assess the performance of existing surface water runoff management systems and to pinpoint low-cost structural changes or maintenance programs for improving pollutant-removal efficiency. Where flooding problems exist, water quality controls should be incorporated into the design of surface water runoff controls. Available land area is often limited in urban areas, and the lack of suitable areas will frequently restrict the use of conventional pond systems. In heavily urbanized areas, sand filters or water quality inlets with oil/grit separators may be appropriate for retrofits because they do not limit land usage.

3. Management Measure Selection

Components (1) and (2) of this management measure were selected so that local communities develop and implement watershed management programs. Watershed management programs are used throughout the 6217 management area although coverage is inconsistent among States and local governments (Puget Sound Water Quality Authority, 1986).

Local conditions, availability of funding, and problem pollutants vary widely in developed communities. Watershed management programs allow these communities to select and implement practices that best address local needs. The identification of priority and/or local regional pollutant reduction opportunities and schedules for implementing appropriate controls were selected as logical starting points in the process of instituting an institutional framework to address nonpoint source pollutant reductions.

Cost was also a major factor in the selection of this management measure. EPA acknowledges the high costs and other limitations inherent in treating existing sources to levels consistent with the standards set for developing areas. Suitable areas are often unavailable for structural treatment systems that can adequately protect receiving waters. The lack of universal cost-effective treatment options was a major factor in the selection of this management measure. EPA was also influenced by the frequent lack of funding for mandatory retrofitting and the extraordinarily high costs associated with the implementation of retention ponds and exfiltration systems in developed areas.

The use of retrofits has been encouraged because of proven water quality benefits. (Table 4-17 illustrates the effectiveness of structural runoff controls for developed areas and retrofitted structures.) Retrofits are currently being used by a number of States and local governments in the 6217 management area, including Maryland, Delaware, and South Carolina.

Management measure components (3) and (4) were selected to preserve, enhance, and establish areas within existing development that provide positive water quality benefits. Refer to the New Development and Site Planning Management Measures for the rationale used in selecting components (3) and (4) of this management measure.

4. Practices

As discussed more fully at the beginning of this chapter and in Chapter 1, the following practices are described for illustrative purposes only. State programs need not require implementation of these practices. However, as a practical matter, EPA anticipates that the management measure set forth above generally will be implemented by applying one or more management practices appropriate to the source, location, and climate. The practices set forth below have been found by EPA to be representative of the types of practices that can be applied successfully to achieve the management measure described above.

■ a. ***Priority NPS pollutants should be targeted, and implementation strategies for mitigating the effects of NPS pollutants should be developed.***

■ b. ***Policies, plans, and organizational structures that ensure that all surface water runoff management facilities are properly operated and maintained should be developed. Periodic monitoring and maintenance may be necessary to ensure proper operation and maintenance.***

Table 4-17. Existing Development Management Practices Effectiveness Summary

Management Practice		% Removal TSS	TP	TN	COD	Pb	Zn	Main Removal Efficiency Factors	References
Water Quality Inlet - Catch Basin (1)	Average:	15	5	5	5	15	5	• Maintenance • Sedimentation storage volume	Pitt, 1986; Field, 1985; Schueler, 1987
	Reported Range:	10-96	5-10	5-10	5-10	10-55	5-10		
	Probable Range:	10-25	5-10	5-10	5-10	10-25	5-10		
	No. Values Considered:	2	1	1	1	3	1		
Water Quality Inlet - Catch Basins With Sand Filter (1)	Average:	80	NA	35	55	80	65	• Sedimentation storage volume • Depth of filter media	Shaver, 1991
	Reported Range:	75-86	NA	30-45	45-70	70-90	50-80		
	Probable Range:	70-90	--	30-40	40-70	70-90	50-80		
	No. Values Considered:	1	0	1	1	1	1		
Water Quality Inlet - Oil/Grid Separator (1)	Average:	15	5	5	5	15	5	• Sedimentation storage volume • Outlet configurations	Pitt, 1986; Schueler, 1987
	Reported Range:	10-25	5-10	5-10	5-10	10-25	5-10		
	Probable Range:	10-25	5-10	5-10	5-10	10-25	5-10		
	Number of References	1	1	1	1	1	1		
Dry Pond Modified Into Ed Dry Pond	Average:	45	25	35	20	45	20	• Storage volume • Detention time • Pond shape	MWCOG, 1983; City of Austin, 1990; Schueler and Helfrich, 1988; Pope and Hess, 1989; OWML, 1987; Welinski and Stack, 1990
	Reported Range:	5-90	10-55	20-60	0-40	25-65	(-40)-65		
	Probable Range (2):	70-80	10-60	20-60	30-40	20-60	40-60		
	No. Values Considered:	6	6	4	5	4	5		

Table 4-17. (Continued)

Management Practice		% Removal						Main Removal Efficiency Factors	References
		TSS	TP	TN	COD	Pb	Zn		
Dry Pond Modified into Wet Pond	Average:	60	45	35	40	70	60	• Pool volume • Pond shape	Wetzka and Oberta, 1988; Yoosef et al., 1986; Collum, 1985; Driscoll, 1983; Driscoll, 1986; MWCOG, 1983; OWML, 1983; Wu et al., 1988; Holter, 1987; Martin, 1988; Darmay et al., 1989; OWML, 1982; City of Austin ,1990
	Reported Range:	(-30)-91	10-85	5-85	5-90	10-95	10-95		
	Probable Range:	50-90	20-90	10-90	10-90	10-95	20-95		
	No. Values Considered:	11	10	7	4	8	7		
Dry Pond or Wet Pond Modified into ED Wet Pond	Average:	80	65	55	NA	40	20	• Pool volume • Pond shape • Detention time	Ontario Ministry of the Environment, 1991
	Reported Range:	50-100	50-80	55	NA	40	20		
	Probable Range:	50-95	50-80	—	—	—	—		
	No. Values Considered:	1	1	1	0	1	1		
Streambank Stabilization	Average:	NA	NA	NA	NA	NA	NA		MWCOG, 1990
	Reported Range:	NA	NA	NA	NA	NA	NA		
	Probable Range:	–	–	–	–	–	–		
	No. Values Considered:	0	0	0	0	0	0		
Riparian Forest (assumed same as Vegetated Filter Strip)	Average:	70	50	60	70	20	50	• Runoff volume • Slope • Soil infiltration rates • Vegetative cover • Buffer length	IEP, 1991; Casman, 1990; Glick et al., 1991; VADC, 1987; Minnesota CA, 1989; Schueler, 1987; Hartigen et al., 1989
	Reported Range:	20-80	30-95	40-70	60-80	20	50		
	Probable Range (3):	40-90	30-80	20-80	–	30-80	20-50		
	No. Values Considered:	6	3	2	1	2	2		

Table 4-17. (Continued)

Management Practice		% Removal						Main Removal Efficiency Factors	References
		TSS	TP	TN	COD	Pb	Zn		
Wetland (assumed same as Constructed Storm Water Wetlands)	Average:	65	25	20	50	65	35	• Storage volume • Detention time • Pool shape • Wetland's biota • Seasonal Variation	Harper et al., 1986; Brown, 1985; Wotzka and Obert, 1988; Hickack et al., 1977; Barten, 1987; Meloria, 1986; Morris et al., 1981; Sherberger and Davis, 1982; ABAG, 1979; Oberts et al., 1989; Rushton and Dye, 1990; Hey and Barrett, 1991
	Reported Range:	(-20)-100	(-120)-100	(-15)-40	20-80	30-95	(-30)-80		
	Probable Range (6):	50-90	(-5)-80	0-40	—	30-95	—		
	No. Values Considered:	14	14	6	2	6	4		

c. Remnant pervious areas in already-built areas should be subject to enforceable preservation requirements. For example, set green space goals to promote tree plantings and pavement reclamation projects.

d. Developed areas in need of local or regional structural solutions should be identified and put in priority order.

e. Regional structural solutions, retrofit opportunities, and nonstructural alternatives should be identified, inventoried, and put in priority order.

f. Where possible, modify existing surface water runoff management structures to address water quality.

g. As capital resources allow, implement practices such as those in Table 4-17.

5. Effectiveness Information and Cost Information

The following is a general description of various retrofit options and their effectiveness. Since each retrofit situation is different, the costs will depend on site-specific factors such as climate, drainage area, or pollutants. Table 4-17 discusses the effectiveness of several practices often implemented when correcting existing NPS pollution problems in urban areas.

a. Construction or Modification of Pollutant Removal Facilities

Many of the management practices described in Section II of this chapter cannot be used in already urbanized areas because they require space that is typically not available in urbanized areas. However, two types of pollutant removal retrofits can be used to treat runoff: new treatment facilities can be built in limited land space, and existing facilities can be modified to obtain increased water quality benefits.

New Facilities. If there is space available, the management practices described in Section II can be applied to provide water quality benefits. Typically, however, there are space constraints in urbanized areas that will not allow construction of these facilities. Water quality inlets may be appropriate in areas where space is limited and runoff from highly impervious areas such as parking lots must be treated. The effectiveness and costs of these facilities would be similar to those previously discussed. There are several types of water quality inlets—catch basins, catch basins with sand filters, and oil/grit separators. These are described in detail in Section II.

Retrofit of Existing Facilities. In the past, many surface water runoff management facilities were constructed to provide peak volume control; however, no provisions for pollutant removal were provided. These existing facilities can be modified to provide water quality benefits. Two common modifications are dry pond conversion and fringe marsh creation.

- Dry Pond Conversion. Many dry ponds for surface water runoff management that provide peak volume control, but no water quality benefits, have been constructed. Many of these ponds can be modified to provide water quality control. These modifications can include decreasing the size of the outlet to increase the detention of the dry pond. A dry pond's outlet may also be modified to detain a permanent pool of water and thus create a wet pond or extended detention wet pond. Prince George's County, Maryland, has a successful program for urban retrofits. They are usually off-line facilities with forebays, vegetative benches, and deeper portions for storage.

- Fringe Marsh Creation. Aquatic vegetation can be planted along the perimeter of constructed wet ponds or other open water systems to enhance sediment control and provide some biological pollutant uptake.

b. Stabilization of Shorelines, Stream Banks, and Channels

Urbanization can significantly increase the volume and velocity of surface water runoff that has the potential to erode streambanks and channels. This erosion can create high sediment loads in surface water. Streambanks can be stabilized by providing plantings along the streambank or by placing boulders, riprap, retaining walls, or other structural controls in eroding areas. Where feasible, vegetation and other soft practices should be used instead of hard, structural practices. See the Shoreline and Streambank Protection section of Chapter 6 for additional information.

c. Protection and Restoration of Riparian Forest and Wetland Areas

Riparian forests and wetlands are very effective water quality controls. They should be protected and restored wherever possible. Riparian forests can be restored by replanting the banks and floodplains of a stream with native species to stabilize erodible soils and improve surface water and ground water quality. Refer to Chapter 7 for additional information.

Some examples of urban watershed retrofit programs are presented below. The first case study, the Anacostia watershed, involves a developed urban area suffering from multiple NPS pollution impacts. As with many of the examples given, the project has advanced only through the planning and early implementation stages. Therefore, performance data are not currently available.

CASE STUDY 1 - ANACOSTIA WATERSHED, MARYLAND

Opportunities for urban retrofitting are limited in developed watersheds, but they can be implemented through extensive onsite evaluations. For example, between 1989 and 1991 over 125 sites in the 179-square-mile Anacostia watershed in Montgomery County, Maryland, were identified as candidates for retrofitting after extensive on-site evaluation (Schueler et al., 1991). Retrofit options developed in the watershed included source reduction, extended detention (ED) marsh ponds or ED ponds to handle the first flush, additional storage capacity in the open channel, routing of surface water runoff away from sensitive channels, diversion of the first flush to sand-peat filters, and installation of oil/grit separators in the drain network itself. The most commonly used retrofit technique in the Anacostia watershed is the retrofit of existing dry surface water runoff detention or flood control structures to improve their runoff storage and treatment capacity. Existing detention ponds are maintained by excavation, adding to the elevation of the embankment, or by construction of low-flow orifices. The newly created storage is used to provide a permanent pool, extended detention storage, or a shallow wetland. Nearly 20 such retrofits are in some stage of design or construction in the Anacostia watershed.

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CASE STUDY 2 - LOCH RAVEN RESERVOIR, MARYLAND
(Stack and Belt, 1989)

Loch Raven Reservoir, a water supply reservoir serving Baltimore, Maryland, had a eutrophication problem due to excessive phosphorus loads. To address this problem, the city examined the effectiveness of its existing phosphorus controls. They found that the more than 24 extended detention dry ponds that had been originally constructed for surface water runoff management had been designed to treat the once-in-10-year or once-in-100-year flood. The extended detention ponds were thus inefficient at treating runoff from frequent storm events, and the city was receiving few water quality benefits from these structures. Modifications, or retrofits, allowed the basins to collect runoff from smaller events and reduce pollutant loadings without affecting their capacity to contain runoff from larger storms.

Difficulties in obtaining permission from private pond owners restricted the number of ponds with planned retrofits to six ponds owned by the county and one privately owned pond. Private owners were concerned about the maintenance costs associated with the retrofits. Changes to the ponds usually involved alteration of the size of the orifice of the low-flow release structure. Computer modeling was used to determine the minimum size that would not interfere with the pond's design criteria (i.e., containing the 2-, 10- and 100-year storms) while providing sufficient detention time to settle the majority of the solids in urban runoff from the more frequent storms. Each retrofit was tailored to the basin's unique outlet and site characteristics, and costs reflect the differences in approach. For example, one of the ponds was modified as an urban runoff wetland for an estimated cost of $27,800. Retrofits of dry ponds were the least expensive, with costs of less than about $2,000. Draining and dredging boosted the cost of retrofitting a wet pond with a clogged low-flow release structure to approximately $13,000.

Monitoring of the performance of the retrofits during 12 storm events measured removal efficiencies for particulate matter of over 90 percent and removal efficiencies for total phosphorus of between 30 and 40 percent. All of the storms monitored were less than the 1-year storm, and detention times ranged from 1 to 5 hours. Trash debris collectors were effective at reducing clogging; thus no maintenance was necessary in the first year of operation.

CASE STUDY 3 - INDIAN RIVER LAGOON, FLORIDA
(Bennett and Heaney, 1991)

Improper surface water runoff drainage practices have degraded the quality of Florida's Indian River Lagoon by increasing the volume of freshwater runoff to the estuarine receiving water, as well as increasing the loading of suspended solids. Draining of wetlands for urban and agricultural development has led to nutrient loading in the lagoon.

The study area, typical of most Florida flatwood watersheds, was selected as a representative drainage catchment. EPA's Storm Water Management Model (SWMM) was used to summarize the relationship between catchment hydrology, channel hydraulics, and pollutant loads. The model, calibrated for the study region, was used to evaluate the effectiveness of the proposed watershed control program and to project performance levels expected after the study region becomes fully developed. The retrofit of multiple structural measures was undertaken as a demonstration-scale project. An existing trunk channel was modified to act as a wet detention basin. Flow from the trunk channel enters a partially disturbed, interdunal, freshwater wetland. The wetland system provides nutrient assimilation, additional water storage capacity, sediment attenuation, and enhanced evapotranspiration. SWMM predicted that the project will remove between 8[illegible] percent and 85 percent of the total suspended solids, depending on the level of future development. The cost of the project in 1989 dollars, including operation and monitoring costs over a 10-year period, was $198,960.

V. ONSITE DISPOSAL SYSTEMS

A. New Onsite Disposal Systems Management Measure

(1) Ensure that new Onsite Disposal Systems (OSDS) are located, designed, installed, operated, inspected, and maintained to prevent the discharge of pollutants to the surface of the ground and to the extent practicable reduce the discharge of pollutants into ground waters that are closely hydrologically connected to surface waters. Where necessary to meet these objectives: (a) discourage the installation of garbage disposals to reduce hydraulic and nutrient loadings; and (b) where low-volume plumbing fixtures have not been installed in new developments or redevelopments, reduce total hydraulic loadings to the OSDS by 25 percent. Implement OSDS inspection schedules for preconstruction, construction, and postconstruction.

(2) Direct placement of OSDS away from unsuitable areas. Where OSDS placement in unsuitable areas is not practicable, ensure that the OSDS is designed or sited at a density so as not to adversely affect surface waters or ground water that is closely hydrologically connected to surface water. Unsuitable areas include, but are not limited to, areas with poorly or excessively drained soils; areas with shallow water tables or areas with high seasonal water tables; areas overlaying fractured bedrock that drain directly to ground water; areas within floodplains; or areas where nutrient and/or pathogen concentrations in the effluent cannot be sufficiently treated or reduced before the effluent reaches sensitive waterbodies;

(3) Establish protective setbacks from surface waters, wetlands, and floodplains for conventional as well as alternative OSDS. The lateral setbacks should be based on soil type, slope, hydrologic factors, and type of OSDS. Where uniform protective setbacks cannot be achieved, site development with OSDS so as not to adversely affect waterbodies and/or contribute to a public health nuisance;

(4) Establish protective separation distances between OSDS system components and groundwater which is closely hydrologically connected to surface waters. The separation distances should be based on soil type, distance to ground water, hydrologic factors, and type of OSDS;

(5) Where conditions indicate that nitrogen-limited surface waters may be adversely affected by excess nitrogen loadings from ground water, require the installation of OSDS that reduce total nitrogen loadings by 50 percent to ground water that is closely hydrologically connected to surface water.

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1. Applicability

This management measure is intended to be applied by States to all new OSDS including package plants and small-scale or regional treatment facilities not covered by NPDES regulations in order to manage the siting, design,

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installation, and operation and maintenance of all such OSDS. Under the Coastal Zone Act Reauthorization Amendments of 1990, States are subject to a number of requirements as they develop coastal NPS programs in conformity with this management measure and will have flexibility in doing so. The application of management measure by States is described more fully in *Coastal Nonpoint Pollution Control Program: Program Development and Approval Guidance*, published jointly by the U.S. Environmental Protection Agency (EPA) and the National Oceanic and Atmospheric Administration (NOAA) of the U.S. Department of Commerce.

2. Description

The purpose of this management measure is to protect the 6217 management area from pollutants discharged by OSDS. The measure requires that OSDS be sited, designed, and installed so that impacts to waterbodies will be reduced, to the extent practicable. Factors such as soil type, soil depth, depth to water table, rate of sea level rise, and topography must be considered in siting and installing conventional OSDS.

The objective of the management measure is to prevent the installation of conventional OSDS in areas where soil absorption systems will not provide adequate treatment of effluents containing solids, phosphorus, pathogens, nitrogen, and nonconventional pollutants prior to entry into surface waters and ground water (e.g., highly permeable soils, areas with shallow water tables or confining layers, or poorly drained soils). In addition to soil criteria, setbacks, separation distances, and management and maintenance requirements need to be established to fulfill the requirements of this management measure. Guidance on design factors to consider in the installation of OSDS is available in EPA's *Design Manual for Onsite Wastewater Treatment and Disposal Systems* (1980), currently under revision. This measure also requires that in areas experiencing pollution problems due to OSDS-generated nitrogen loadings, OSDS designs should employ denitrification systems or some other nitrogen removal process that reduces total nitrogen loadings by at least 50 percent. Additionally, hydraulic loadings to OSDS can be reduced by up to 25 percent by installing low-volume plumbing fixtures and enforcing water conservation measures. Garbage disposals are to be discouraged in all new development or redevelopment where conventional OSDS are employed as another means of reducing overloading and ensure proper operation of the OSDS. Regularly scheduled maintenance and pumpout of OSDS will prolong the life of the system and prevent degradation of surface waters.

States need not conduct new monitoring programs or collect new monitoring data to determine whether ground water is closely hydrologically connected to surface water, nor are States expected to determine exactly where the resulting water quality problems are significant. Rather, States are encouraged to make reasonable determinations based upon existing information and data sources.

3. Management Measure Selection

This management measure was selected to address the proper siting, design, and installation of new OSDS in the 6217 management area. OSDS have been identified as contributors of pathogens, nutrients, and other pollutants to ground water and surface waters. Nearly all coastal States have siting regulations establishing criteria for setbacks, separation distances, and percolation rates (Myers, 1991; WCFS, 1992). However, these programs often do not adequately protect surface waters from pollutants generated by OSDS. This management measure was selected to ensure that States comprehensively control new OSDS siting, design, and installation in order to protect surface waters.

The management measure components were selected to address problems known to be associated with OSDS. These management measure components were selected because proper siting of OSDS and the use of setbacks have been identified as effective methods for reducing nutrient and pathogen loadings to ground water and surface waters. All components of this management measure were selected to direct the placement of OSDS away from areas where site conditions are inadequate to allow proper treatment to occur and areas where there is a high potential for subsequent system failures that may cause contamination of waterbodies. In addition, this management measure was selected because siting and density controls can be effective complements to denitrifying systems. However, these requirements alone are often not adequate to protect surface waters, particularly in situations where installation and replacement of OSDS are allowed without thorough consideration of OSDS-related impacts. Periodic reevaluation of these requirements is necessary to ensure protection of surface waters.

Management measure components (1) (a) and (b) were selected to reduce occurrences of hydraulic overloading of conventional OSDS, which may result in inadequate treatment of septic system effluent and contamination of ground water or surface water. When excessive wastewater volumes are delivered to the soil absorption field, failure can occur. In addition, soil saturated with wastewater will not allow oxygen to pass into the soil. Hydraulic overloading often results from changes in water use habits, such as increased family size, the addition of new water-using appliances that require increased water consumption, or high seasonal use. New systems may fail within a few months if water use exceeds the system's capacity to absorb effluent (Mancl, 1985). Water conservation reduces the amount of water an absorption field must accept.

Since numerous States have responded to this concern by adopting low-flow plumbing fixture regulations (Table 4-18), requiring such fixtures is not unreasonable. In addition, a number of States have regulations prohibiting the installation of garbage disposals where OSDS are used. If low-flow plumbing fixtures are used, it is important that OSDS design not be modified to decrease the required septic tank size. The use of smaller septic tanks will negate the advantages of using low-flow plumbing fixtures.

For absorption fields to operate properly, they must have aerobic conditions. Jarrett et al. (1985) stated that 75 percent of the total number of soil absorption field failures could be attributed to hydraulic overloading. High-efficiency plumbing fixtures can reduce the total water load by as much as 60 percent (Jarrett et al., 1985) and reduce the chance of absorption field failure. Table 4-19 illustrates daily water use and pollutant loadings.

Management measure component (5) was selected to abate OSDS nitrogen loadings to surface waters where nitrogen is a cause of surface water degradation. The Chesapeake Bay Program (1990) found that 55 to 85 percent of the nitrogen entering a conventional OSDS can be discharged into ground water. Conventional septic systems account for 74 percent of the nitrogen entering Buttermilk Bay (at the northern end of Buzzard's Bay) in Massachusetts (Horsely Witten Hegeman, 1991). A study of nitrogen entering the Delaware Inland Bays found that a significant portion of the total pollutant load could be attributed to septic systems. The study determined that septic systems accounted for 15 percent, 16 percent, and 11 percent of the nitrogen inputs to Assawoman, Indian River, and Rehoboth Bays, respectively (Reneau, 1977; Ritter, 1986). Alternatives to conventional OSDS that can substantially reduce nitrogen loadings are available.

In 1980, EPA developed a design manual for onsite wastewater treatment and disposal systems. An update of this document is being prepared.

4. Practices

As discussed more fully at the beginning of this chapter and in Chapter 1, the following practices are described for illustrative purposes only. State programs need not require implementation of these practices. However, as a practical matter, EPA anticipates that the management measure set forth above generally will be implemented by applying one or more management practices appropriate to the source, location, and climate. The practices set forth below have been found by EPA to be representative of the types of practices that can be applied successfully to achieve the management measure described above.

Many of the following practices involve siting and locating OSDS within the 6217 management area. They address issues such as minimum lot size, depth to water table, and site-specific characteristics such as soil percolation rate. Table 4-20 illustrates the variability in State and local requirements for siting of OSDS. The practices were developed to address the issue of siting OSDS given the variable nature of this activity.

■ a. *Develop setback guidelines and official maps showing areas where conditions are suitable for conventional septic OSDS installation.*

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Table 4-18. States That Have Adopted Low-Flow Plumbing Fixture Regulations (In gallons per flush for toilets and gallons per minute for other fixtures) (Small Flows Clearinghouse, 1991)[a]

State	Effective Date	Water Closets	Urinal	Shower Heads	Lavatory Faucets	Kitchen Faucets
California	01/01/92	1.6	1.0	2.5 @ 80 psi	2.2 @ 60 psi	2.2 @ 60 psi
Colorado	01/01/90	3.5		3.0 @ 80 psi	2.5 @ 80 psi	2.5 @ 80 psi
Connecticut	10/01/90		1.0	2.5	2.5	2.5
	01/01/92	1.6				
Delaware	07/01/91	1.6	1.5	3.0 @ 80 psi	3.0 @ 80 psi	3.0 @ 80 psi
Georgia						
Residential	04/01/92	1.6	1.0	2.5 @ 60 psi	2.0	2.5
Commercial	07/01/92	1.6	1.0	2.5 @ 60 psi	2.0	2.5
Massachusetts	03/02/89	1.6 (1-piece)	1.5			
	01/01/88			3.0		
	09/01/91	1.6 (all others)				
New Jersey	07/01/91	1.6	1.5	3.0	3.0	3.0
New York	1980			3.0 @ psi		3.0
	01/26/88		1.0			
	01/01/91				2.0	
	01/01/92	1.6				
Oregon	07/01/93	1.6	1.0	2.5	2.5	2.5
Rhode Island	09/01/90	1.6 (2-piece)		2.5 @ 80 psi	2.0 @ 80 psi	2.0 @ 80 psi
	03/01/91	1.6 (all others)	1.0			
Texas	01/01/92	1.6[b]	1.0	2.75 @ 80 psi	2.2 @ 80 psi	2.2 @ 80 psi
Washington	07/01/93	1.6	1.0	2.5 @ 80 psi	2.5 @ 80 psi	2.5 @ 80 psi

psi = pounds per square inch.
[a] Information provided by Judith L. Ranton, City of Portland, Oregon, Bureau of Water Works.
[b] 2.0 gallons or flow rate for ANSI ultra-low flush toilets, whichever is lowest for wall-mounted with flushometers.

Table 4-19. Daily Water Use and Pollutant Loadings by Source (USEPA, 1980)

Water Use	Volume (L/capita)	BOD (g/capita)	SS (g/capita)	Total N (g/capita)	Total P (g/capita)
Garbage Disposal	4.54	10.8	15.9	0.4	0.6
Toilet	61.3	17.2	27.6	8.6	1.2
Basins and Sinks	84.8	22.0	13.6	1.4	2.2
Misc.	25.0	0	0	0	0
Total	175.6	50.0	57.0	10.4	3.5

L = liters
g = grams

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Both conventional and alternative OSDS usually include a soil absorption field. These absorption fields require a certain minimum area of soil surrounding the system to effectively remove pathogens and other pollutants. Setbacks from wells, surface waters, building foundations, and property boundaries are necessary to minimize the threat to public health and the environment. The setback should be based on soil type, slope, presence and character of the water table (as defined on a map developed by the implementing agency), and the type of OSDS. Setback guidelines should be set for both traditional and alternative OSDS. The *Design Manual for Onsite Wastewater Treatment and Disposal Systems* (USEPA, 1980) recommends the following setbacks for soil absorption systems, although other increased setbacks may be necessary to protect ground water and surface waters from viral and bacteria transport to account for tidal influences and accommodate sea level rise. (NOTE: Setback distance requirements may vary considerably based on local soil conditions and aquifer properties):

Water supply wells	50 to 100 feet
Surface waters, springs	50 to 100 feet
Escarpments	10 to 20 feet
Boundary of property	5 to 10 feet
Building foundations	10 to 20 feet (30 feet when located up-slope from a building in slowly permeable soils)

For mound systems, the mound perimeter requires down-slope setbacks to make certain that the basal area of the mound is sufficient to absorb the wastewater before it reaches the perimeter of the mound to avoid surface seepage. The *Design Manual for Onsite Wastewater Treatment and Disposal Systems* (USEPA, 1980) provides guidance on setbacks for mound systems.

b. OSDS should be sited, designed, and constructed so that there is sufficient separation between the soil absorption field and the seasonal high water table or limiting layer, depending on site characteristics, including but not limited to hydrology, soils, and topography.

Studies have shown that at least 4 feet of unsaturated soil below the ponded liquid in a soil absorption field is necessary to (1) remove bacteria and viruses to an acceptable level, (2) remove most organics and phosphorus, and (3) nitrify a large portion of the ammonia (University of Wisconsin, 1978). The majority of coastal States already require a minimum separation distance of at least 2 feet (Woodward-Clyde, 1992). Massachusetts requires a minimum separation of 4 feet; 5 feet is required by towns with sensitive surface waters. Several towns on Cape Cod have adopted 5 feet as the minimum. A prescribed minimum distance is necessary to prevent contaminants from directly entering ground water and surface waters. Areas with rapid soil permeabilities (e.g., a percolation rate of less than 5 minutes/inch) may require a greater separation distance. However, because of local variation, these numbers are provided only as guidance.

A study on a barrier island of North Carolina (Carlile et al., 1981) found high concentrations of nitrogen, phosphorus, and pathogens in shallow ground-water wells located beneath septic system soil absorption fields. These high concentrations were suspected to be the result of inadequate separation distance to the water table. Further analysis revealed that, at the design loading rate, a greater separation distance reduced the ground-water concentration of indicator organisms from 4.6 to 2.3 logs, and phosphorus by 93 percent. Nitrogen levels were also reduced, but this improvement (10 percent) was not as dramatic as that observed for bacteria and phosphorus.

c. Require assessments of site suitability prior to issuing permits for OSDS.

Site assessments should be performed to determine the soil infiltration rate, soil pollutant removal capacity, acceptable hydraulic loading rate, and depth to the water table prior to issuing permits for OSDS. Percolation tests are usually performed to determine the soil infiltration rate. However, Hill and Frink (1974) stated that percolation tests are often performed improperly and system failures have resulted from improper siting and inadequate percolation rates. In addition, regulatory values based on acceptable percolation rates vary considerably (e.g., Delaware - 6 to 60 min/in; Georgia - 50 to 90 min/in; Michigan - 3 to 60 min/in; and Virginia - 5 to 120 min/in

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Table 4-20. Example Onsite Sewage Disposal System Siting Requirements

State	OSDS Siting Requirement
Florida	With respect to ground-water movement, the State requires that onsite systems must be placed no closer than 75 ft from a private potable water well, 100 ft from a public drinking water well, and 200 ft from a public drinking water well serving a facility with an estimated sewage flow of more than 2,000 gallons per day. Systems must not be located within 5 ft of building foundations or laterally within 75 ft of the mean high water line. Subdivisions and lots where each lot has a minimum area of at least 1/2 acre and either a minimum dimension of 100 ft or a mean of at least 100 ft from the street may be developed with private potable wells or wells serving water systems and onsite sewage disposal systems.
Massachusetts	The State requires that no septic tank shall be closer than 10 ft and no leaching facility shall be closer than 20 ft to surface water supplies; no septic tank shall be closer than 25 ft and no leaching facility shall be closer than 50 ft to watercourses. Onsite systems must be at least 4 ft above ground water.
South Carolina	No State requirement. County requirements vary. For example, the County of Charleston recommends a minimum lot size of 12,500 ft^2 with a 70-ft front on lots with public water supplies and 30,000 ft^2 with a 100-ft front for lots with private water supplies.
Virginia	The Chesapeake Bay Act requires that no sewage system shall be placed within 25 ft of a Resource Preservation Watercourse or within 100 ft of a Resource Management Watercourse. In the event that these requirements cannot be met, the State requires minimum setbacks of 70 ft for shellfish waters, 50 ft for impounded surface waters, and 50 ft for streams.
Washington	The State requires a 1/2- to 1-acre minimum lot size, dependent upon soil type, for areas served by public water supplies and a 1- to 2-acre minimum lot size for septic tank siting, dependent upon soil type, for individual areas served by water supplies and private wells.
Wisconsin	The State requirements of lot areas and widths vary according to percolation rate (measured as time required to percolate 1 inch). For example, for a lot with a private water supply system and a percolation rate of under 10 minutes, a minimum lot area of 20,000 ft^2, a minimum average lot width of 100 ft, and a minimum continuous suitable soil area of 10,000 ft^2 are required before an OSDS can be sited. For areas served by a community water supply system, a lot with a percolation rate of under 10 minutes requires a minimum lot area of 12,000 ft^2, a minimum average lot width of 75 ft, and a minimum continuous suitable soil area of 6,000 ft.

(Woodward-Clyde, 1992). States such as Florida and Mississippi require soil evaluations to determine the suitability of an absorption field. A soil evaluation should also be used in conjunction with percolation test results to determine whether a site is acceptable, and soil percolation requirements should be phased out, if appropriate. These evaluations should examine the organic content of the soil, the grain size distribution, and the structure of the soil. In addition, hydraulic loading should be evaluated to determine the suitability of a site for septic tank use.

A system such as DRASTIC methodology (USEPA, 1987) can also be used to map areas where aquifers may be vulnerable to pollution from OSDS. DRASTIC considers soil permeability, depth to ground water, and aquifer characteristics.

■ *d. If OSDS are sited in areas where conditions indicate that nitrogen-limited waters may be adversely affected by excessive nitrogen loading, minimize densities of development in those areas and require the use of denitrification systems.*

In areas where nitrogen is a problem pollutant, it is important to consider the density of OSDS. As the density of residences increases, lot sizes decrease and impacts (especially from nitrogen) on underlying ground water may intensify. One-half to 5-acre lots are generally the minimal requirement for siting OSDS, but the lot size may need to be larger if nitrogen is a problem pollutant. Limits on the density of absorption fields should also reflect variations in climate (Rutledge et al., undated). In Buzzards Bay, Massachusetts, a minimum lot size of 70,000 square feet was recommended as necessary to avoid nitrogen-induced degradation (Horsely Witten Hegeman, 1991). However, this practice should not preclude implementation of the use of cluster development to retain open areas necessary for controlling NPS pollution.

A number of treatment systems are known to remove nitrogen using denitrification. Such systems include sand and anaerobic upflow filters, and constructed wetlands. These systems are described in practice "f." Most of these systems require nitrification of septic tank effluent as an initial stage of the treatment process. When properly operated, these systems have been shown to have the potential to remove over 50 percent of the total nitrogen from septic tank effluent.

■ *e. Develop and implement local plumbing codes that require practices that are compatible with OSDS use.*

As stated previously, the majority of OSDS soil absorption field failures are attributed to hydraulic overload. Solids loads from garbage disposals can also lead to clogging and failure of an absorption field. To address these problems, plumbing codes that minimize the potential for soil absorption field failure should be implemented.

Plumbing codes that require the use of high-efficiency plumbing fixtures in new development can reduce these water loads considerably. Such high-efficiency fixtures include toilets of 1.5 gallons or less per flush, shower heads of 2.0 gallons per minute (gpm), faucets of 1.5 gpm or less, and front-loading washing machines of up to 27 gallons per 10- to 12-pound load. Implementing these fixtures can reduce total in-house water use by 30 percent to 70 percent (*Consumer Reports* July 1990, February 1991).

■ *f. In areas suitable for OSDS, select, design, and construct the appropriate OSDS that will protect surface waters and ground water.*

Selection of an OSDS should consider site soil and ground-water characteristics and the sensitivity of the receiving water(s) to OSDS effluent. Descriptions and design considerations for systems have been provided below. Table 4-21 contains available cost and effectiveness data for some of these systems. Design and operation and maintenance information on these devices can be found in *Design Manual for Onsite Wastewater Treatment and Disposal Systems* (USEPA, 1980).

Conventional Septic System. A conventional septic system consists of a settling or septic tank and a soil absorption field. The traditional system accepts both greywater (wastewater from showers, sinks, and laundry) and blackwater (wastewater from toilets). These systems are typically restricted in that the bottom invert of the absorption field must be at least 2 feet above the seasonally high water table or impermeable layer (separation distance) and the percolation rate of the soil must be between 1 and 60 minutes per inch. Also, to ensure proper operation, the tank should be pumped every 3 to 5 years. Nitrogen removal of these systems is minimal and somewhat dependent on temperature. The most common type of failure of these systems is from clogging of the absorption field, insufficient separation distance to the water table, insufficient percolation capacity of the soil, and overloading of water.

Mound Systems. Mound systems are an alternative to conventional OSDS and are used on sites where insufficient separation distance or percolation conditions exist. Mound systems are typically designed so the effluent from the

Table 4-21. OSDS Effectiveness and Cost Summary

Practice	Effectiveness[a] Water (%)	TSS (%)	BOD (%)	TN (%)	TP (%)	Path. (Logs)	Cost Capital Cost[b] ($/House)	Maintenance Cost[b] ($/Year)	References
Conventional Septic System									USEPA, 1977, 1980, 1989, 1991; Sandy et al., 1988; Lamb et al., 1988; Rhode Island, 1989; Degen et al., 1991; Healy, 1982; Hanson et al., 1988; Dix, 1986; Fulhage and Day, 1988.
Average	NA	72	45	28	57	3.5	$4,500	$70	
Probable Range	NA	60-70	40-65	10-45	30-60	3-4	$2,000-$8,000	$50-$100	
Observed Range	NA	54-83	30-60	0-58	0-95	3-4	$2,000-$10,000	$25-$110	
No. Values Considered	0	7	7	13	12	2	8	4	
Mound Systems									USEPA, 1977, 1980, 1991; Small Flows Clearinghouse, undated.; Hanson et al., 1988; Degen et al., 1991.
Average	NA	NA	NA	44	NA	NA	$8,300	$180	
Probable Range	NA	60-70	40-66	10-45	30-80	3-4	$7,000-$10,000	$100-$300	
Observed Range	NA	NA	NA	44-44	NA	NA	$6,800-$11,000	$90-$310	
No. Values Considered	0	0	0	1	0	0	4	4	
Low Pressure Systems									Fulhage and Day, 1988; USEPA, 1980.
Average	NA	NA	NA	NA	NA	NA	$5,100	$150	
Probable Range	NA	60-70	40-66	10-45	30-80	3-4	$4,000-$6000	$100-$200	
Observed Range	NA	NA	NA	NA	NA	NA	$2,800-$7,400	$150-$150	
No. Values Considered	0	0	0	0	0	0	2	1	
Anaerobic Upflow Filter									USEPA, 1991; Venhuizen, 1991; Mitchell, undated.
Average	NA	44	62	59	NA	NA	$5,550	NA	
Probable Range	NA	30-60	50-75	40-75	60-80	3-4	$3,000-$8,000	$150-$400	
Observed Range	NA	24-89	46-84	20-75	NA	NA	$3,000-$8,000	NA	
No. Values Considered	0	6	6	6	0	0	2	0	
Intermittent Sand Filter									USEPA, 1977, 1980, 1991; Small Flows Clearinghouse, undated.; Venhuizen, 1991.
Average	NA	92	92	56	80	3.2	$5,400	$275	
Probable Range	NA	80-95	90-95	50-66	70-90	3-4	$4,000-$8,000	$250-$400	
Observed Range	NA	70-99	80-99	40-75	70-90	2-4	$2,300-$10,000	$100-$440	
No. Values Considered	0	7	10	7	2	6	7	5	

Table 4-21. (Continued)

Practice	Effectiveness[a] Water (%)	TSS (%)	BOD (%)	TN (%)	TP (%)	Path. (Logs)	Cost Capital Cost[b] ($/House)	Maintenance Cost[b] ($/Year)	References
Recirculating Sand Filter									Hoxie et al., 1988; Small Flows Clearinghouse, undated.; Fulhage and Day, 1988; USEPA, 1991; Venhuizen, 1991; Swanson and Dix, 1988; Lamb et al., 1988; Laak, 1986; USEPA, 1980; Sandy et al., 1988.
Average	NA	90	92	64	80	2.9	$3,900	$145	
Probable Range	NA	85-95	85-95	60-65	70-90	2-4	$5,000-$8,000	$250-$400	
Observed Range	NA	70-98	75-98	1-94	70-90	2-4	$1,850-$9,200	$15-$410	
No. Values Considered	0	12	15	13	2	8	5	7	
Water Separation System									USEPA, 1991; USEPA, 1986; USEPA, 1980; USEPA, 1977.
Average	NA	60	42	83	30	3	$8,000	$300	
Probable Range	NA	55-70	35-55	70-90	30-55	2-4	$5,000-$11,000	$300-$750	
Observed Range	NA	36-75	22-65	68-99	14-42	NA	$5,000-$11,000	$300-$300	
No. Values Considered	0	4	3	6	6	0	1	1	
Constructed Wetlands									Reed, 1991; Small Flows Clearinghouse, undated.; USEPA, 1980; Amberg, 1990; Dwyer et al., 1989.
Average	NA	80	81	90	NA	4	$710	$25	
Probable Range	NA	60-90	70-90	60-90	30-70	3-4	$1,000-$3,000	$25-$100	
Observed Range	NA	50-983	65-97	90-90	NA	4-4	$50-$350	$25-$25	
No. Values Considered	0		4	2	0	NA	19	1	
Cluster Systems									Decker, 1987; Small Flows Clearinghouse, undated.
Average	NA	NA	NA	NA	NA	NA	$4,950	$370	
Probable Range	NA	NA	NA	NA	NA	NA	$5,000-$7,000	$300-$400	
Observed Range	NA	NA	NA	NA	NA	NA	$3,000-$6,900	$370-$370	
No. Values Considered	0	NA	NA	NA	NA	NA	3	1	

Table 4-21. (Continued)

Practice	Effectiveness[a] Water (%)	TSS (%)	BOD (%)	TN (%)	TP (%)	Path. (Logs)	Cost: Capital Cost[b] ($/House)	Maintenance Cost[b] ($/Year)	References
Eliminating Garbage Disposals									USEPA, 1980, 1986, 1991.
Average	NA	37	28	5	2.5	NA	NA	NA	
Probable Range	NA	35-40	25-30	5-10	2-3	NA	Negligible	Negligible	
Observed Range	NA	37-37	28-28	5-5	2-3	NA	NA	NA	
No. Values Considered	0	3	2	2	2	NA	NA	NA	
Low Phosphate Detergents									USEPA, 1980, 1991.
Average	NA	NA	NA	NA	50	NA	NA	NA	
Probable Range	NA	NA	NA	NA	40-50	NA	Negligible	Negligible	
Observed Range	NA	NA	NA	NA	50-50	NA	NA	NA	
No. Values Considered	0	0	0	0	2	0	0	0	
Water Conservation Fixtures									USEPA, 1977, 1980, 1991;
Average									Small Flows
Probable Range	45	NA	NA	NA	NA	NA	NA	NA	Clearinghouse, undated.;
Observed Range	25-80	NA	NA	NA	NA	NA	Varies	Negligible	Jarrett et al., 1985.
No. Values Considered	4-90	NA	NA	NA	NA	NA	NA	NA	
	11	0	0	0	0	0	0	0	
Holding Tanks									Small Flows
Average	NA	NA	NA	NA	NA	NA	$3,900	$1,300	Clearinghouse, undated.;
Probable Range	NA	95-100	95-100	95-100	95-100	3-4	$4,000-$6,000	$1,000-$2,000	Dix, 1986; Hanson et al.,
Observed Range	NA	NA	NA	NA	NA	NA	$1,220-$6,670	$100-$2,400	1988.
No. Values Considered	0	0	0	0	0	0	8	12	

NA - Not available.
[a] Effectiveness values reflect total system reductions including soil absorption fields.
[b] Costs are in 1988 equivalent dollars, and an average household with four occupants was assumed.

septic tank is routed to a dosing tank and then pumped to a soil absorption field that is located in elevated sand fill above the natural soil surface. There is evidence suggesting that pressure dosing provides more uniform distribution of effluent throughout the absorption field and may result in marginally better performance. A major limitation to the use of mounds is slope. In Pennsylvania, elevated sand mound beds are permitted only in areas with slopes less than 8 percent (Mancl, 1985).

Where adequate area is available for subsurface effluent discharge, and permanent or seasonal high ground water is at least 2 feet below the surface, the elevated sand mound may be used in coastal areas. This system can treat septic tank effluent to a level that usually approaches primary drinking water standards for BOD_5, suspended solids, and pathogens by the time the effluent plume passes the property line for single-family dwellings. A mound system will not normally produce significant reductions in levels of total nitrogen discharged, but should achieve high levels of nitrification.

Intermittent Sand Filter. Intermittent sand filters are used in conjunction with pretreatment methods such as septic tanks and soil absorption fields. An intermittent sand filter receives and treats effluent from the septic tank before it is distributed to the leaching field. The sand filter consists of a bed (either open or buried) of granular material from 24 to 36 inches deep. The material is usually from 0.35 to 1.0 mm in diameter. The bed of granular material is underlain with graded gravel and collector drains. These systems have been shown to be effective for nitrogen removal; however, this process is dependent on temperature. Water loading recommendations for intermittent sand filters are typically between 1 and 5 gallons per day/square foot (gpd/ft^2) but can be higher depending on wastewater characteristics. Primary failure of sand filters is from clogging, and the following maintenance is recommended to keep the system performing properly: resting the bed, raking the surface layer, or removing the top surface medium and replacing it with clean medium. In general, the filters should be inspected every 3 to 4 months to ensure that they are operating properly (Otis, undated).

Intermittent sand filters are used for small commercial and institutional developments and individual homes. The size of the facility is limited by land availability. The filters should be buried in the ground, but may be constructed above ground in areas of shallow bedrock or high water tables. Covered filters are required in areas with extended periods of subfreezing weather. Excessive long-term rainfall and runoff may be detrimental to filter performance, requiring measures to divert water away from the system (USEPA, 1980).

Recirculating Sand Filter. A recirculating sand filter is a modified intermittent sand filter in which effluent from the filter is recirculated through the septic tank and/or the sand filter before it is discharged to the soil absorption field. The addition of the recirculation loop in the system may enhance removal effectiveness and allows media size to be increased to as much as 1.5 mm in diameter and allows water loading rates in the range of 3 to 10 gpd/ft^2 to be used. Recirculation rates of 3:1 to 5:1 are generally recommended.

Buried or recirculating sand filters can achieve a very high level of treatment of septic tank effluent before discharge to surface water or soil. This usually means single-digit figures for BOD_5 and suspended solids and secondary body contact standards for pathogens (in practice, 100-900 per 100 ml). Dosed recycling between sand filter and septic tank or similar devices can result in significant levels of nitrification/denitrification, equivalent to between 50 and 75 percent overall nitrogen removal, depending on the recycling ratio. Regular buried or recirculating sand filters may require as much as 1 square foot of filter per gallon of septic tank effluent.

Anaerobic Upflow Filter. An anaerobic upflow filter (AUF) resembles a septic tank filled with 3/8-inch gravel with a deep inlet tee and a shallow outlet tee. An AUF system includes a septic tank, an AUF, a sand filter, and a soil absorption field. As with the sand filter, dose recycling can be used to enhance this system's performance. Hydraulic loading for an AUF is generally in the range of 3 to 15 gpd. An AUF resembles a septic tank or the second chamber of a dual-chambered tank. It should be sized to allow retention times between 16 and 24 hours. There is a high degree of removal of suspended solids and insoluble BOD. Dosed recycling between sand filter and AUF can result in 60 to 75 percent overall nitrogen removal.

A growing body of data at the University of Arkansas and elsewhere suggests that an AUF can provide further treatment of septic tank effluent before discharge to a sand filter. This treatment allows a drastic reduction (by a factor of 8 to 20) in the size of sand filter needed to attain the performance described above, with major reductions in cost (Krause, 1991).

Trenches and Beds. Trenches are typically 1 to 3 feet wide and can be greater than 100 feet long. Infiltration occurs through the bottom and sides of the trench. Each trench contains one distribution pipe, and there may be multiple trenches in a single system. Like conventional septic systems, they require 2 to 4 feet between the bottom of the system and the seasonally high water table or bedrock, and are best suited in sandy to loamy soils where the infiltration rate is 1 to 60 minutes per inch. Gravelly soils or poor-permeability soils (60 to 90 minutes per inch) are not suitable for trench systems. However, where the infiltration rate is greater than 1 minute per inch, 6 inches of loamy soil can be added around the system to create the proper infiltration rate (Otis, undated).

Beds are similar to trenches except that infiltration occurs only through the bottom of the bed. Beds are usually greater than 3 feet wide and contain one distribution pipe per bed. Single beds are commonly used; however, dual beds may be installed and used alternately. The same soil suitability conditions that apply to trenches apply to bed systems.

Trenches are often preferred to beds for a few reasons. First, with equal bottom areas, trenches have five times the sidewall area for effluent absorption; second, there is less soil damage during the construction of trenches; and third, trenches are more easily used on sloped sites.

The effluent from trenches or beds can be distributed by gravity, dosing, or uniform application. Dosing refers to periodically releasing the effluent using a siphon or pump after a small quantity of effluent has accumulated. Uniform application similarly stores the effluent for a short time, after which it is released through a pressurized system to achieve uniform distribution over the bed or trench. Uniform application results in the least amount of clogging.

Maintenance of trenches and beds is minimal. Dual trench or bed systems are especially effective because they allow the use of one system while the other rests for 6 months to a year to restore its effectiveness (Otis, undated).

Water Separation System. A water separation system separates greywater and blackwater. The greywater is treated using a conventional septic system, and the blackwater is contained in a vault/holding tank. The blackwater is later hauled off site for disposal.

For extreme situations or for seasonal residents, some form of separation of toilet wastes from bath and kitchen wastes may be helpful. Most nitrogen discharges in residential wastewater come from human urine. A very efficient toilet (0.8 gallon per flush), if routed to a separate holding tank, would need pumping only three or four times per year even for a family of four permanent residents.

Constructed Wetlands. Constructed wetlands are usually used for polishing of septage effluent that has already had some degree of treatment (processing through a septic tank or other aggregated system). The performance of constructed wetlands will be degraded in colder climates during winter months because of plant die-off and reduction in the metabolic rate of aquatic organisms.

Cluster Systems. For the purposes of this guidance, a cluster system can be defined as a collection of individual septic systems where primary treatment of septage occurs on each site and the resulting effluent is collected and treated to further reduce pollutants. Additional treatment may involve the use of sand filters or AUF, constructed wetlands, chemical treatment, or aerobic treatment. The use of cluster systems may provide advantages due to increased treatment capability and economy of scale.

Evapotranspiration (ET) and Evapotranspiration/Absorption (ETA) Systems. ET and ETA systems combine the process of evaporation from the surface of a bed and transpiration from plants to dispose of wastewater. The wastewater would require some form of pretreatment such as a septic tank. An ET bed usually consists of a liner, drainfield tile, and gravel and sand layers. ET and ETA systems are useful where soils are unsuitable for subsurface disposal, where the climate is favorable to evaporation, and where ground-water protection is essential. In both types of systems, distribution piping is laid in gravel, overlain by sand, and planted with suitable vegetation. Plants can transpire up to 10 times the amount of water evaporated during the daytime. For an ET system to be effective, evaporation must be equal to or greater than the total water input to the system because it requires an impermeable seal around the system. In the United States, this limits use of ET systems to the Southwest. The size of the system depends on the quantity of effluent inflow, precipitation, the local evapotranspiration rate, and soil permeability (Otis, undated). Data were unavailable on this BMP, so its cost and effectiveness were not evaluated.

Vaults or Holding Tanks. Vaults or holding tanks are used to containerize wastewater in emergency situations or other temporary functions. This technology should be discouraged because of high anticipated overloads due to difficult pumping logistics. Such systems require frequent pumping, which can be expensive.

Fixed Film Systems. A fixed film system employs media to which microorganisms may become attached. Fixed film systems include trickling filters, upflow filters, and rotating biological filters. These systems require pretreatment of sewage in a septic tank; final effluent can be discharged to a soil absorption field. Cost and effectiveness data for this BMP were not available.

Aerobic Treatment Units. Aerobic treatment units can be employed on site. A few systems are available commercially that employ various types of aerobic technology. However, these systems require regular supervision and maintenance to be effective. They require pretreatment by a septic tank, and effluent can be discharged to a soil absorption field. Power requirements can be significant for certain types of these packages. Cost and effectiveness data for this BMP were not available.

Sequencing Batch Reactor. A sequencing batch reactor is a modified conventional continuous-flow activated sludge treatment system. Conventional activated sludge systems treat wastewater in a series of separate tanks. Sequencing batch reactors carry out aeration and sedimentation/clarification simultaneously in the same tank. They are designed for the removal of biochemical oxygen demand (BOD) and total suspended solids (TSS) from typical municipal and industrial wastewater at flow rates of less than 5 MGD. Modification to the design of the basic system allows for nitrification and denitrification and for the removal of biological phosphorus to occur.

The sequencing batch reactor is particularly suitable for small flows and for nutrient removal. Sequencing batch reactors can be either used for new developments or connected to existing septic systems. Small reactors can be sited in areas of only a few hundred square feet. While sequencing batch reactor cost and operation and maintenance requirements are greater than those for conventional OSDS, sequencing batch reactors may be suitable alternatives for sites where high-density development and/or unsuitable soils may preclude adequate treatment of effluent.

Sequencing batch reactors can also be used where municipal and industrial wastes require conventional or extended aeration activated sludge treatment. They are most applicable at flow rates of 3000 gpd to 5 MGD but lose their cost-effectiveness at design rates exceeding 10 MGD (USEPA, 1992). Sequencing batch reactors are very useful for the pretreatment of industrial waste and for small flow applications. They are also optimally useful where wastewater is generated for less than 12 hours per day.

Disinfection Devices. In some areas, pathogen contamination from OSDS is a major concern. Disinfection devices may be used in conjunction with the above systems to treat effluent for pathogens before it is discharged to a soil absorption field. Disinfection devices include halogen applicators (for chlorine and iodine), ozonators, and UV applicators. Of these three types, halogen applicators are usually the most practical (USEPA, 1980). Installation of these devices in an OSDS increases the system's cost and adds to the system's operation and maintenance requirements. However, it may be necessary in some areas to install these devices to control pathogen contamination of surface waters and ground water.

(NOTE: The use of disinfection systems should be evaluated to determine the potential impacts of chlorine or iodine loadings. Some States, such as Maryland, have additional requirements or prohibit the use of these processes.)

Massachusetts has adopted a provision of its State Environmental Code that allows for "approval of innovative disposal systems if it can be demonstrated that their impact on the environment and hazard to public health is not greater than that of other approved systems" (310 CMR 15.18). Commonly referred to as Title 5, this legislation requires evaluation of pollutant loadings as well as management requirements prior to approval of alternative systems (Venhuizen, 1992).

g. Design sites so that an area for a backup soil absorption field is planned for in case of failure of the first field.

In preparation of site plans and designs for OSDS, it is recommended that a suitable area be identified and reserved for construction of a second or replacement soil absorption field, in the event that the first fails or expansion is necessary. Oliveri and others (1981) determined that continuously loaded soil absorption fields have a finite life span and that 50 percent of all fields fail within 25 years. Consequently, dual systems or a plan for a backup system is necessary. The area for the backup soil absorption field should be located to facilitate simultaneous or alternate loading of the old and new systems. With trench systems, the area between the original trenches can serve as the replacement area as long as sufficient vertical spacing exists between the trenches.

h. During construction of OSDS, soils should not be compacted in the primary or the backup soil absorption field area.

Care must be taken during the construction of OSDS so that the soil in the absorption field area is not compacted. Compaction could severely decrease the infiltration capacity of the soil and lead to failure of the absorption field.

i. Perform postconstruction inspection of OSDS.

A postconstruction inspection program should be implemented to ensure that OSDS were installed properly. The inspection should ensure that design specifications were followed and that soil absorption field areas were not compacted during construction. Many local governments in Massachusetts require postconstruction inspection for OSDS (Myers, 1991).

5. Effectiveness Information and Cost Information

Cost and effectiveness data on alternative OSDS systems are presented in Table 4-21.

The availability of high-quality, water-efficient plumbing fixtures (1.6-gallon toilets, 1.5-gpm showerheads, etc.) can provide a reduction of 50 percent in residential water use and wastewater volume, at an incremental cost of only about $20 to $100 for new homes. For on-site treatment, the higher influent concentrations are counterbalanced by longer septic tank retention time. This water conservation can allow further reductions in the size of sand filters or other forms of treatment (Krause, 1991).

The elimination of garbage disposals will reduce hydraulic loadings to OSDS and decrease the potential for solids to clog the absorption field, as shown in Table 4-22.

Performance data on sequencing batch reactors show that typical designs can achieve BOD and TSS concentrations of less than 10 mg/L and that modified systems can denitrify to limits of 1 to 2 mg/L NH_3-N (EPA, 1992). Some modified sequencing batch reactors have been shown to exhibit denitrification. Biological phosphorus removal to less than 1.0 mg/L has also been achieved (EPA, 1992).

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Table 4-22. Reduction in Pollutant Loading by Elimination of Garbage Disposals

Parameter	Reduction in Pollutant Loading (%)
Suspended Solids	25-40
Biohemical Oxygen Demand	20-28
Total Nitrogen	3.6
Total Phosphorus	1.7

The costs for sequencing batch reactors, adjusted to 1991 dollars, for constructing and operating sequencing batch reactors were determined for several existing systems. The capital costs for six treatment systems were found to range from $1.93 to $30.69/gpd of design flow (USEPA, 1992). The operating costs for three existing systems, based on 1990 average flow rates, ranged from $0.17/gpd to $2.88/gpd (USEPA, 1992).

Costs for a complete mound system, including a septic tank, in the rural Midwest are typically $7,000 installed (Krause, 1991). The cost for a residential septic tank/AUF/sand filter combination in the rural Midwest normally ranges from $3,000 to $4,000 (Krause, 1991). Costs for buried or recirculatng sand filters depend on the filter size and the availability of sand of the proper texture. Costs for a complete system in the rural Midwest may range between $5,000 and $10,000 (Krause, 1991).

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B. [illegible] Measure

(1) Establish and implement policies and systems to ensure that existing OSDS are operated and maintained to prevent the discharge of pollutants to the surface of the ground and to the extent practicable reduce the discharge of pollutants into ground waters that are closely hydrologically connected to surface waters. Where necessary to meet these objectives, encourage the reduced use of garbage disposals, encourage the use of low-volume plumbing fixtures, and reduce total phosphorus loadings to the OSDS by 15 percent (if the use of low-level phosphate detergents has not been required or widely adopted by OSDS users). Establish and implement policies that require an OSDS to be repaired, replaced, or modified where the OSDS fails, or threatens or impairs surface waters;

(2) Inspect OSDS at a frequency adequate to ascertain whether OSDS are failing;

(3) Consider replacing or upgrading OSDS to treat influent so that total nitrogen loadings in the effluent are reduced by 50 percent. This provision applies only:

(a) where conditions indicate that nitrogen-limited surface waters may be adversely affected by significant ground water nitrogen loadings from OSDS, and

(b) where nitrogen loadings from OSDS are delivered to ground water that is closely hydrologically connected to surface water.

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1. Applicability

This management measure is intended to be applied by States to all operating OSDS. Under the Coastal Zone Act Reauthorization Amendments of 1990, States are subject to a number of requirements as they develop coastal NPS programs in conformity with this management measure and will have flexibility in doing so. The application of management measures by States is described more fully in *Coastal Nonpoint Pollution Control Program: Program Development and Approval Guidance*, published jointly by the U.S. Environmental Protection Agency (EPA) and the National Oceanic and Atmospheric Administration (NOAA) of the U.S. Department of Commerce. This management measure does not apply to existing conventional OSDS that meet all of the following criteria: (1) treat wastewater from a single family home; (2) are sited where OSDS density is less than or equal to one OSDS per 20 acres; and (3) the OSDS is sited at least 1,250 feet away from surface waters.

2. Description

The purpose of this management measure is to minimize pollutant loadings from operating OSDS. This management measure requires that OSDS be modified, operated, repaired, and maintained to reduce nutrient and pathogen loadings in order to protect and enhance surface waters. In the past, it has been a common practice to site conventional OSDS

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in coastal areas that have inadequate separation distances to ground water, fractured bedrock, sandy soils, or other conditions that prevent or do not allow adequate treatment of OSDS-generated pollutants. Eutrophication in surface waters has also been attributed to the low nitrogen reductions provided by conventional OSDS designs.

Poorly designed or operating systems can cause ponding of partially treated sewage on the ground that can reach surface waters through runoff. In addition to oxygen-demanding organics and nutrients, these surface sources contain bacteria and viruses that present problems to human health. Viral organisms can persist in temperatures as low as -20 °F, suggesting that they may survive over winter in contaminated ice, later becoming available to ground water in the form of snowmelt (Hurst et al., undated). Although ground-water contamination from toxic substances is more often life-threatening, the majority of ground-water-related health complaints are associated with pathogens from septic tank systems (Yates, 1985).

Where development utilizing OSDS has already occurred, States and local governments have a limited capability to reduce OSDS pollutant loadings. One way to reduce the possibility of failed systems is to required scheduled pumpouts and regular maintenance of OSDS. Frequent inspections and proper operation and maintenance are the keys to achieving the most cost-effective OSDS pollutant reductions. Inspections upon resale or change of ownership of properties are also a cost-effective solution to ensure that OSDS are operating properly and meet current standards necessary to protect surface waters from OSDS-generated pollutants. Where phosphorus is a problem, phosphate bans can reduce phosphorus loadings by 14 to 17 percent (USEPA, 1992). Garbage disposal restrictions and low-volume plumbing fixtures can help ensure that conventional systems continue to operate properly. Low-volume plumbing fixtures have been shown to reduce hydraulic loadings to OSDS by 25 percent.

An option for managing and maintaining OSDS is through wastewater management utilities or districts. From a regulatory standpoint, a wastewater management program can reduce water quality degradation and save the time and money a local government or homeowner may spend maintaining and repairing systems. A variety of agencies are taking on the responsibilities of managing OSDS. Water utilities are the leading decentralized wastewater management agency (Dix, 1992). The following case studies illustrate successful wastewater management programs used where there are OSDS.

CASE STUDY 1 - GEORGETOWN DIVIDE PUBLIC UTILITIES, CALIFORNIA

The Georgetown Divide Public Utility District in California manages water reservoirs, two water treatment plants, an irrigation canal system, and two hydroelectric plants. Approximately 10 percent of the agency's resources are allocated to managing onsite systems in a large subdivision. The utility provides a comprehensive site evaluation program, designs the onsite system for each lot, lays out the system for the contractor, and makes numerous inspections during construction. There is also continued communication between the homeowners and the utility after construction, including scheduled inspections. For the service homeowners pay $12.50 per month for management of single-family systems. Owners of undeveloped lots pay $6.25 per month (Dix, 1992).

CASE STUDY 2 - STINSON BEACH COUNTY WATER DISTRICT, CALIFORNIA

In addition to monitoring the operation of septic tank systems, the Stinson Beach County Water District in California monitors ground water, streams, and sensitive aquatic systems that surround the coastal community to detect contamination from OSDS. Routine monitoring has identified people who use straight pipes and failures due to residents using overloaded systems. Homeowners pay a monthly fee of $12.90, in addition to the cost of construction or repair.

3. Management Measure Selection

This management measure was selected to control OSDS-related pollutant loadings to surface waters. Numerous States have implemented inspection requirements at title transfer, low-volume plumbing fixture regulations, garbage disposal prohibitions, and other requirements. Conventional systems are designed to operate over a specified period of time. At the end of the expected life span, replacement is generally necessary. Because failures of conventional systems may occur if systems are not properly designed and maintained, it is essential that programs are established to inspect and correct failing systems and to reduce pollutant loadings, public health problems, and inconveniences. Low-flow plumbing fixture installations and garbage disposal restrictions should be encouraged because as many as 75 percent of all system failures can be attributed to hydraulic overloading (Jarrett et al., 1985). Failure occurs when a system does not provide the level of treatment that is expected from the specific OSDS design.

National and local studies have indicated that conventional OSDS experience a significant rate of failure. Failure rates typically range between 1 and 5 percent per year (De Walle, 1981). In the State of Washington, high failure rates were observed in coastal regions (failure rates in 1971: King County - 6.1 percent; Gray's Harbor - 3.3 percent; and Skagit County - 2.6 percent). It has also been estimated in various soils of Connecticut that 4 percent of conventional OSDS fail per year. The failure rate in coastal areas may be greater because many systems (such as those in North Carolina) are approved for unsuitable soil conditions (Duda and Cromartie, 1982). Jarrett and others (1985) presented suggestions from several researchers describing the possible causes of high OSDS failure rates. These suggestions include:

- Smearing of trench bottoms during construction;
- Inadequate absorption areas;
- Improperly performed percolation tests;
- Inadequate design;
- Flooding and high water tables;
- Improper construction and installation;
- Inadequate soil permeability; and
- Use of cleaners and additives.

As stated previously, conventional OSDS do not remove nitrogen effectively and OSDS nitrogen loadings have been linked to degraded surface waters and ground water (Chesapeake Bay Program, 1990).

States should consider replacement with denitrifying OSDS in areas with nitrogen-limited waters. While all OSDS should be inspected periodically (at a recommended interval of once every 3 years) and corrected if failing, requiring that denitrifying systems be installed in all cases where existing systems fail to adequately treat nitrogen was deemed unduly burdensome and impractical.

Refer to the selection statement in the New OSDS Management Measure for additional rationale for selections relating to denitrification, garbage disposals, and low-flow plumbing fixtures.

Phosphorus reductions have been implemented in a number of States (see Table 4-23). Significant reductions in phosphorus loadings (14 to 17 percent) have resulted from such phosphate reductions, with nominal increases in costs for phosphate-free detergents.

4. Practices

As discussed more fully at the beginning of this chapter and in Chapter 1, the following practices are described for illustrative purposes only. State programs need not require implementation of these practices. However, as a practical matter, EPA anticipates that the management measure set forth above generally will be implemented by applying one or more management practices appropriate to the source, location, and climate. The practices set forth below have been found by EPA to be representative of the types of practices that can be applied successfully to achieve the management measure described above.

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Table 4-23. Phosphate Limits in Detergents
(The Soap and Detergent Association, 1992)

State	Phosphorus (P) Laundry Detergents	Phosphorus (P) Dishwashing Detergents	Industrial and Institutional	Effective Date
Connecticut	7 grams recommended use level			2/1/72
Florida	8.7% by weight as elemental P			12/31/72
Georgia	0.5% by weight as elemental P	8.7% by weight as elemental P		1/1/91
Indiana	0.5% by weight as elemental P			1/1/73
Maine	0.5% by weight as elemental P			7/1/93
Maryland	0.5% by weight as elemental P	8.7% by weight as elemental P	8.7% by weight as elemental P	12/1/85
Michigan	0.5% by weight as elemental P	8.7% by weight as elemental P	20% by weight as elemental P	10/1/77
Minnesota	0.5% by weight as elemental P	11% by weight as elemental P		8/30/79
New York	0.5% by weight as elemental P	8.7% by weight as elemental P		6/1/73
North Carolina	0.5% by weight as elemental P	8.7% by weight as elemental P		1/1/88
Oregon	0.5% by weight as elemental P	8.7% by weight as elemental P		7/1/92
Pennsylvania	0.5% by weight as elemental P	8.7% by weight as elemental P		3/1/91
South Carolina	0.5% by weight as elemental P	8.7% by weight as elemental P		1/1/92
Virginia	0.5% by weight as elemental P	8.7% by weight as elemental P		1/1/88
Wisconsin	0.5% by weight as elemental P	8.7% by weight as elemental P		1/1/84

a. *Perform regular inspections of OSDS.*

As previously stated, the high degree of failure of OSDS necessitates that systems be inspected regularly. This can be accomplished in several ways. Homeowners can serve as monitors if they are educated on how to inspect their own systems. Brochures can be made available to instruct individuals on how to inspect their systems and the steps they need to take if they determine that their OSDS is not functioning properly. Trained inspectors, such as those in Maine, also can aid in identifying failing systems.

State or local officials should also develop a program for regular inspection. By using utilities and wastewater management programs or agencies, the costs can be kept minimal. At a minimum, systems should be inspected when the ownership of a property is changed. If, prior to the transfer of ownership, the system is found to be deficient, corrective action should be taken. States and localities can also indirectly assess whether OSDS are failing through surface water and ground-water monitoring. If indicator pollutants (e.g., pathogens) are found during the course of monitoring, nearby OSDS should be inspected to determine whether they are the primary source of the indicators. USEPA (1991) has presented a method for tracing effluent from failing septic systems. This method could be followed as part of an indirect inspection program to locate failing systems.

b. Perform regular maintenance of OSDS.

OSDS are not maintenance-free systems. Huang (1983) stated that half of OSDS failures are due to poor operation and maintenance. Most septic tanks are designed so that wastewater is held for 24 hours to allow removal of solids, greases, and fats. Up to 50 percent of the solids retained in the tank decompose naturally by bacterial and chemical action (Mancl and Magette, 1991). However, during normal use, sludge accumulates on the bottom of the tank, leaving less time for the solids in the influent to settle. When little or no settling occurs, the solids move directly to the soil absorption system and may clog (Mancl and Magette, 1991). Consequently, periodic removal of the solids from the tank is necessary to protect the soil absorption system.

Management options for OSDS maintenance include (NSFCH, 1989):

- Maintenance via contract;
- Operating permits;
- Private management systems; and
- Local ordinances/utility management.

Most tanks need to be pumped out every 3 to 5 years; however, several factors need to be considered when determining the frequency of pumping required. These factors include (Mancl and Magette, 1991):

- Capacity of the tank;
- Flow of wastewater (based on family size); and
- Volume of solids in the wastewater (more solids are produced if a garbage disposal is used).

Failure will not occur immediately if a septic system is not pumped regularly; however, continued neglect will cause the system to fail because the soil absorption system is no longer protected from solids and may need to be replaced (at considerable expense).

Table 4-24 shows an estimate of how often a septic tank should be pumped based on tank and household size. The Arlington County, Virginia, Chesapeake Bay Preservation Ordinance requires that all septic tanks be pumped at least once every 5 years.

Alternative OSDS may have maintenance requirements in addition to septic tank pumping. These maintenance requirements are discussed in the descriptions of the systems presented in Management Measure V.A.

c. Retrofit or upgrade improperly functioning systems.

Improperly functioning systems are usually the result of failure of the soil absorption field. Several practices are available to retrofit these failing systems so that they operate properly. The most common reason for failure of the absorption field is hydraulic overload. Jarrett and others (1985) and other researchers have had good success in retrofitting failing systems by combining the construction of backup soil absorption fields with water conservation measures. A backup absorption system is constructed so that water can be diverted from the primary absorption system. The primary system is rested, and in many cases biological activity will unclog the system and aerobic conditions will be restored in the soil. Scheduling is then done to alternate the use of the primary and backup

Table 4-24. Suggested Septic Tank Pumping Frequency (Years) (Cooperative Extension Service - University of Maryland, 1991)

Tank Size (gal)	Household Size (number of people)									
	1	2	3	4	5	6	7	8	9	10
500	5.8	2.6	1.5	1.0	0.7	0.4	0.3	0.2	0.1	-
750	9.1	4.2	2.6	1.8	1.3	1.0	0.7	0.6	0.4	0.3
1,000	12.4	5.9	3.7	2.6	2.0	1.5	1.2	1.0	0.8	0.7
1,250	15.6	7.5	4.8	3.4	2.6	2.0	1.7	1.4	1.2	1.0
1,500	18.9	9.1	5.9	4.2	3.3	2.6	2.1	1.8	1.5	1.3
1,750	22.1	10.7	6.9	5.0	3.9	3.1	2.6	2.2	1.9	1.6
2,000	25.4	12.4	8.0	5.9	4.5	3.7	3.1	2.6	2.2	2.0
2,250	28.6	14.0	9.1	6.7	5.2	4.2	3.5	3.0	2.6	2.3
2,500	31.9	15.6	10.2	7.5	5.9	4.8	4.0	4.0	3.0	2.6

systems (e.g., use of each system 6 months of the year), so that systems in marginally permeable soils can continue to operate properly. Garbage disposals should be eliminated, and low-volume plumbing fixtures should be installed in cases where the absorption field has failed in order to reduce total pollutant and water loads to the field. (Refer to discussion in Management Measure V.A.)

In some cases, either because of improper siting (e.g., inadequate separation distance, proximity to surface water, poor soil conditions, or lack of land available for a backup absorption system) or the inadequacy of conventional OSDS to remove pollutants of concern, the above retrofit practice may not be feasible. In these cases, alternative OSDS, constructed wetlands, filters, or holding tanks may be necessary to adequately protect surface waters or ground water. Descriptions of these systems and their respective effectiveness and cost are provided in Management Measure V.A.

■ d. ***Use denitrification systems where conditions indicate that nitrogen-limited surface waters may be adversely impacted by excessive nitrogen loading.***

As stated previously, even properly functioning conventional OSDS are not effective at removing nitrogen. In areas where nitrogen is a problem pollutant, existing conventional systems should be retrofitted to denitrification OSDS to provide adequate nitrogen removal. Several systems such as sand filters and constructed wetlands have been shown to remove over 50 percent of the total nitrogen from septic tank effluent (see Table 4-21). Descriptions of these types of systems and their effectiveness and cost are presented in Management Measure V.A.

■ e. ***Discourage the use of phosphate in detergents.***

Conventional OSDS are usually very effective at removing phosphorus. However, certain soil conditions, combined with close proximity to sensitive surface waters, can result in phosphorus pollution problems from OSDS. In such cases the use of detergents containing phosphates may need to be discouraged or banned. Low-phosphate detergents are commercially available from a variety of manufacturers with negligible increases in cost. Eliminating phosphates from detergent can reduce phosphorus loads to OSDS by 40 to 50 percent (USEPA, 1980).

■ *f. Eliminate the use of garbage disposals.*

As presented in Table 4-22, eliminating the use of garbage disposals can significantly reduce the loading of suspended solids and BOD to OSDS. Total nitrogen and phosphorus loads may also be slightly reduced because of decreased loadings of vegetative matter and foodstuffs. Eliminating garbage disposals can also reduce the buildup of solids in the septic tank and reduce the frequency of pumping required. Reduction of the solids also provides added protection against clogging of the soil absorption system.

■ *g. Discourage or ban the use of acid and organic chemical solvent septic system additives.*

Organic solvents used as septic system cleaners are frequently linked to pollution from septic systems. Many brands of septic system cleaning solvents are currently on the market. Makers of these solvents, which often contain halogenated and aromatic hydrocarbons, advertise that they reduce odors, clean, unclog, and generally enhance septic system operations. Manufacturers also advertise that cleaning solvents provide an alternative to periodic pumping of septage from septic tanks. However, there is little evidence indicating that these cleaners perform any of the advertised functions. In fact, their use may actually hinder effective septic system operation by destroying useful bacteria that aid in the degradation of waste, resulting in disrupted treatment activity and the discharge of contaminants.

In addition, since the organic chemicals in the solvents are highly mobile in the soils and toxic (some are suspected carcinogens), they can easily contaminate ground water and surface waters and threaten public health. Research on the common septic system cleaner constituents (methylene chloride (MC) and 1,1,1-trichloroethane (TCA), which are listed on EPA's priority pollutant list and for which EPA's Office of Drinking Water has issued health advisories) has shown that application rates recommended by the manufacturer have resulted in high MC and moderate TCA discharges to ground water.

This issue is discussed further in the pollution prevention section.

■ *h. Promote proper operation and maintenance of OSDS through public education and outreach programs.*

This practice is discussed in the pollution prevention section (Section VI).

VI. POLLUTION PREVENTION

Pollution Prevention Management Measure

Implement pollution prevention and education programs to reduce nonpoint source pollutants generated from the following activities, where applicable:

- **The improper storage, use, and disposal of household hazardous chemicals, including automobile fluids, pesticides, paints, solvents, etc.;**
- **Lawn and garden activities, including the application and disposal of lawn and garden care products, and the improper disposal of leaves and yard trimmings;**
- **Turf management on golf courses, parks, and recreational areas;**
- **Improper operation and maintenance of onsite disposal systems;**
- **Discharge of pollutants into storm drains including floatables, waste oil, and litter;**
- **Commercial activities including parking lots, gas stations, and other entities not under NPDES purview; and**
- **Improper disposal of pet excrement.**

1. Applicability

This management measure is intended to be applied by States to reduce the generation of nonpoint source pollution in all areas within the section 6217 management area. The adoption of the Pollution Prevention Management Measure does not exclude applicability of other management measures to those sources covered by this management measure. Under the Coastal Zone Act Reauthorization Amendments of 1990, States are subject to a number of requirements as they develop coastal NPS programs in conformity with this management measure and will have flexibility in doing so. The application of management measures by States is described more fully in *Coastal Nonpoint Pollution Control Program: Program Development and Approval Guidance*, published jointly by the U.S. Environmental Protection Agency (EPA) and the National Oceanic and Atmospheric Administration (NOAA) of the U.S. Department of Commerce.

2. Description

This management measure is intended to prevent and reduce NPS pollutant loadings generated from a variety of activities within urban areas not addressed by other management measures within Chapter 4. Source reduction is considered preferable over waste recycling for pollution reduction (DOI, 1991; USEPA, 1991). Everyday activities have the potential to contribute to nonpoint source pollutant loadings. Some of the major sources include households, garden and lawn care activities, turf grass management, diesel and gasoline vehicles, OSDS, illegal discharges to urban runoff conveyances, commercial activities, and pets and domesticated animals. These sources are described below. By reducing pollutant generation, adverse water quality impacts from these sources can be decreased.

a. Households

Everyday household activities generate numerous pollutants that may affect water quality. Common household NPS pollutants include paints, solvents, lawn and garden care products, detergents and cleansers, and automotive products such as antifreeze and oil. The use and disposal of these products are chronic sources of pollution (Puget Sound Water Quality Authority, 1991). Table 4-25 summarizes estimated pollutant loadings from various household chemicals that may contaminate runoff. These pollutants are typically introduced into the environment due to ignorance on the part of the user or the lack of proper disposal options. Storm drains are commonly mistaken for treatment systems, and significant loadings to waterbodies result from this misconception. Other wastes and chemicals are dumped directly onto the ground (Washington State Department of Ecology, 1990).

b. Improper Disposal of Used Oil

The improper disposal of used oil and antifreeze can significantly degrade surface waters. The Washington Department of Ecology estimated that over 4.5 million gallons of used oil are dumped in Washington State each year. Of this total, 2 million gallons eventually are discharged into the Puget Sound (USEPA, 1988). Such loadings can severely degrade surface waters. One quart of oil can contaminate up to 2 million gallons of drinking water; 4 quarts of oil can form an oil slick approximately 8 acres in size (University of Maryland Cooperative Extension Service, 1987).

Table 4-25. Estimates of Improperly Disposed Used Oil and Household Hazardous Waste

Reference	Chemical and Estimated Amount
USEPA, 1989	Estimated that 40% of used oil from DIYs[a] is poured onto roads, driveways, or yards or into storm sewers (80 million gallons per year).
Hoffman et al., 1980	Survey of Providence, RI, residents revealed that 35% were DIYs. Of this group, 42% used improper disposal methods (30% disposed of used oil by backyard dumping, 7% by dumping into sewers or storm drains, and 5% by pouring onto roads).
Stanek et al., 1987	Survey of Massachusetts households revealed that one-third changed their oil (17% dumped used oil on the ground and 3% discharged used oil into the town sewers); 17% changed their antifreeze (54% used ground disposal and 14% discharged into the sewer). The majority of the 10% who disposed of oil-based paints or pesticides annually used improper methods.
Voorhees and Temple, Baker and Sloane, Inc., 1989	Survey of studies estimated that between 52% and 64% of private vehicle owners are DIYs. Nationally, DIYs have been estimated to generate 193 million gallons of used oil per year. Of this amount, it was estimated that 61% (118 million gallons) was improperly disposed of.
King County Solid Waste Division, 1990	Estimated that 15% to 20% of household hazardous wastes end up in storm drains or runoff. Estimated that one-third of DIYs dump used oil directly into storm drains or onto the ground.
King County Solid Waste Division, 1990	Estimated that 83% of DIYs that changed their antifreeze flushed their car radiators directly into a storm sewer or street.

[a] DIYs - Do-it-yourself oil changers.

c. Landscape Maintenance and Turf Management

The care of landscaped areas, including golf courses, can contribute significantly to nonpoint source pollutant loadings. The application of fertilizers and pesticides in coastal areas can be detrimental to surface waters. After a site is developed, a significant area of maintained landscape may be regularly treated with fertilizer and pesticides. Heavily landscaped areas include residential yards, golf courses, and parks. In the coastal zone, much residential development commonly is sited on unconsolidated coastal plain with sandy soils. Where such soils are present, frequent fertilization, pesticide application, and watering must occur to maintain turf grasses. Turf management programs and landscaping ordinances that require minimum maintenance and minimum disturbance or xeriscaping can effectively reduce these loadings.

In areas where nitrogen is a problem pollutant, measures to control the introduction of nitrogen into runoff and leachate are important. Several studies have been completed that demonstrate the leaching potential of nitrogen from turf. Researchers at Cornell University found that 60 percent of nitrogen applied to turf leached to ground water (Long Island Regional Planning Board, 1984). Shultz (1989) suggests that 50 percent of the nitrogen applications are leached out and not used by plants. A study completed by Exner and others (1991) showed that as much as 95 percent of nitrate applied in late August on an urban lawn was leached below the turf grass root zone. In coastal areas, where soils are highly permeable and ground water and surface waters are hydrologically connected, reduced applications of nutrients may be necessary to control subsurface flow of nutrients into surface waters.

A recent nonpoint source loading analysis (Cahill and Associates, 1991) indicated that 10 percent of the nitrogen and 4 percent of the phosphorus applied annually in a 193-square-mile area (an area approximately 10 miles by 20 miles) of maintained landscaped residential development end up in surface waters as the result of overapplication. A total of 512.7 tons of nitrogen and 49.4 tons of phosphorus enter surface waters from this area. These estimated pollutant delivery rates are conservative. Delivery rates in coastal areas with sandy soils may be much higher. Schultz (1989) found that over 50 percent of the nitrogen in fertilizer leaches from lawns when improperly applied. In addition, the proximity of sources to waterbodies may result in increased loadings. Where waterbodies are nitrogen- or phosphorus-limited, applications of fertilizers should be reduced or prohibited. Fertilizer control programs can effectively reduce nitrogen and phosphorus loadings by encouraging the proper application of nutrients. Fertilizer costs may also be reduced.

A study in Rhode Island concluded that medium-density residential development has the highest loading factor of pesticides and fertilizers of all land uses in the State (RIDEM, 1988). These results echoed the findings of research conducted on the Chesapeake Bay watershed that identified medium- and high-density residential development as having the highest loading factors for nitrogen and phosphorus in the Bay area (Chesapeake Bay Local Advisory Committee, 1989). Table 4-26 shows a summary of results from various studies quantifying application rates of household fertilizers. Table 4-27 summarizes recommended application rates.

Home use is estimated to account for 20 percent of pesticide use in the Puget Sound area, and household users often apply pesticides excessively or in too concentrated a formulation (PSWQA, 1991). The Puget Sound Water Quality

Table 4-26. Summary of Application Rates of Fertilizers from Various Studies

Estimated Application Rates	Reference
3.3 lb/1000 ft² (affluent areas) 1.1 lb/1000 ft² (less affluent areas)	Cornell Water Resources Institute, 1985
2.2 lb/1000 ft²/yr to 3.9 lb/1000 ft²/yr	Long Island Planning Board, 1984
3.03 lb/ft²/yr (Nitrogen) 0.77 lb/ft²/yr (Phosphorus) (New Jersey)	Cahill and Associates, 1992

Table 4-27. Recommended Fertilizer Application Rates

Recommended Rate	Reference
Virginia - No more than 1 lb/1000 ft^2 at any one time — not to exceed 3 lb/1000 ft^2/yr	Hall, personal communication, 1991; No. VA Soil and Water Conservation District, 1991; VA Cooperative Extension, 1991
Virginia — 1.5 to 2 lb/1000 ft^2/yr	Bowling, personal communication, 1991
Long Island — 1 lb/1000 ft^2/yr	Long Island Regional Planning Board, 1984
Long Island — no more than 1 lb/1000 ft^2/yr on mature lawns	Myers, 1988
General — 2 lb/1000 ft^2/yr	Shultz, 1989

Authority summarized available data in a 1990 issue paper on pesticides in the Puget Sound. This research revealed that 50 to 80 percent of all household users apply some form of pesticides for lawn and garden use. EPA Region 10 and the Puget Sound Water Quality Authority (PSWQA, 1990) reviewed data and surveyed pesticide use in 12 counties in the Puget Sound basin and concluded that household pesticide use in 1988 was greater than 213,000 pounds. Unnecessary pesticide loadings to surface waters may result from homeowner overapplication, poor knowledge of proper application techniques, or applications during grass dormancy. Both the PSWQA and the Virginia Cooperative Extension Survey (1991) have determined that such improper use commonly occurs.

Consideration of the potential for exposure and toxic effects of applied fertilizers and pesticides should be an important component of golf course policy decisions. Some of the technical issues concerning intensive management of turf grass include (1) extent of nutrient and pesticide applications, (2) chronic and acute toxicity to nontarget organisms, (3) potential for exposure of nontarget organisms to applied chemicals, (4) use of increasingly scarce water resources for irrigation, (5) potential off-site movement of fertilizers and pesticides, (6) effects of maintenance and storage facilities on soil and water quality, and (7) potential loss of and effects on wetlands resulting from construction and turf grass maintenance (Balogh and Walker, 1992).

While quantitative information is not currently available regarding the effectiveness of fertilizer and pesticide control measures, it can be assumed that application reductions will result in corresponding decreases in pollutant loadings. Table 4-28 provides guidance useful for reducing fertilizer and pesticide use. This guidance was developed by the Northern Virginia Soil and Water Conservation District, the Lake Barcroft Watershed Improvement District, the Northern Virginia Planning District Commission, and the Virginia Cooperative Extension service for use by commercial lawn care companies and households that choose to use commercial lawn care services. This advice, however, is useful for all turf grass management.

d. Yard Trimmings Management

Improper disposal of yard trimmings can lead to increased nutrient levels in runoff. Yard trimmings deposited on street corners may be washed down storm sewers and result in elevated nutrient loadings to surface waters. Proper management of yard trimmings and home composting can reduce the level of nutrients in runoff and decrease overall runoff volumes through the addition of humus to the soil. Increased levels of humus enhance soil permeability, decrease erodibility, and provide nutrients in a less soluble form than commercial fertilizers.

e. Improper Installation and Maintenance of Onsite Disposal Systems

As discussed in Section V of this chapter, failing or improperly sited or designed OSDS may contribute both pathogens and nutrients to surface waters. Many engineers, contractors, surveyors, drain-layers, sanitarians, OSDS installers, waste haulers, building inspectors, local and State officials, and owners of OSDS are insufficiently informed regarding the need for proper siting, design, and maintenance of onsite systems. While a number of States

Table 4-28. Watershed Chemical Control Standards

Nutrient and Pesticide Control Standard	Estimated Savings and Impacts
Decrease fertilizer use.	The average DIY* applies 2 to 4 times the desirable amount of fertilizer. By reducing fertilizer amounts, costs can be reduced accordingly.
Use phosphorus-free or low-phophorus-content fertilizers.	Cost increases $1.00 to $1.50 per household where phosphate-free fertilizer are used. In the Lake Barcroft, Virginia, Water Management District, Natural Lawn estimated a 7,000-pound reduction in fall phosphorus loadings and an 80-85% decrease in spring loadings due to the use of phosphate-free fertilizers (Natural Lawn, personal communication, 1991).
Use slow-release fertilizers.	Organic fertilizers tend to be slow acting and less soluble than chemical fertilizers (Shultz, 1989). Depending on the fertilizer source, conversion to organic fertilizers would reduce costs to $0.00 where compost from a municipal or county facility is used; costs would increase $1.00 per 100 ft^2 for the purchase of commercial organic fertilizer (Cook, 1991)
Test soils to determine appropriate application rates.	Soil tests and fertilizer recommendations range in cost from $0.00 to $5.00 if done by a Cooperative Extension Service. Private soil test labs may charge $30.00 to $45.00 for the service (Carr et al., 1991).
Stagger fertilizer applications instead of using one large application.	Excess fertilizer may leach into ground water if not utilized by plants. Plants have a limited capacity to utilize fertilizer in any one application; fertilizer costs can be reduced by staggered applications so that the bulk of available nutrients are utilized and excess fertilizers are not applied.
Spot-apply pesticides to control broad-leafed weeds.	Natural Lawn Company reports that by switching from blanket applications to spot applications of herbicides, herbicide use can be reduced 85% to 90% (Bonifant, personal communication, 1991). Volume reductions will result in a comparable cost savings.
Mow lawn at the recommended height.	Shultz (1989) and Carr (1991) suggest that proper mowing techniques result in healthier lawns and can reduce pesticide and fertilizer use.
Retain grass clippings on lawns and other areas planted with turf grass.	Research conducted by Starr and DeRoo (1981) on grass grown in low-nitrogen sandy loam soils showed that grass clippings are beneficial as fertilizer for continued grass growth. Use of clippings as fertilizer can enhance grass growth, reduce the need for additional fertilizer, and decrease total fertilizer costs. *(This recommendation is promoted by the Professional Lawn Care Association of America.)*

* DIY - Do-it-yourself lawn caretaker.

currently license OSDS installers and waste haulers in accordance with State health standards, these licensing procedures may be out-of-date. In addition, many of these standards address only limited health-related issues and do not address the complex joint issues of water quality and public health (Myers, 1991).

Many homeowners are unaware of proper OSDS operation and maintenance principles. They often do not know how frequently their septic tanks need to be pumped, what hydraulic load their systems can accommodate, and what should or should not be disposed of in their systems (Huang, 1983). Some homeowners use septic system cleaners containing substances that may contaminate ground water, may provide little to no benefit to the OSDS, and may even be harmful to the system (RIDEM, 1988). Public education programs can help homeowners to prepare, operate, and maintain OSDS and thus help to ensure the continued pollutant removal effectiveness of the OSDS. A variety of brochures and other educational materials regarding OSDS have already been developed, and these materials have been used in many areas to educate the general public about proper OSDS operation and maintenance (e.g., the Chesapeake Bay Region, Puget Sound). State and local agencies should make use of these materials and implement mailing and information dissemination programs. Brochures mailed to homeowners as part of general utility correspondence or as special mailings are also effective. Posters and other materials distributed at libraries can help disseminate this information to the public. Educational and outreach programs should target builders, buyers, system installation contractors, inspectors, and enforcement personnel, in addition to homeowners, realtors, and pumpers.

f. Discharges Into Storm Drains

Significant loadings of NPS pollutants enter surface waters and tributaries via illegal discharges into storm drains. The public unknowingly assumes that storm drains discharge into sanitary sewers, and materials are dumped into storm drains under the assumption that treatment will occur at the sewage treatment plant. Illicit discharges may also be a problem. Public education programs, such as storm drain stenciling, and identification of illicit discharges can be effective tools to reduce pollutant loadings. Sanitary surveys are also a useful method to help managers identify the presence and entry point(s) of illicit discharges or other sources of pollutants to storm sewer systems.

g. Litter

Litter along coastal waterways, estuaries, and inland shorelines has become a significant source of nonpoint source pollution. · Litter, debris, and dumped large solid items impair coastal water quality, as well as the aesthetic and recreational value of coastal waters, and may also be a hazard to wildlife. Storm sewers have been identified as a significant source of marine debris (Younger and Hodge, 1992).

Plastics are the major debris problem in the marine environment. Plastic accounts for 59 percent of the debris collected in coastal cleanup efforts (Younger and Hodge, 1992). Other litter may also be a problem. The State Adopt-a-Highway programs have revealed that beverage cans are the item most frequently removed from the side of roads. These wastes commonly have entered surface waters via storm sewers or swale systems. During 1991-1992, participants in the Virginia Adopt-a-Highway program removed 36,000 cubic yards of debris with volunteer hours valued at $2 million (M. Kornwolf, Virginia Dept. of Transportation, personal communication, 1992).

h. Commercial Activities

Nonpoint source runoff from commercial land areas such as shopping centers, business districts, and office parks, and large parking lots or garages may contain high hydrocarbon loadings and metal concentrations that are twice those found in the average urban area (Woodward-Clyde, 1991). These loadings can be attributed to heavy traffic volumes and large areas of impervious surface on which these pollutants concentrate (Long Island Sound Regional Planning Board, 1982). For example, contributions of lead to the Milwaukee River south watershed have been estimated as 20 to 25 percent from commercial areas and 40 to 55 percent from industrial areas (Wisconsin Department of Natural Resources, 1991). Where activities other than traffic, such as liquids storage and equipment use and maintenance, are associated with specific commercial activities, other pollutants may also be present in runoff. BMPs suited to the control of automotive-related pollutants and any other pollutants associated with specific commercial uses should be used to control their entry into surface waters.

Gas stations, in most communities, are designated as a commercial land use and are subject to the same controls as shopping centers and office parks. However, gas stations may generate high concentrations of heavy metals, hydrocarbons, and other automobile-related pollutants that can enter runoff (Santa Clara Valley Water Control District, 1992). Since gas stations have high potential loadings and pollutant profiles similar to those of industrial sites, the good housekeeping controls used on industrial sites are usually necessary.

i. Pet Droppings

Pet droppings have been found to be important contributors of NPS pollution in estuaries and bays where there are high populations of dogs. Fecal coliform and fecal streptococcal bacteria levels in runoff in several drainage basins in Long Island, New York, can be attributed to the dog population (Long Island Regional Planning Board, 1982). Although dogs cause the more common pet droppings problem, other urban animals, such as domestic or semi-wild ducks, also contribute to NPS pollution where their populations are high enough. Eliminating or significantly reducing the quantity of pet droppings washed into storm drains and hence into surface waters can improve the quality of urban runoff. It has been estimated that for a small bay watershed (up to 20 square miles), 2 to 3 days of droppings from a population of 100 dogs contribute enough bacteria, nitrogen, and phosphorus to temporarily close a bay to swimming and shellfishing (George Heufelder, personal communication, 1992).

The Soil Conservation Service in the Nassau-Suffolk region of New York collected data indicating that domestic animals contribute BOD, COD, bacteria, nitrogen, and phosphorus to ground water and surface waters (Nassau-Suffolk Regional Planning Board, 1978). Runoff containing pet droppings has been found to be responsible for numerous shellfish bed closures in Massachusetts (George Heufelder, personal communication, 1992; Nassau-Suffolk Regional Planning Board, 1978). In New York the large populations of semi-wild White Pekin ducks contribute heavily to runoff problems, while in a Massachusetts study, dog feces alone were found to be sufficient to account for the closures.

3. Management Measure Selection

This management measure was selected to ensure that communities implement solutions that may result in behavioral changes to reduce nonpoint source pollutant loading from the sources listed in the management measure. A number of States and local communities, including Washington, Maryland, Virginia, Florida, and Alameda County, California, are using pollution prevention activities to protect or enhance coastal water quality. Such activities include public education, promotion of alternative and public transportation, proper management of maintained landscapes, pollution prevention, training and urban runoff control plans for commercial sources, and OSDS inspection and maintenance. To allow flexibility, specific controls have not been specified in the management measure. Communities may select practices that best fit local priorities and the availability of funding. In addition, flexibility is necessary to account for community acceptance, which is often the major determinant affecting whether education and outreach activities and administrative mechanisms such as certification and training requirements are practical or effective solutions.

CASE STUDY - ARLINGTON COUNTY, VIRGINIA

Arlington County, Virginia, is drafting a source control plan for "minimizing impacts on its streams, a well as impacts to the Potomac River and the Chesapeake Bay, from pollutants entering the streams from many diverse sources." The plan is aimed at implementing individual programs for controlling sources of nonpoint pollution. Projects include:

Storm drainage master plan;
Educational programs for lawn management;
Evaluation of street sweeping programs;
Stream valley stabilization and restoration;
Evaluation of parking lot and street design requirements;
Land use planning;
Leaf and debris collection;
Household hazardous waste disposal; and
Storm drain stenciling.

4. Practices, Effectiveness Information, and Cost Information

As discussed more fully at the beginning of this chapter and in Chapter 1, the following practices are described for illustrative purposes only. State programs need not require implementation of these practices. However, as a practical matter, EPA anticipates that the management measure set forth above generally will be implemented by applying one or more management practices appropriate to the source, location, and climate. The practices set forth below have been found by EPA to be representative of the types of practices that can be applied successfully to achieve the management measure described above.

a. *Promote public education programs regarding proper use and disposal of household hazardous materials and chemicals.*

Public education is an important component of this management measure. The provision of information regarding the environmental impacts of common household activities can produce long-term shifts in behavior and may result in significant reductions in household-generated pollutants. School curricula on watershed protection, including nonpoint pollution control, have been developed for elementary and secondary school education programs. An example is the program developed by the Washington State Office of Environmental Education (Puget Sound Water Quality Authority, 1989). Incorporating such programs into regular school curricula is an effective way to educate youth about the importance of environmentally conscious behavior, which in turn can help reduce the need for and cost of technology-based pollution control.

Florida developed a comprehensive Statewide plan for environmental education coordinated by its Council on Comprehensive Environmental Education to be implemented through formal and informal education programs and State agency programs. All teachers receive the training, as well as State agency personnel and school children in grades kindergarten through 12 (Florida Council on Comprehensive Environmental Education, 1987).

Public participation is an effective means of educating the public and is also necessary for successfully creating and implementing a nonpoint pollution control plan. Public involvement should be encouraged during the planning process through attendance at meetings, workshops, and private or group consultations, and by encouraging the public to comment on planning documents. Support for the documents and the plans being developed is fostered through public involvement. Newsletters are an effective means of keeping the public informed of what planning steps are being taken and how the public can become and stay involved. Metropolitan Seattle has printed an educational brochure concerning waste oil disposal in six languages in order to reach a wider audience (Washington State Department of Ecology, 1992).

b. *Establish programs such as Amnesty Days to encourage proper disposal of household hazardous chemicals.*

Recognizing the potential impacts for environmental degradation from the improper disposal of hazardous household materials and chemicals, many communities have implemented programs to collect these chemicals. There has been an exponential growth in the number of such collection programs since the early 1980s. Two programs were in place in 1980; 822 were in place in 1990. The most common type of collection system is a 1-day event at a temporary site (often referred to as an Amnesty Day). More local governments are beginning to sponsor these programs several times a year, and many communities are establishing permanent programs, including retail store drop-off programs, curbside collection, and mobile permanent facilities (Duxbury, 1990). Table 4-29 summarizes the cost and effectiveness of some household chemical collection programs.

In spite of relatively low participation rates, collection programs can have a significant impact on the amount of hazardous chemicals and materials entering the waste stream. It has been estimated that the amount of hazardous chemicals collected in States having approved coastal management programs was approximately 51,000 drums, or 280,500 gallons, in 1990 (extrapolated from Duxbury, 1990).

c. *Develop used oil, used antifreeze, and hazardous chemical recycling programs and site collection centers in convenient locations.*

Household hazardous chemical (HHC) collection programs already exist in many counties throughout the United States. Specific days are usually designated as drop-off days and are advertised through television, newspapers,

Table 4-29. Waste Recycling Cost and Effectiveness Summary

Program Description	Effectiveness	Cost
University of Alabama - Project ROSE[a] • Initiated in 1977 • Focuses on used oil • Includes curbside collection (as part of regular garbage pick-up), collection centers (primarily service stations), and drum placement (in more rural areas) • Involves public outreach program	Of the approximately 17 million gallons of used oil generated annually in Alabama, 8 million gallons (47 percent) was reclaimed in 1990.	Annual budget is $80,000 ($45,000 is spent on public education).
Sunnyvale, CA, Curbside Used Oil Collection[b] • Curbside collection of used oil, along with other recyclable products • Residents provided with gallon containers to hold the oil • Involves large public outreach program	75 to 120 gallons of used oil from 28,000 homes collected daily. A 40 percent increase in participation was observed from FY 87-88 to FY 90-91.	Exact breakdowns were not available. Costs are kept low by incorporating the program into an existing recycling program; public information is distributed by such means as flyers in utility bills and brochures left by city employees such as repair crews and street sweepers.
Seattle, WA, Mobile Permanent Collection System • Established in 1989 by King County Solid Waste Department • 5,000 ft² mobile facility equipped to collect household hazardous materials ("Wastemobile") • Collected material is either recycled, detoxified, or taken to a secured hazardous waste facility • Includes extensive public outreach program	In the first 6 months of operation, 276.8 tons of material was collected; participation was twice that expected (one site recorded 875 cars in 6 days) In the first quarter, 98.3 tons were collected with the following breakdown: • 44.3 tons (45%) paint • 23.1 tons (23.5%) waste oil • 8.6 tons (8.8%) solvents • 5.9 tons (6%) pesticides. The balance was miscellaneous other household wastes.	The Wastemobile cost $110,000. King County has budgeted $1.5 million (including public outreach and staff) over a 28-month period.
San Francisco, CA, Permanent Collection Facility[c] • A permanent household waste site that was initiated as a pilot project • 65 percent of the collected material was recycled or reused	30,730 gallons of hazardous wastes (excluding batteries) were collected the first year. The most common type of waste was paint, which was recycled and used by citizens groups to paint over graffiti.	Operated by the private company that hauls the city's solid waste. Funds are obtained from the residential rate mechanism. The city is responsible for public education, waste disposal, and facility inspection.

[a] USEPA, 1989; Project ROSE Fact Sheet, 1991.
[b] USEPA, 1988.
[c] Johnston and Kehoe, 1989.
[d] Misner, 1990

flyers, and radio. In Arlington County, Virginia, collection during the week is by appointment with a water pollution chemist employed by the county and on one Saturday a month. Other HHC collection programs have once-a-week or once-a-month collection days, and some programs have a single day set aside each year for all HHC collection for the county or region. The waste collected by these programs is usually disposed of by a licensed HHC contractor. Table 4-29 presents program descriptions, effectiveness, and cost information for representative HHC collection programs. Many service stations currently provide used oil and antifreeze recycling facilities for "do-it-yourselfers" to encourage environmentally sound disposal.

d. Encourage proper lawn management and landscaping.

The care of landscaped areas can contribute significantly to NPS pollutant loadings. Results of a telephone survey conducted in 1982 by the Virginia Polytechnic Insitute and State University showed that only 12 to 15 percent of home lawns in Virginia were being managed properly. The majority of homeowners preferred to do their own lawn work; only 8 to 10 percent of the households used commercial lawn care companies. A similar survey conducted on Long Island concluded that in affluent neighborhoods, 72 percent of the respondents used a lawn care service; in the least affluent neighborhoods, no one subscribed to commercial lawn care (Cornell Water Resources Institute, 1985). The extent of nonpoint source pollution from fertilizer application is site-specific and depends on a number of factors, including soil type, application rate, type of fertilizer, precipitation and watering amount, and socioeconomic status of residents. Because most people are not trained in proper fertilization and maintenance application, homeowner lawn care may result in significant amounts of nonpoint source pollution.

To significantly decrease homeowners' pesticide and fertilizer loadings requires a broad-based educational effort. The State Cooperative Extension Service (CES) is one educational vehicle; however, the CES reaches only a small percentage of the population. Mass media approaches are generally the most effective way to reach a large part of the population, though some other possibilities are discussed below (Puget Sound Water Quality Authority, 1991). The following practices are part of proper lawn management and landscaping.

- ***Proper pesticide and herbicide use, and reduced applications***

  While few studies have been conducted to correlate pesticide and herbicide use with adverse effects on marine water quality, the magnitude of potential impacts can be inferred from incidents such as the extensive ground-water contamination in counties bordering the Puget Sound following widespread use of the pesticide ethylene dibromide (EDB) (Puget Sound Water Quality Authority, 1989). Estimates of pesticide use in the Puget Sound area reveal that 20 percent of the volume of pesticides applied is from residential sources and that these applications are typically in excess of recommended amounts or are too concentrated (Puget Sound Water Quality Authority, 1991).

  Maintaining a buffer between surface water and areas treated with pesticides is one method to increase the transport distance and reduce the potential for offsite movement of toxics. Selection of less toxic, mobile, and persistent chemicals with greater selective control of pests is encouraged (Spectrum Research, 1990).

- ***Reduced fertilizer applications and proper application timing***

  Lawn fertilization has been identified as a source of excess nitrogen and phosphorus loadings that may lead to eutrophication. A modeling study of urban runoff pollution conducted in Pennsylvania, Maryland, Washington, DC, and Virginia by Cohn-Lee and Cameron (1991) estimated that the nonpoint source loadings of nutrients were equal to or greater than loadings discharged from POTWs and industries in the Chesapeake Bay area.

  Ground-water contamination also may be of concern especially where interflow exists between surface waters and ground waters. Schultz (1989) found that over 50 percent of the nitrogen in fertilizer leaches from a lawn when improperly applied. NVSWCD et al. (1991) found that up to two-thirds less fertilizer can be applied than is typically recommended by manufacturers. The use of slow-release forms of nitrogen and proper watering may also decrease nonpoint source pollution loadings (Nassau-Suffolk Regional Planning Board, 1978).

- ***Limited lawn watering***

  Nonpoint source runoff from lawns can be reduced by employing efficient watering techniques. Overwatering can increase nitrogen loss 5 to 11 times the amount lost when proper watering strategies are used (Morton et al., 1988).

Soaker hoses and trickle or drip irrigation systems are an alternative to sprinkler systems. These types of systems deliver water at lower rates, which can increase the volume infiltrated, conserve water, and avoid runoff that can be associated with improperly operated sprinkler systems.

- *Use of minimum maintenance/minimum disturbance and IPM methods*

Minimum maintenance/minimum disturbance policies and strategies can effectively reduce land disturbance and associated soil loss and can reduce fertilizer, pesticide, and herbicide loadings. Where new development is occurring, community standards that limit the use of fertilizers or require commercial lawn care companies to use low-impact lawn care practices can decrease NPS loadings. Such practices can be promoted through public education programs for both new and existing developments.

Effective use of IPM strategies can further reduce nonpoint source loadings. Regional soil conservation services, agricultural extension offices, local conservation districts, or the U.S. Department of Agriculture are good sources of information on IPM. A study in Maryland on IPM for street and landscape trees in a planned suburban community demonstrated that pesticide use could be reduced by 79 to 87 percent when spot application techniques were substituted for cover spray techniques. An average annual cost savings of 22 percent also resulted from the program.

Effective IPM Strategies include (Washington State Department of Ecology, 1992):

- Use of natural predators and pathogens;
- Mechanical control;
- Use of native and resistant plantings;
- Maintainenance of proper growing conditions;
- Removal of or substitutions for less-favored pest habitat;
- Timing annual crops to avoid pests;
- Localized use of appropriate chemicals as a last alternative.

- *Xeriscaping*

Xeriscaping, creative landscaping for decreased water, energy, and pesticide/fertilizer inputs, can be used to reduce urban runoff and minimize the application of lawn care products that may adversely impact coastal waters. The use of xeriscaping practices can reduce required lawn maintenance up to 50 percent and reduce watering requirements by 60 percent (Clemson University, 1991). Florida has passed legislation requiring xeriscaping on the grounds of all State buildings. Several other States, including New Jersey and California, actively support xeriscaping efforts. A more detailed discussion of xeriscaping is in Section II.C of this chapter.

- *Reduced runoff potential*

Rainwater from roofs can be infiltrated into the ground in gravel-filled trenches in well-drained soils or collected in rain barrels for later irrigation. Wood decking or brick pavers allow greater infiltration than do solid concrete structures. Landscape terracing reduces runoff and erosion when gardening on slopes (Washington State Department of Ecology, 1992).

- *Training, certification, and licensing programs for landscaping and lawn care professionals*

Training, certification, and licensing programs are an effective method to educate lawn care professionals about potential nonpoint pollution problems associated with fertilizer, pesticide, and herbicide applications. The State Cooperative Extension Service commonly provides these services. Trained lawn care professional can also help educate the general public about the advantages of low-input approaches.

e. *Encourage proper onsite recycling of yard trimmings.*

Home composting promotes onsite recycling of plant nutrients contained in yard trimmings and reduces the potential for nutrients to enter surface waters. Unlike most commercial fertilizers, compost releases nutrients slowly and is a source of trace metals (Hansen and Mancl, 1988). When added as an amendment to lawn or garden soils, compost increases the organic content of the soil, which increases infiltration, reduces runoff, and decreases the need for watering. Sediment and bound nutrients in soils with high organic content are less mobile and less likely to migrate from the site. Compost applications may also result in increased plant health and vigor, allowing for the reduced use of pesticides (Logsdon, 1990).

Home composting programs may result in municipal cost savings. An average suburban yard generates up to 1,500 pounds of yard trimmings per year, most of which is usually landfilled (McNelly, undated). Homeowners should be encouraged to place compost piles or bins away from streams and roadways that may serve as conveyances of leached nutrients. Recycling of grass clippings and mulched leaves should also be encouraged through education programs. The retention of grass clippings and mulched leaves reduces the need for supplemental water and fertilizer inputs.

Suggested backyard composting programs include the following:

- Provide compost bins free or at cost.
- Create pamphlets explaining benefits and methods.
- Start a "Master Composter" program in which graduates receive free equipment and conduct their own workshops.
- Provide credits on waste removal fees to people who compost yard wastes.

f. *Encourage the use of biodegradable cleaners and other alternatives to hazardous chemicals.*

Improperly disposed household cleaners containing nonbiodegradable chemicals have the potential to contaminate surface waters and ground water. OSDS systems may also be adversely impacted by these substances (PSWQA, 1989). The use of nontoxic, biodegradable alternatives, which quickly break down, should be encouraged through public education efforts (Reef Relief, 1992).

g. *Manage pet excrement to minimize runoff into surface waters.*

The Soil Conservation Service in the Nassau-Suffolk region of New York collected data indicating that domestic animals contribute BOD, COD, bacteria, nitrogen, and phosphorus to ground water and surface waters (Nassau-Suffolk Regional Planning Board, 1978). Urban runoff containing pet excrement has been found to be responsible for numerous shellfish bed closures in New York and has been implicated in shellfish bed closures in Massachusetts (George Huefelder, personal communication, 1992; Nassau-Suffolk Regional Planning Board, 1978). In New York, the large populations of semi-wild Pekin ducks contribute heavily to water quality problems. A study in Massachusetts found that dog droppings alone were significant enough to cause shellfish bed closures.

Curb laws, requiring that dogs be walked close to street curbs so they will defecate on the streets near curbs, are intended to ensure that street sweeping operations collect the droppings and prevent them from entering runoff. However, traditional street sweeping has been found to be an ineffective means for controlling fines and soluble NPS pollution and the dog droppings are more often swept into sewers and delivered to bays and estuaries during rain storms (Long Island Regional Planning Board, 1982; 1984; Nassau-Suffolk Regional Planning Board, 1978). Curbing ordinances should therefore be repealed where they are in effect, and laws requiring pet owners to clean up after their pets when they are walked in public areas and to dispose of the droppings properly should be enacted.

Proper cleanup and disposal of canine fecal material and discouragement of public feeding of waterfowl are two ways of potentially controlling the adverse impacts of animal droppings. The following examples from the Long Island Regional Planning Board (1984) illustrate controls for NPS pollution from animal droppings.

Control of NPS pollution from dogs:

- Enactment of "pooper-scooper" laws requiring the removal and proper disposal of dog feces on public property.
- Enforcement of existing "pooper-scooper" and leash laws should be improved in priority target areas where animal feces are known to be an NPS pollution problem.

Control of NPS pollution from horses:

- Instituting zoning ordinances to control the keeping of horses. These ordinances should include:
  - Minimum acreage requirements per horse;
  - Specifying areas where horse waste may be stored; and
  - Designated areas where horses may be kept.
- Limiting the density of horses in deep aquifer recharge areas, in selected shallow aquifer recharge areas, in areas immediately adjacent to surface waters, and where slopes are greater than 5 percent.

Public education programs:

- The Cooperative Extension Service and similar agencies should be encouraged to develop and distribute informational material on all aspects of animal waste problems.

Owners of large animals should use BMPs similar to those for pasture management, including the fencing of animals away from surface waters, avoidance of "overgrazing," "grazing area" rotation, and limited "grazing" when soil is wet. Manure is best stored away from waterbodies on an impervious surface with a cover or roof (Washington State Department of Ecology, 1992).

The following actions can be used to help control the problem of pet excrement:

- Pass regulations controlling the disposal of excrement from domestic animals;
- Enact domestic animal clean-up regulations; and
- Require commercial domestic animal operations (e.g., pet stores, kennels) to implement BMPs for the control and proper disposal of animal excrement.

h. *Use storm drain stenciling in appropriate areas.*

Storm drain stenciling programs can be effective tools to reduce illegal dumping of litter, leaves, and toxic substances down urban runoff drainage systems. These programs also serve as educational reminders to the public that such storm drains often discharge untreated runoff directly to coastal waters.

A successful program was initiated in Anne Arundel County, Maryland. The program was implemented by volunteers to prevent dumping of harmful material into storm drains that ultimately discharge to the Chesapeake Bay. The county's only involvement has been to publicize the program and provide stencils and painting materials.

Approximately 60 to 70 percent of all communities in the county have participated. Several other counties around the Chesapeake Bay have inquired about the program. Data on effectiveness in terms of pounds of pollutant removed were not available; however, an informal survey that occurred after the program was implemented revealed that there is increased public understanding that storm drains should not be used for disposal of hazardous materials and dumping has decreased. Costs were nominal ($7.00 per stencil kit, including paint and brushes; the average neighborhood cost was $40.00) There is a similar program in place in Puget Sound, Washington. The total cost of implementing the stenciling program for the Sound was $2,644.39, including materials and labor. This practice is currently being used in other States and localities, including the Indian River Lagoon, Florida, drainage basin.

■ i. *Encourage alternative designs and maintenance strategies for impervious parking lots.*

Parking lot runoff accounts for a significant percentage of nonpoint source pollution in commercial areas, depending on the proportion of building size to parking lot size. Sweeping is a viable method of reducing this runoff from paved areas. If a lot is rectangular and has no parking bumpers or medians dividing it, the job is easier and less expensive. As indicated in the case study, a computer model proved to be a useful tool in evaluating the effectiveness of pavement sweeping as a method to control one source of nonpoint pollution (Broward County Planning Council, 1982).

CASE STUDY - FORT LAUDERDALE, FLORIDA

Through an EPA Continuing Planning Process Grant, the Broward County Planning Council received funding to conduct a study to determine the effectiveness of parking lot sweeping as a method to abate water pollution. A computer model, utilizing simple and multiple regression equations, was used to simulate the conditions at the study area and to predict the runoff loads from the area due to rainfall. Some results of the study are as follows: for paved commercial parking lots, the 3-day to 28-day sweeping cycle produces a pollutant removal range of 60 percent to 20 percent, respectively; as the quantity of residue increases, sweeper efficiency also increases, and there is a point of diminishing return for pollutant removal by sweeping and for sweeper efficiency in removing pollutant loadings (Broward County Planning Council, 1982).

Equipment types commonly used for street sweeping include abrasive brush and vacuum device sweepers. Both abrasive brush and vacuum sweepers have been shown to be generally inefficient at picking up fine solids of less than 43 microns. Although vacuum sweepers are more effective at removing fine particulates than brush sweepers, they are still generally considered to be inefficient. A newly developed helical brush sweeper that incorporates a steel brush with vacuum has been shown to be more effective at removing fine solids and is currently being evaluated. Although currently used sweeper technologies have been shown to be inefficient at removing fine particulates, their use in conjunction with other BMPs that are effective in trapping fine solids could improve downstream water quality (NVPDC, 1987).

Another promising method of street cleaning that concentrates on oil and grease removal is wet-sweeping. By spraying a small area with water containing biodegradable soaps or detergents that solubilize the oil and grease deposited on pavement surfaces, increased removal can occur with a combination of sweeping and vacuum action. This method, however, is a fairly new concept and requires further testing (Silverman et al., 1986).

Vegetated areas/grassed swales are another method commonly used to reduce pollutant loadings from pavement runoff. These areas can be designed to accept runoff with relatively high oil and grease concentrations from parking lots. Percolation through soil and underlying layers typically results in hydrocarbon filtration and adsorption, and degradation by naturally occurring soil bacteria.

j. *Control commercial sources of NPS pollutants by promoting pollution prevention assessments and developing NPS pollution reduction strategies or plans and training materials for the workplace.*

The opportunities for and advantages of pollution prevention practices vary from industry to industry, location to location, and activity to activity. Therefore, it is important to develop pollution prevention programs tailored specifically to an activity or site. Pollution prevention assessments on a site-by-site basis reduce some wastes and possibly eliminate the generation of other wastes. Such assessments are often necessary for successful pollution prevention programs (DOI, 1991).

States should promote and/or provide pollution prevention training and on-site assessments of individual facilities to help reduce the amount of hazardous wastes entering the environment from households and commercial facilities. A typical assessment for a facility will identify the types of waste produced, appropriate disposal methods and sites, and source reduction techniques. An education program to instruct personnel about proper materials handling and waste reduction strategies is also recommended.

The Alachua County, Florida, Office of Environmental Protection produced a handbook of BMPs to be applied in 12 separate commercial operations. Many of the BMPs are common to more than one type of operation, though specifics are mentioned for each category of activities. The 12 operations mentioned are small and large mechanical repair, dry cleaning, junk yards, photo processing, print and silk screening, machine shops and airport maintenance, boat manufacturing and repair, concrete and mining, agricultural, paint manufacturers and distributors, and plastic manufacturers (Alachua County Office of Environmental Protection, 1991).

The Santa Clara Valley Nonpoint Source Pollution Control Program and the San Jose Office of Environmental Management produced a handbook of BMPs for automobile service stations (Santa Clara Valley Water Control District, 1992). The handbook describes 18 BMPs that can be used to control onsite nonpoint source pollutants. Many of these BMPs require little or no investment for implementation. Most of the BMPs rely on education-induced behavior changes to minimize spills and disposal of chemicals and wastewaters down storm drains. Recycling, spill prevention and response plans, and proper material storage are also covered.

The City of Lacy, Washington, developed guidelines to control NPS pollution impacts from service stations and automotive repair facilities on Puget Sound. These include:

- Straining used solvents and paint thinner for reuse;
- Recycling antifreeze, oil, metal chips, and batteries;
- Properly disposing of wastes, including oils, machine-tool coolant, and batteries;
- Using dry floor cleaners, such as kitty litter or vermiculite; and
- Limiting use of water to clean driveways and walkways.

The city developed educational material for distribution that describes these guidelines, defines procedures for potential hazardous materials problems, and provides the State Hazardous Substance Hotline.

The City of Bellevue, Washington, Storm and Surface Water Utility, in cooperation with local businesses, has conducted a series of workshops aimed at the prevention of nonpoint pollution for automotive, construction, landscaping, food, and building maintenance businesses. The city gives recognition to businesses that attend a workshop and prepare a water quality action program. Videos of the workshops and accompanying manuals are also produced by the City of Bellevue (Washington State Department of Ecology, 1992).

k. *Promote water conservation.*

Excessive use of water contributes to numerous NPS pollution problems, including runoff from fertilized areas, OSDS drainfield failures, and sewage leaks. Water overuse may also contribute indirectly to NPS pollution problems: streams, rivers, and ground water may be excessively drawn down for water supply, decreasing their capacity to absorb pollutant runoff and upsetting their natural flow (Long Island Regional Planning Board, 1982; Maddaus, 1989). Additional information on water conservation is contained in the OSDS section of this chapter.

l. Discourage the use of septic system additives.

A 1980 EPA study identified 23 priority pollutants that are likely to be disposed of down household drains. Disposal of these chemicals into OSDS may impair OSDS function and contaminate ground water. Septic system cleaners are included in this category. There is little scientific evidence that septic system cleaners are effective in improving the function of septic systems. Many of the septic system cleaners contain chemicals such as chlorinated hydrocarbons, aromatic organic compounds, and acids and bases that may have an adverse affect on the biological treatment system and that may also pollute ground water. Many of these chemicals are also highly persistent in the ground water. Studies of ground-water contamination in New York and Connecticut have monitored these compounds in ground water and have found that (1) the septic system additives are not effective in improving the treatment systems and (2) the additives pass into ground water in relatively unaltered form (RIDEM, 1988).

Many States and local governments have adopted legislation prohibiting the use of septic system cleaning solvents, including the States of Maine and Delaware, the New Jersey Pinelands Regional Planning Commission, and several jurisdictions in Massachusetts. Rhode Island prohibits the disposal of acids or organic chemical solvents in septic systems and specifically discourages the use of septic tank cleaners. The State of Connecticut Department of Environmental Protection has taken the process one step further by banning the sale and use of cleaning solvents and also implementing the law through press releases, statewide surveys, direct manufacturer contact, and contact with the State Retail Merchants Association.

m. Encourage litter control.

While street sweeping historically has been found to provide little benefit in reducing fines and pollutants associated with small particulates because of outdated sweeping equipment and irregular sweeping frequencies, litter control can be an effective means to improve the quality of urban runoff. Both the Baltimore and Long Island Nationwide Urban Runoff Program (NURP) projects found that litter control substantially influenced the quality of runoff from urban areas (Myers, 1989). Suggestions for controlling litter include:

- Encouraging businesses to keep the streets in front of their buildings free of litter;
- Developing local ordinances restricting or prohibiting food establishments from using disposable food packaging, especially plastics, styrofoam, and other floatables;
- Implementing "bottle bills" and mandatory recycling laws;
- Providing technical and financial assistance for establishing and maintaining community waste collection programs;
- Distributing public education materials on the benefits of recycling; and
- Developing "user-friendly" ways for recycling, such as curbside pick-up, voluntary container buy-back systems, and drop-off recycling centers.

n. Promote programs such as Adopt-a-Stream to assist in keeping waterways free of litter and other debris.

Such programs can eliminate much of the floatable debris found in coastal waters and their tributaries. These programs involve volunteers who pick up trash along designated streambeds. Several successful programs similar to these are being implemented in Maryland, Alaska, Virginia, North Carolina, and Washington. The International

Coastal Cleanup, the largest coastal cleanup effort in the country, is coordinated by the Center for Marine Conservation (CMC). With the use of data cards, plastic gloves, and trash bags, 130,152 volunteers cleared 4,347 miles of beaches and waterways of 2,878,913 pounds of trash during the 1991 cleanup effort (Younger and Hodge, 1992).

In addition to the visible benefits of such clean-up efforts, these programs offer valuable educational opportunities for volunteers and provide a significant amount of data on the amounts and types of debris being found in waterways. The sources of various types of debris can be traced as well. Debris can be traced to a specific company or organization based on labeling or marking. Where possible, CMC contacts these organizations about the finding of their debris, informs them of the problems caused by marine debris, and asks them to join the battle against the debris problem. From the 1990 CMC coastal clean-up effort, approximately 150 organizations were identified and contacted. As a result, the majority of organizations responded positively by printing educational "Do not litter" slogans on their products, and several launched internal investigations into current waste-handling procedures (Younger and Hodge, 1992).

■ o. ***Promote proper operation and maintenance of OSDS through public education and outreach programs.***

Many of the problems associated with improper use of OSDS may be attributed to lack of knowledge on operation and maintenance of onsite systems. Training courses for installers and inspectors and education materials for homeowners on proper maintenance may reduce some of the incidences of OSDS failure.

VII. ROADS, HIGHWAYS, AND BRIDGES

NOTE: Management Measures II.A and II.B of this chapter also apply to planning, siting, and developing roads and highways.[a]

[illegible]

Plan, site, and develop roads and highways to:

(1) Protect areas that provide important water quality benefits or are particularly susceptible to erosion or sediment loss;

(2) Limit land disturbance such as clearing and grading and cut and fill to reduce erosion and sediment loss; and

(3) Limit disturbance of natural drainage features and vegetation.

1. Applicability

This measure is intended to be applied by States to site development and land disturbing activities for new, relocated, and reconstructed (widened) roads (including residential streets) and highways in order to reduce the generation of nonpoint source pollutants and to mitigate the impacts of urban runoff and associated pollutants from such activities. Under the Coastal Zone Act Reauthorization Amendments of 1990, States are subject to a number of requirements as they develop coastal NPS programs in conformity with this management measure and will have some flexibility in doing so. The application of management measures by States is described more fully in *Coastal Nonpoint Pollution Control Program: Program Development and Approval Guidance*, published jointly by the U.S. Environmental Protection Agency (EPA) and the National Oceanic and Atmospheric Administration (NOAA) of the U.S. Department of Commerce.

2. Description

The best time to address control of NPS pollution from roads and highways is during the initial planning and design phase. New roads and highways should be located with consideration of natural drainage patterns and planned to avoid encroachment on surface waters and wet areas. Where this is not possible, appropriate controls will be needed to minimize the impacts of NPS runoff on surface waters.

This management measure emphasizes the importance of planning to identify potential NPS problems early in the design process. This process involves a detailed analysis of environmental features most associated with NPS pollution, erosion and sediment problems such as topography, drainage patterns, soils, climate, existing land use, estimated traffic volume, and sensitive land areas. Highway locations selected, planned, and designed with consideration of these features will greatly minimize erosion and sedimentation and prevent NPS pollutants from entering watercourses during and after construction. An important consideration in planning is the distance between

[a] Management measure II.A applies only to runoff that emanates from the road, highway, and bridge right-of-way. This management measure does not apply to runoff and total suspended solid loadings from upland areas outside the road, highway, or bridge project.

a highway and a watercourse that is needed to buffer the runoff flow and prevent potential contaminants from entering surface waters. Other design elements such as project alignment, gradient, cross section, and the number of stream crossings also must be taken into account to achieve successful control of erosion and nonpoint sources of pollution. (Refer to Chapter 3 of this guidance for details on road designs for different terrains.)

The following case study illustrates some of the problems and associated costs that may occur due to poor road construction and design. These issues should be addressed in the planning and design phase.

> ***CASE STUDY - ANNAPOLIS, MARYLAND***
>
> Poor road siting and design resulted in concentrated runoff flows and heavy erosion that threatened several house foundations adjacent to the road. Sediment-laden runoff was also discharged into Herring Bay. To protect the Chesapeake Bay and the nearby houses, the county corrected the problem by installing diversions, a curb-and-drain urban runoff conveyance, and a rock wall filtration system, at a total cost of $100,000 (Munsey, 1992).

3. Management Measure Selection

This management measure was selected because it follows the approach to highway development recommended by the American Association of State Highway and Transportation Officials (AASHTO), Federal Highway Administration (FHWA) guidance, and highway location and design guidelines used by the States of Virginia, Maryland, Washington, and others.

Additionally, AASHTO has location and design guidelines (AASHTO, 1990, 1991) available for State highway agency use that describe the considerations necessary to control erosion and highway-related pollutants. Federal Highway Administration policy (FHWA, 1991) requires that Federal-aid highway projects and highways constructed under direct supervision of the FHWA be located, designed, constructed, and operated according to standards that will minimize erosion and sediment damage to the highway and adjacent properties and abate pollution of surface water and ground-water resources.

4. Practices

As discussed more fully at the beginning of this chapter and in Chapter 1, the following practices are described for illustrative purposes only. State programs need not require implementation of these practices. However, as a practical matter, EPA anticipates that the management measure set forth above generally will be implemented by applying one or more management practices appropriate to the source, location, and climate. The practices set forth below have been found by EPA to be representative of the types of practices that can be applied successfully to achieve the management measure described above.

a. *Consider type and location of permanent erosion and sediment controls (e.g., vegetated filter strips, grassed swales, pond systems, infiltration systems, constructed urban runoff wetlands, and energy dissipators and velocity controls) during the planning phase of roads, highway, and bridges. (AASHTO, 1991; Hartigan et al., 1989)*

b. *All wetlands that are within the highway corridor and that cannot be avoided should be mitigated. These actions will be subject to Federal Clean Water Act section 404 requirements and State regulations.*

■ c. *Assess and establish adequate setback distances near wetlands, waterbodies, and riparian areas to ensure protection from encroachment in the vicinity of these areas.*

Setback distances should be determined on a site-specific basis since several variables may be involved such as topography, soils, floodplains, cut-and-fill slopes, and design geometry. In level or gently sloping terrain, a general rule of thumb is to establish a setback of 50 to 100 feet from the edge of the wetland or riparian area and the right-of-way. In areas of steeply sloping terrain (20 percent or greater), setbacks of 100 feet or more are recommended. Right-of-way setbacks from major waterbodies (oceans, lakes, estuaries, rivers) should be in excess of 100 to 1000 feet.

■ d. *Avoid locations requiring excessive cut and fill. (AASHTO, 1991)*

■ e. *Avoid locations subject to subsidence, sink holes, landslides, rock outcroppings, and highly erodible soils. (AASHTO, 1991; TRB, Campbell, 1988)*

■ f. *Size rights-of-way to include space for siting runoff pollution control structures as appropriate. (AASHTO, 1991; Hartigan, et al., 1989)*

Erosion and sediment control structures (extended detention dry ponds, permanent sediment traps, catchment basins, etc.) should be planned and located during the design phase and included as part of the design specifications to ensure that such structures, where needed, are provided within the highway right-of-way.

■ g. *Plan residential roads and streets in accordance with local subdivision regulations, zoning ordinances, and other local site planning requirements (International City Managers Association, Model Zoning/Subdivision Codes). Residential road and street pavements should be designed with minimum widths.*

Local roads and streets should have right-of-way widths of 36 to 50 feet, with lane widths of 10 to 12 feet. Minimum pavement widths for residential streets where street parking is permitted range from 24 to 28 feet between curbs. In large-lot subdivisions (1 acre or more), grassed drainage swales can be used in lieu of curbs and gutters and the width of paved road surface can be between 18 and 20 feet.

■ h. *Select the most economic and environmentally sound route location. (FHWA, 1991)*

■ i. *Use appropriate computer models and methods to determine urban runoff impacts with all proposed route corridors. (Driscoll, 1990)*

Computer models to determine urban runoff from streets and highways include TR-55 (Soil Conservation Service model for controlling peak runoff); the P-8 model to determine storage capacity (Palmstrom and Walker); the FHWA highway runoff model (Driscoll et al., 1990); and others (e.g., SWMM, EPA's stormwater management model; HSP continuous simulation model by Hydrocomp, Inc.).

■ j. *Comply with National Environmental Policy Act requirements including other State and local requirements. (FHWA, T6640.8A)*

■ k. *Coordinate the design of pollution controls with appropriate State and Federal environmental agencies. (Maryland DOE, 1983)*

■ *i. Develop local official mapping to show location of proposed highway corridors.*

Official mapping can be used to reserve land areas needed for public facilities such as roads, highways, bridges, and urban runoff treatment devices. Areas that require protection, such as those which are sensitive to disturbance or development-related nonpoint source pollution, can be reserved by planning and mapping necessary infrastructure for location in suitable areas.

5. Effectiveness Information and Cost Information

The most economical time to consider the type and location of erosion, sediment, and NPS pollution control is early in the planning and design phase of roads and highways. It is much more costly to correct polluted runoff problems after a road or highway has already been built. The most effective and often the most economical control is to design roads and highways as close to existing grade as possible to minimize the area that must be cut or filled and to avoid locations that encroach upon adjacent watercourses and wet areas. However, some portions of roads and highways cannot always be located where NPS pollution does not pose a threat to surface waters. In these cases, the impact from potential pollutant loadings should be mitigated. Interactive computer models designed to run on a PC are available (e.g., FHWA's model, Driscoll et al., 1990) and can be used to examine and project the runoff impacts of a proposed road or highway design on surface waters. Where controls are determined to be needed, several cost-effective management practices, such as vegetated filter strips, grassed swales, and pond systems, can be considered and used to treat the polluted runoff. These mitigating practices are described in detail in the discussion on urban developments (Management Measure IV.A).

B. Management Measure for Bridges

Site, design, and maintain bridge structures so that sensitive and valuable aquatic ecosystems and areas providing important water quality benefits are protected from adverse effects.

1. Applicability

This management measure is intended to be applied by States to new, relocated, and rehabilitated bridge structures in order to control erosion, streambed scouring, and surface runoff from such activities. Under the Coastal Zone Act Reauthorization Amendments of 1990, States are subject to a number of requirements as they develop coastal NPS programs in conformity with this management measure and will have some flexibility in doing so. The application of management measures by States is described more fully in *Coastal Nonpoint Pollution Control Program: Program Development and Approval Guidance*, published jointly by the U.S. Environmental Protection Agency (EPA) and the National Oceanic and Atmospheric Administration (NOAA) of the U.S. Department of Commerce.

2. Description

This measure requires that NPS runoff impacts on surface waters from bridge decks be assessed and that appropriate management and treatment be employed to protect critical habitats, wetlands, fisheries, shellfish beds, and domestic water supplies. The siting of bridges should be a coordinated effort among the States, the FHWA, the U.S. Coast Guard, and the Army Corps of Engineers. Locating bridges in coastal areas can cause significant erosion and sedimentation, resulting in the loss of wetlands and riparian areas. Additionally, since bridge pavements are extensions of the connecting highway, runoff waters from bridge decks also deliver loadings of heavy metals, hydrocarbons, toxic substances, and deicing chemicals to surface waters as a result of discharge through scupper drains with no overland buffering. Bridge maintenance can also contribute heavy loads of lead, rust particles, paint, abrasive, solvents, and cleaners into surface waters. Protection against possible pollutant overloads can be afforded by minimizing the use of scuppers on bridges traversing very sensitive waters and conveying deck drainage to land for treatment. Whenever practical, bridge structures should be located to avoid crossing over sensitive fisheries and shellfish-harvesting areas to prevent washing polluted runoff through scuppers into the waters below. Also, bridge design should account for potential scour and erosion, which may affect shellfish beds and bottom sediments.

3. Management Measure Selection

This management measure was selected because of its documented effectiveness and to protect against potential pollution impacts from siting bridges over sensitive waters and tributaries in the coastal zone. There are several examples of siting bridges to protect sensitive areas. The Isle of Palms Bridge near Charleston, South Carolina, was designed without scupper drains to protect a local fishery from polluted runoff by preventing direct discharge into the waters below. In another example, the Louisiana Department of Transportation and Development specified stringent requirements before allowing the construction of a bridge to protect destruction of fragile wetlands near New Orleans. A similar requirement was specified for bridge construction in the Tampa Bay area in Florida (ENR, 1991).

4. Practices

As discussed more fully at the beginning of this chapter and in Chapter 1, the following practices are described for illustrative purposes only. State programs need not require implementation of these practices. However, as a practical matter, EPA anticipates that the management measure set forth above generally will be implemented by applying one or more management practices appropriate to the source, location, and climate. The practices set forth below have been found by EPA to be representative of the types of practices that can be applied successfully to achieve the management measure described above.

Additional erosion and sediment control management practices are listed in the construction section for urban sources of pollution (Management Measure IV.A).

- a. *Coordinate design with FHWA, USCG, COE, and other State and Federal agencies as appropriate.*

- b. *Review National Environmental Policy Act requirements to ensure that environmental concerns are met (FHWA, T6640.8A and 23 CFR 771).*

- c. *Avoid highway locations requiring numerous river crossings. (AASHTO, 1991)*

- d. *Direct pollutant loadings away from bridge decks by diverting runoff waters to land for treatment.*

Bridge decks should be designed to keep runoff velocities low and control pollutant loadings. Runoff waters should be conveyed away from contact with the watercourse and directed to a stable storm drainage, wetland, or detention pond. Conveyance systems should be designed to withstand the velocities of projected peak discharge.

- e. *Restrict the use of scupper drains on bridges less than 400 feet in length and on bridges crossing very sensitive ecosystems.*

Scupper drains allow direct discharge of runoff into surface waters below the bridge deck. Such discharges can be of concern where the waterbody is highly susceptible to degradation or is an outstanding resource such as a spawning area or shellfish bed. Other sensitive waters include water supply sources, recreational waters, and irrigation systems. Care should be taken to protect these areas from contaminated runoff.

- f. *Site and design new bridges to avoid sensitive ecosystems.*

Pristine waters and sensitive ecosystems should be protected from degradation as much as possible. Bridge structures should be located in alternative areas where only minimal environmental damage would result.

- g. *On bridges with scupper drains, provide equivalent urban runoff treatment in terms of pollutant load reduction elsewhere on the project to compensate for the loading discharged off the bridge.*

5. Effectiveness Information and Cost Information

Effectively controlling NPS pollutants such as road contaminants, fugitive dirt, and debris and preventing accidental spills from entering surface waters via bridge decks are necessary to protect wetlands and other sensitive ecosystems. Therefore, management practices such as minimizing the use of scupper drains and diverting runoff waters to land for treatment in detention ponds and infiltration systems are known to be effective in mitigating pollutant loadings. Tables 4-7 and 4-8 in Section II provide cost and effectiveness data for ponds, constructed wetlands, and filtration devices.

Management Measure for Construction Projects

(1) Reduce erosion and, to the extent practicable, retain sediment onsite during and after construction and

(2) Prior to land disturbance, prepare and implement an approved erosion control plan or similar administrative document that contains erosion and sediment control provisions.

1. Applicability

This management measure is intended to be applied by States to new, replaced, restored, and rehabilitated road, highway, and bridge construction projects in order to control erosion and offsite movement of sediment from such project sites. Under the Coastal Zone Act Reauthorization Amendments of 1990, States are subject to a number of requirements as they develop coastal NPS programs in conformity with this management measure and will have some flexibility in doing so. The application of management measures by States is described more fully in *Coastal Nonpoint Pollution Control Program: Program Development and Approval Guidance*, published jointly by the U.S. Environmental Protection Agency (EPA) and the National Oceanic and Atmospheric Administration (NOAA) of the U.S. Department of Commerce.

2. Description

Erosion and sedimentation from construction of roads, highways, and bridges, and from unstabilized cut-and-fill areas, can significantly impact surface waters and wetlands with silt and other pollutants including heavy metals, hydrocarbons, and toxic substances. Erosion and sediment control plans are effective in describing procedures for mitigating erosion problems at construction sites before any land-disturbing activity begins. Additional relevant practices are described in Management Measures III.A and III.B of this chapter.

Bridge construction projects include grade separations (bridges over roads) and waterbody crossings. Erosion problems at grade separations result from water running off the bridge deck and runoff waters flowing onto the bridge deck during construction. Controlling this runoff can prevent erosion of slope fills and the undermining failure of the concrete slab at the bridge approach. Bridge construction over waterbodies requires careful planning to limit the disturbance of streambanks. Soil materials excavated for footings in or near the water should be removed and relocated to prevent the material from being washed back into the waterbody. Protective berms, diversion ditches, and silt fences parallel to the waterway can be effective in preventing sediment from reaching the waterbody.

Wetland areas will need special consideration if affected by highway construction, particularly in areas where construction involves adding fill, dredging, or installing pilings. Highway development is most disruptive in wetlands since it may cause increased sediment loss, alteration of surface drainage patterns, changes in the subsurface water table, and loss of wetland habitat. Highway structures should not restrict tidal flows into salt marshes and other coastal wetland areas because this might allow the intrusion of freshwater plants and reduce the growth of salt-tolerant species. To safeguard these fragile areas, the best practice is to locate roads and highways with sufficient setback distances between the highway right-of-way and any wetlands or riparian areas. Bridge construction also can impact water circulation and quality in wetland areas, making special techniques necessary to accommodate construction. The following case study provides an example of a construction project where special considerations were given to wetlands.

> **CASE STUDY - BRIDGING WETLANDS IN LOUISIANA**
>
> To provide protection for an environmentally critical wetland outside New Orleans, the Louisiana Department of Transportation and Development (DOTD) required a special construction technique to build almost 2 miles of twin elevated structures for the Interstate 310 link between I-10 and U.S. Route 90. A technique known as "end-on" construction was devised to work from the decks of the structures, building each section of the bridge from the top of the last completed section and using heavy cranes to push each section forward one bay at a time. The cranes were also used to position steel platforms, drive in support pilings, and lay deck slabs, alternating this procedure between each bay. Without this technique, the Louisiana DOTD would not have been permitted to build this structure. The twin 9,200-foot bridges took 485 days to complete at a cost of $25.3 million (*Engineering News Record*, 1991).

3. Management Measure Selection

This management measure was selected because it supports FHWA's erosion and sediment control policy for all highway and bridge construction projects and is the administrative policy of several State highway departments and local governmental agencies involved in land development activity. Examples of erosion and sediment controls and NPS pollutant control practices are described in AASHTO guidelines and in several State erosion control manuals (AASHTO, 1991; North Carolina DOT, 1991; Washington State DOT, 1988). A detailed discussion of cost-effective management practices is available in the urban development section (Section II) of this chapter. These example practices are also effective for highway construction projects.

4. Practices

As discussed more fully at the beginning of this chapter and in Chapter 1, the following practices are described for illustrative purposes only. State programs need not require implementation of these practices. However, as a practical matter, EPA anticipates that the management measure set forth above generally will be implemented by applying one or more management practices appropriate to the source, location, and climate. The practices set forth below have been found by EPA to be representative of the types of practices that can be applied successfully to achieve the management measure described above.

Additional erosion and sediment control management practices are listed in the construction section (Section III) of this chapter.

■ a. *Write erosion and sediment control requirements into plans, specifications, and estimates for Federal aid construction projects for highways and bridges (FHWA, 1991) and develop erosion control plans for earth-disturbing activities.*

Erosion and sediment control decisions made during the planning and location phase should be written into the contract, plans, specifications, and special provisions provided to the construction contractor. This approach can establish contractor responsibility to carry out the explicit contract plan recommendations for the project and the erosion control practices needed.

■ b. *Coordinate erosion and sediment controls with FHWA, AASHTO, and State guidelines.*

Coordination and scheduling of the project work with State and local authorities are major considerations in controlling anticipated erosion and sediment problems. In addition, the contractor should submit a general work schedule and plan that indicates planned implementation of temporary and permanent erosion control practices, including shutdown procedures for winter and other work interruptions. The plan also should include proposed methods of control on restoring borrow pits and the disposal of waste and hazardous materials.

c. Install permanent erosion and sediment control structures at the earliest practicable time in the construction phase.

Permanent or temporary soil stabilization practices should be applied to cleared areas within 15 days after final grade is reached on any portion of the site. Soil stabilization should also be applied within 15 days to denuded areas that may not be at final grade but will remain exposed to rain for 30 days or more. Soil stabilization practices protect soil from the erosive forces of raindrop impact and flowing water. Temporary erosion control practices usually include seeding, mulching, establishing general vegetation, and early application of a gravel base on areas to be paved. Permanent soil stabilization practices include vegetation, filter strips, and structural devices.

Sediment basins and traps, perimeter dikes, sediment barriers, and other practices intended to trap sediment on site should be constructed as a first step in grading and should be functional before upslope land disturbance takes place. Structural practices such as earthen dams, dikes, and diversions should be seeded and mulched within 15 days of installation.

d. Coordinate temporary erosion and sediment control structures with permanent practices.

All temporary erosion and sediment controls should be removed and disposed of within 30 days after final site stabilization is achieved or after the temporary practices are no longer needed. Trapped sediment and other disturbed soil areas resulting from the disposition of temporary controls should be permanently stabilized to prevent further erosion and sedimentation (AASHTO, 1991).

e. Wash all vehicles prior to leaving the construction site to remove mud and other deposits. Vehicles entering or leaving the site with trash or other loose materials should be covered to prevent transport of dust, dirt, and debris. Install and maintain mud and silt traps.

f. Mitigate wetland areas destroyed during construction.

Marshes and some types of wetlands can often be developed in areas where fill material was extracted or in ponds designed for sediment control during construction. Vegetated strips of native marsh grasses established along highway embankments near wetlands or riparian areas can be effective to protect these areas from erosion and sedimentation (FHWA, 1991).

g. Minimize the area that is cleared for construction.

h. Construct cut-and-fill slopes in a manner that will minimize erosion.

Cut-and-fill slopes should be constructed in a manner that will minimize erosion by taking into consideration the length and steepness of slopes, soil types, upslope drainage areas, and ground-water conditions. Suggested recommendations are as follows: reduce the length of long steep slopes by adding diversions or terraces; prevent concentrated runoff from flowing down cut-and-fill slopes by containing these flows within flumes or slope drain structures; and create roughened soil surfaces on cut-and-fill slopes to slow runoff flows. Wherever a slope face crosses a water seepage plane, thereby endangering the stability of the slope, adequate subsurface drainage should be provided.

i. Minimize runoff entering and leaving the site through perimeter and onsite sediment controls.

j. Inspect and maintain erosion and sediment control practices (both on-site and perimeter) until disturbed areas are permanently stabilized.

k. Divert and convey offsite runoff around disturbed soils and steep slopes to stable areas in order to prevent transport of pollutants off site.

l. After construction, remove temporary control structures and restore the affected area. Dispose of sediments in accordance with State and Federal regulations.

m. All storm drain inlets that are made operable during construction should be protected so that sediment-laden water will not enter the conveyance system without first being filtered or otherwise treated to remove sediment.

5. Effectiveness Information and Cost Information

The detailed cost and effectiveness information presented under the construction measure for urban development is also applicable to road, highway, and bridge construction. See Tables 4-15 and 4-16 in Section III.

[illegible]

(1) Limit the application, generation, and migration of toxic substances;

(2) Ensure the proper storage and disposal of toxic materials; and

(3) Apply nutrients at rates necessary to establish and maintain vegetation without causing significant nutrient runoff to surface water.

1. Applicability

This management measure is intended to be applied by States to new, resurfaced, restored, and rehabilitated road, highway, and bridge construction projects in order to reduce toxic and nutrient loadings from such project sites. Under the Coastal Zone Act Reauthorization Amendments of 1990, States are subject to a number of requirements as they develop coastal NPS programs in conformity with this management measure and will have some flexibility in doing so. The application of management measures by States is described more fully in *Coastal Nonpoint Pollution Control Program: Program Development and Approval Guidance*, published jointly by the U.S. Environmental Protection Agency (EPA) and the National Oceanic and Atmospheric Administration (NOAA) of the U.S. Department of Commerce.

2. Description

The objective of this measure is to guard against toxic spills and hazardous loadings at construction sites from equipment and fuel storage sites. Toxic substances tend to bind to fine soil particles; however, by controlling sediment mobilization, it is possible to limit the loadings of these pollutants. Also, some substances such as fuels and solvents are hazardous and excess applications or spills during construction can pose significant environmental impacts. Proper management and control of toxic substances and hazardous materials should be the adopted procedure for all construction projects and should be established by erosion and sediment control plans. Additional relevant practices are described in Management Measure III.B of this chapter.

3. Management Measure Selection

This management measure was selected because of existing practices that have been shown to be effective in mitigating construction-generated NPS pollution at highway project sites and equipment storage yards. In addition, maintenance areas containing road salt storage, fertilizers and pesticides, snowplows and trucks, and tractor mowers have the potential to contribute NPS pollutants to adjacent watercourses if not properly managed (AASHTO, 1988, 1991a). This measure is intended to safeguard surface waters and ground water from toxic and hazardous pollutants generated at construction sites. Examples of effective implementation of this measure are presented in the section on construction in urban areas. Several State environmental agencies are using this approach to regulate toxic and hazardous pollutants (Florida DER, 1988; Puget Sound Basin, 1991).

4. Practices

As discussed more fully at the beginning of this chapter and in Chapter 1, the following practices are described for illustrative purposes only. State programs need not require implementation of these practices. However, as a practical matter, EPA anticipates that the management measure set forth above generally will be implemented by applying one or more management practices appropriate to the source, location, and climate. The practices set forth below have been found by EPA to be representative of the types of practices that can be applied successfully to achieve the management measure described above.

The practices that are applicable to this management measure are described in Section III.B.

5. Effectiveness Information and Cost Information

The detailed cost and effectiveness data presented in the Section III.A of this chapter describing NPS controls for construction projects in urban development areas are also applicable to highway construction projects.

F. Management Measure for Operation and Maintenance

Incorporate pollution prevention procedures into the operation and maintenance of roads, highways, and bridges to reduce pollutant loadings to surface waters.

1. Applicability

This management measure is intended to be applied by States to existing, restored, and rehabilitated roads, highways, and bridges. Under the Coastal Zone Act Reauthorization Amendments of 1990, States are subject to a number of requirements as they develop coastal NPS programs in conformity with this management measures and will have some flexibility in doing so. The application of measures by States is described more fully in *Coastal Nonpoint Pollution Control Program: Program Development and Approval Guidance*, published jointly by the U.S. Environmental Protection Agency (EPA) and the National Oceanic and Atmospheric Administration (NOAA) of the U.S. Department of Commerce.

2. Description

Substantial amounts of eroded material and other pollutants can be generated by operation and maintenance procedures for roads, highways, and bridges, and from sparsely vegetated areas, cracked pavements, potholes, and poorly operating urban runoff control structures. This measure is intended to ensure that pollutant loadings from roads, highways, and bridges are minimized by the development and implementation of a program and associated practices to ensure that sediment and toxic substance loadings from operation and maintenance activities do not impair coastal surface waters. The program to be developed, using the practices described in this management measure, should consist of and identify standard operating procedures for nutrient and pesticide management, road salt use minimization, and maintenance guidelines (e.g., capture and contain paint chips and other particulates from bridge maintenance operations, resurfacing, and pothole repairs).

3. Management Measure Selection

This management measure for operation and maintenance was selected because (1) it is recommended by FHWA as a cost-effective practice (FHWA, 1991); (2) it is protective of the human environment (Puget Sound Water Quality Authority, 1989); (3) it is effective in controlling erosion by revegetating bare slopes (AASHTO, 1991b); (4) it is helpful in minimizing polluted runoff from road pavements (Transportation Research Board, 1991); and (5) both Federal (Richardson, 1974) and State highway agencies (Minnesota Pollution Control Agency, 1989; Pitt, 1973) advocate highway maintenance as an effective practice for minimizing pollutant loadings.

Maintenance of erosion and sediment control practices is of critical importance. Both temporary and permanent controls require frequent and periodic cleanout of accumulated sediment. Any trapping or filtering device, such as silt fences, sediment basins, buffers, inlets, and check dams, should be checked and cleaned out when approximately 50 percent of their capacity is reached, as determined by the erodible nature of the soil, flow velocity, and quantity of runoff. Seasonal and climatic differences may require more frequent cleanout of these structures. The sediments removed from these control devices should be deposited in permanently stabilized areas to prevent further erosion and sediment from reaching drainages and receiving streams. After periods of use, control devices may require replacement of deteriorated materials such as straw bales and silt fence fabrics, or restoration and reconstruction of sediment basins and riprap installations.

Permanent erosion controls such as vegetated filter strips, grassed swales, and velocity dissipators should be inspected periodically to determine their integrity and continued effectiveness. Continual deterioration or damage to these controls may indicate a need for better design or construction.

4. Practices

As discussed more fully at the beginning of this chapter and in Chapter 1, the following practices are described for illustrative purposes only. State programs need not require implementation of these practices. However, as a practical matter, EPA anticipates that the management measure set forth above generally will be implemented by applying one or more management practices appropriate to the source, location, and climate. The practices set forth below have been found by EPA to be representative of the types of practices that can be applied successfully apply to achieve the management measure described above.

■ a. *Seed and fertilize, seed and mulch, and/or sod damaged vegetated areas and slopes.*

■ b. *Establish pesticide/herbicide use and nutrient management programs.*

Refer to the Management Measure for Construction Site Chemical Control in this chapter.

■ c. *Restrict herbicide and pesticide use in highway rights-of-way to applicators certified under the Federal Insecticide, Fungicide, and Rodenticide Act (FIFRA) to ensure safe and effective application.*

■ d. *The use of chemicals such as soil stabilizers, dust palliatives, sterilants, and growth inhibitors should be limited to the best estimate of optimum application rates. All feasible measures should be taken to avoid excess application and consequent intrusion of such chemicals into surface runoff.*

■ e. *Sweep, vacuum, and wash residential/urban streets and parking lots.*

■ f. *Collect and remove road debris.*

■ g. *Cover salt storage piles and other deicing materials to reduce contamination of surface waters. Locate them outside the 100-year floodplain.*

■ h. *Regulate the application of deicing salts to prevent oversalting of pavement.*

■ i. *Use specially equipped salt application trucks.*

■ j. *Use alternative deicing materials, such as sand or salt substitutes, where sensitive ecosystems should be protected.*

■ k. *Prevent dumping of accumulated snow into surface waters.*

■ l. *Maintain retaining walls and pavements to minimize cracks and leakage.*

■ m. *Repair potholes.*

■ n. *Encourage litter and debris control management.*

o. Develop an inspection program to ensure that general maintenance is performed on urban runoff and NPS pollution control facilities.

To be effective, erosion and sediment control devices and practices must receive thorough and periodic inspection checks. The following is a suggested checklist for the inspection of erosion and sediment controls (AASHTO Operating Subcommittee on Design, 1990):

- Clean out sediment basins and traps; ensure that structures are stable.
- Inspect silt fences and replace deteriorated fabrics and wire connections; properly dispose of deteriorated materials.
- Renew riprapped areas and reapply supplemental rock as necessary.
- Repair/replace check dams and brush barriers; replace or stabilize straw bales as needed.
- Regrade and shape berms and drainage ditches to ensure that runoff is properly channeled.
- Apply seed and mulch where bare spots appear, and replace matting material if deteriorated.
- Ensure that culverts and inlets are protected from siltation.
- Inspect all permanent erosion and sediment controls on a scheduled, programmed basis.

p. Ensure that energy dissipators and velocity controls to minimize runoff velocity and erosion are maintained.

q. Dispose of accumulated sediment collected from urban runoff management and pollution control facilities, and any wastes generated during maintenance operations, in accordance with appropriate local, State, and Federal regulations.

r. Use techniques such as suspended tarps, vacuums, or booms to reduce, to the extent practicable, the delivery to surface waters of pollutants used or generated during bridge maintenance (e.g., paint, solvents, scrapings).

s. Develop education programs to promote the practices listed above.

5. Effectiveness Information and Cost Information

Preventive maintenance is a time-proven, cost-effective management approach. Operation schedules and maintenance procedures to restore vegetation, proper management of salt and fertilizer application, regular cleaning of urban runoff structures, and frequent sweeping and vacuuming of urban streets have effective results in pollution control. Litter control, clean-up, and fix-up practices are a low-cost means for eliminating causes of pollution, as is the proper handling of fertilizers, pesticides, and other toxic materials including deicing salts and abrasives. Table 4-30 presents summary information on the cost and effectiveness of operation and maintenance practices for roads, highways, and bridges. Many States and communities are already implementing several of these practices within their budget limitations. As shown in Table 4-30, the use of road salt alternatives such as calcium magnesium acetate (CMA) can be very costly. Some researchers have indicated, however, that reductions in corrosion of infrastructure, damage to roadside vegetation, and the quantity of material that needs to be applied may offset the higher cost of CMA. Use of road salt minimization practices such as salt storage protection and special salt spreading equipment reduces the amount of salt that a State or community must purchase. Consequently, implementation of these practices can pay for itself through savings in salt purchasing costs. Similar programs such as nutrient and pesticide management can also lead to decreased expenditures for materials.

CMA Eligible for Matching Funds

Calcium magnesium acetate (CMA) is now eligible for Federal matching funds under the Bridge Program of the Intermodal Surface Transportation Efficiency Act (ISTEA) of 1991. The Act provides 80 percent funding for use of CMA on salt-sensitive bridges in order to protect against corrosion and to extend their useful life. CMA can also be used to protect vegetation from salt damage in environmentally sensitive areas.

Table 4-30. Effectiveness and Cost Summary for Roads, Highways, and Bridges Operation and Maintenance Management Practices

Management Practice	% Removal						Cost
	TSS	TP	TN	COD	Pb	Zn	
MAINTAIN VEGETATION							
For Sediment Control							Natural succession allowed to occur -
Average:	90	NA	NA	NA	NA	NA	Avg: $100/ac/year
Reported Range:	50-100	NA	NA	NA	NA	NA	Reported Range: $50-$200/ac/year
Probable Range:	80-100	-	-	-	-	-	
For Pollutant Removal							Natural succession not allowed to occur -
Average:	60	40	40	50	50	50	Avg: $800/ac/year
Reported Range	0-100	0-100	0-70	20-80	0-100	50-60	Reported Range: $700-$900/ac/year
Probable Range:	0-100	0-100	0-100	0-100	0-100	0-100	
PESTICIDE/HERBICIDE USE MANAGEMENT							Generally accepted as an economical program to control excessive use
Average:	NA						
Reported Range:	NA						
Probable Range:							
STREET SWEEPING							
Smooth Street, Frequent Cleaning (One or More Passes Per Week)							Avg: $20/curb mile Reported Range: $10-$30/curb mile
Average:	20	NA	NA	5	25	NA	
Reported Range:	20	NA	NA	0-10	5-35	NA	
Probable Range:	20-50	-	-	0-10	20-50	10-30	
Infrequent Cleaning (One Pass Per Month or Less)							
Average:	NA	NA	NA	NA	5	NA	
Reported Range:	NA	NA	NA	NA	0-10	NA	
Probable Range:	0-20	-	-	-	0-20	0-10	
LITTER CONTROL							Generally accepted as an economical approach to control excessive use
Average:	NA						
Reported Range:	NA						
Probable Range:							

Table 4-38. (Continued)

Management Practice	% Removal TSS	TP	TN	COD	Pb	Zn	Cost
GENERAL MAINTENANCE (e.g., pothole and roadside repairs)							Generally accepted as an economical preventive maintenance program by local and State agencies
Average:	NA						
Reported Range:	NA						
Probable Range:							
PROTECTION OF SALT PILES							For salt storage building -
Average:	NA						Ave: $30/ton salt
Reported Range:	NA						Reported Range: $10-$70/ton salt
Probable Range:	90-100[a]						
MINIMIZATION OF APPLICATION OF DEICING SALTS							Generally accepted as an economical preventive maintenance program by local and State agencies
Average:	NA						
Reported Range:	NA						
Probable Range:	Deicing salts that are not applied to roads will not enter runoff.[a]						
SPECIALLY EQUIPPED SALT APPLICATION TRUCKS							For spread rate control on truck -
Average:	NA						Ave: $6,000/truck
Reported Range:	NA						Reported Range: $6,000/truck
Probable Range:	Deicing salts that are not applied to roads will not enter runoff.[a]						
USE OF ALTERNATIVE DEICING MATERIALS							CMA -
Average:	NA						Ave: $650/ton
Reported Range:	NA						Reported Range: $650/ton
Probable Range:	Deicing salts that are not applied to roads will not enter runoff.[a]						(note: cost of salt $30/ton)
CONTAIN POLLUTANTS GENERATED DURING BRIDGE MAINTENANCE							Varies with method of containment use
Average:	NA						
Reported Range:	NA						
Probable Range:	50-100[b]						

NA = Not applicable.
[a]Measured as reduction in salt.
[b]Measured as reduction of all pollutants.

[illegible]

Develop and implement runoff management systems for existing roads, highways, and bridges to reduce runoff pollutant concentrations and volumes entering surface waters.

(1) Identify priority and watershed pollutant reduction opportunities (e.g., improvements to existing urban runoff control structures; and

(2) Establish schedules for implementing appropriate controls.

1. Applicability

This management measure is intended to be applied by States to existing, resurfaced, restored, and rehabilitated roads, highways, and bridges that contribute to adverse effects in surface waters. Under the Coastal Zone Act Reauthorization Amendments of 1990, States are subject to a number of requirements as they develop coastal NPS programs in conformity with this management measure and will have some flexibility in doing so. The application of management measures by States is described more fully in *Coastal Nonpoint Pollution Control Program: Program Development and Approval Guidance*, published jointly by the U.S. Environmental Protection Agency (EPA) and the National Oceanic and Atmospheric Administration (NOAA) of the U.S. Department of Commerce.

2. Description

This measure requires that operation and maintenance systems include the development of retrofit projects, where needed, to collect NPS pollutant loadings from existing, reconstructed, and rehabilitated roads, highways, and bridges. Poorly designed or maintained roads and bridges can generate significant erosion and pollution loads containing heavy metals, hydrocarbons, sediment, and debris that run off into and threaten the quality of surface waters and their tributaries. In areas where such adverse impacts to surface waters can be attributed to adjacent roads or bridges, retrofit management projects to protect these waters may be needed (e.g., installation of structural or nonstructural pollution controls). Retrofit projects can be located in existing rights-of-way, within interchange loops, or on adjacent land areas. Areas with severe erosion and pollution runoff problems may require relocation or reconstruction to mitigate these impacts.

Runoff management systems are a combination of nonstructural and structural practices selected to reduce nonpoint source loadings from roads, highways, and bridges. These systems are expected to include structural improvements to existing runoff control structures for water quality purposes; construction of new runoff control devices, where necessary to protect water quality; and scheduled operation and maintenance activities for these runoff control practices. Typical runoff controls for roads, highways, and bridges include vegetated filter strips, grassed swales, detention basins, constructed wetlands, and infiltration trenches.

3. Management Measure Selection

This management measure was selected because of the demonstrated effectiveness of retrofit systems for existing roads and highways that were constructed with inadequate nonpoint source pollution controls or without such controls. Structural practices for mitigating polluted runoff from existing highways are described in the literature (Silverman, 1988).

4. Practices

As discussed more fully at the beginning of this chapter and in Chapter 1, the following practices are described for illustrative purposes only. State programs need not require implementation of these practices. However, as a practical matter, EPA anticipates that the management measure set forth above generally will be implemented by applying one or more management practices appropriate to the source, location, and climate. The practices set forth below have been found by EPA to be representative of the types of practices that can be applied successfully to achieve the management measure described above.

- a. ***Locate runoff treatment facilities within existing rights-of-way or in medians and interchange loops.***
- b. ***Develop multiple-use treatment facilities on adjacent lands (e.g., parks and golf courses).***
- c. ***Acquire additional land for locating treatment facilities.***
- d. ***Use underground storage where no alternative is available.***
- e. ***Maximize the length and width of vegetated filter strips to slow the travel time of sheet flow and increase the infiltration rate of urban runoff.***

5. Effectiveness Information and Cost Information

Cost and effectiveness data for structural urban runoff management and pollution control facilities are outlined in Tables 4-15 and 4-16 in Section III and discussed in Section IV of this chapter and are applicable to determine the cost and effectiveness of retrofit projects. Retrofit projects can often be more costly to construct because of the need to locate the required structures within existing space or the need to locate the structures within adjacent property that requires purchase. However, the use of multiple-use facilities on adjacent lands, such as diverting runoff waters to parkland or golf courses, can offset this cost. Nonstructural practices described in the urban section also can be effective in achieving source control. As with other sections of this document, the costs of loss of habitat, fisheries, and recreational areas must be weighed against the cost of retrofitting control structures within existing rights-of-way.

6. Pollutants of Concern

Table 4-31 lists the pollutants commonly found in urban runoff from roads, highways, and bridges and their sources. The disposition and subsequent magnitude of pollutants found in highway runoff are site-specific and are affected by traffic volume, road or highway design, surrounding land use, climate, and accidental spills.

The FHWA conducted an extensive field monitoring and laboratory analysis program to determine the pollutant concentration in highway runoff from 31 sites in 11 States (Driscoll et al., 1990). The event mean concentrations (EMCs) developed in the study for a number of pollutants are presented in Table 4-32. The study also indicated that for highways discharging into lakes, the pollutants of major concern are phosphorus and heavy metals. For highways discharging into streams, the pollutants of major concern are heavy metals—cadmium, copper, lead, and zinc.

Table 4-31. Highway Runoff Constituents and Their Primary Sources

Constituents	Primary Sources
Particulates	Pavement wear, vehicles, atmosphere, maintenance
Nitrogen, Phosphorus	Atmosphere, roadside fertilizer application
Lead	Leaded gasoline (auto exhaust), tire wear (lead oxide filler material, lubricating oil and grease, bearing wear)
Zinc	Tire wear (filler material), motor oil (stabilizing additive), grease
Iron	Auto body rust, steel highway structures (guard rails, bridges, etc.), moving engine parts
Copper	Metal plating, bearing and bushing wear, moving engine parts, brake lining wear, fungicides and insecticides
Cadmium	Tire wear (filler material), insecticide application
Chromium	Metal plating, moving engine parts, break lining wear
Nickel	Diesel fuel and gasoline (exhaust), lubricating oil, metal plating, bushing wear, brake lining wear, asphalt paving
Manganese	Moving engine parts
Cyanide	Anticake compound (ferric ferrocyanide, sodium ferrocyanide, yellow prussiate of soda) used to keep deicing salt granular
Sodium, Calcium, Chloride	Deicing salts
Sulphate	Roadway beds, fuel, deicing salts
Petroleum	Spills, leaks or blow-by of motor lubricants, antifreeze and hydraulic fluids, asphalt surface leachate

In colder regions where deicing agents are used, deicing chemicals and abrasives are the largest source of pollutants during winter months. Deicing salt (primarily sodium chloride, NaCl) is the most commonly used deicing agent. Potential pollutants from deicing salt include sodium chloride, ferric ferrocyanide (used to keep the salt in granular form), and sulfates such as gypsum. Table 4-33 summarizes potential environmental impacts caused by road salt. Other chemicals used as a salt substitute include calcium magnesium acetate (CMA) and, less frequently, urea and glycol compounds. Researchers have differing opinions on the environmental impacts of CMA compared to those of road salt (Chevron Chemical Company, 1991; Salt Institute, undated; Transportation Research Board, 1991).

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Table 4-32. Pollutant Concentrations in Highway Runoff (Driscoll et al., 1990)

Pollutant	Event Mean Concentration for Highways With Fewer Than 30,000 Vehicles/Day[a] (mg/L)	Event Mean Concentration for Highways With More Than 30,000 Vehicles/Day[a] (mg/L)
Total Suspended Solids	41	142
Volatile Suspended Solids	12	39
Total Organic Carbon	8	25
Chemical Oxygen Demand	49	114
Nitrite and Nitrate	0.46	0.76
Total Kjeldahl Nitrogen	0.87	1.83
Phosphate Phosphorus	0.16	0.40
Copper	0.022	0.054
Lead	0.080	0.400
Zinc	0.080	0.329

[a]Event mean concentrations are for the 50% median site.

Table 4-33. Potential Environmental Impacts of Road Salts

Environmental Resource	Potential Environmental Impact of Road Salt (NaCl)
Soils	May accumulate in soil. Breaks down soil structure, increases erosion. Causes soil compaction that results in decreased permeability.
Vegetation	Osmotic stress and soil compaction harm root systems. Spray causes foliage dehydration damage. Many plant species are salt-sensitive.
Ground Water	Mobile Na and Cl ions readily reach ground water. Increases NaCl concentration in well water, as well as alkalinity and hardness.
Surface Water	Causes density stratification in ponds and lakes that can prevent reoxygenation. Increases runoff of heavy metals and nutrients through increased erosion.
Aquatic Life	Monovalent Na and Cl ions stress osmotic balances. Toxic levels: Na - 500 ppm for stickleback; Cl - 400 ppm for trout.
Human/Mammalian	Sodium is linked to heart disease and hypertension. Chlorine causes unpleasant taste in drinking water. Mild skin and eye irritant. Acute oral LD_{50} in rats is approximately 3,000 mg/kg (slightly toxic).

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VIII. GLOSSARY

Unless otherwise noted, the source of these definitions is *Glossary of Environmental Terms and Acronym List* (USEPA, 1989).

Bankfull event (also bankfull discharge): A flow condition in which streamflow completely fills the steam channel up to the top of the bank. In undisturbed watersheds, the discharge condition occurs on average every 1.5 to 2 years and controls the shape and form of natural channels. (Schueler, 1987)

Berm: An earthen mound used to direct the flow of runoff around or through a best management practice (BMP) (Schueler, 1987).

Constructed urban runoff wetlands: Those wetlands that are intentionally created on sites that are not wetlands for the primary purpose of wastewater or urban runoff treatment and are managed as such. Constructed wetlands are normally considered as part of the urban runoff collection and treatment system.

Conveyance system: The drainage facilities, both natural and human-made, which collect, contain, and provide for the flow of surface water and urban runoff from the highest points on the land down to a receiving water. The natural elements of the conveyance system include swales and small drainage courses, streams, rivers, lakes, and wetlands. The human-made elements of the conveyance system include gutters, ditches, pipes, channels, and most retention/detention facilities (Washington Department of Ecology, 1992).

Denitrification: The anaerobic biological reduction of nitrate nitrogen to nitrogen gas.

Discharge: Outflow; the flow of a stream, canal, or aquifer. One may also speak of the discharge of a canal or stream into a lake, river, or ocean. (Hydraulics) Rate of flow, specifically fluid flow; a volume of fluid passing a point per unit of time, commonly expressed as cubic feet per second, cubic meters per second, gallons per minute, gallons per day, or millions of gallons per day. (Washington Department of Ecology, 1992)

Drainage basin: A geographic and hydrologic subunit of a watershed (Washington Department of Ecology, 1992).

Ecosystem: The interacting system of a biological community and its nonliving environmental surroundings.

Erosion: The wearing away of the land surface by wind or water. Erosion occurs naturally from weather or runoff but can be intensified by land-clearing practices related to farming, residential or industrial development, road building, or timber cutting.

Forebay: An extra storage space provided near an inlet of a BMP to trap incoming sediments before they accumulate in a pond BMP (Schueler, 1987).

Heavy metals: Metallic elements with high atomic weights, e.g., mercury, chromium, cadmium, arsenic, and lead. They can damage living things at low concentrations and tend to accumulate in the food chain.

Illicit discharge: All nonurban runoff discharges to urban runoff drainage systems that could cause or contribute to a violation of State water quality, sediment quality, or ground-water quality standards, including but not limited to sanitary sewer connections, industrial process water, interior floor drains, car washing, and greywater systems (Washington Department of Ecology, 1992).

Impervious surface: A hard surface area that either prevents or retards the entry of water into the soil mantle as under natural conditions prior to development and/or a hard surface area that causes water to run off the surface in greater quantities or at an increased rate of flow from the flow present under natural conditions prior to development. Common impervious surfaces include, but are not limited to, rooftops, walkways, patios, driveways, parking lots,

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storage areas, concrete or asphalt paving, gravel roads, packed earthen materials, and oiled, macadam, or other surfaces that similarly impede the natural infiltration of urban runoff. Open, uncovered retention/detention facilities shall not be considered as impervious surfaces. (Washington Department of Ecology, 1992)

Invasive exotic plants: Non-native plants having the capacity to compete and proliferate in introduced environments (Washington Department of Ecology, 1992).

Land conversion: A change in land use, function, or purpose (Washington Department of Ecology, 1992).

Land-disturbing activity: Any activity that results in a change in the existing soil cover (both vegetative and nonvegetative) and/or the existing soil topography. Land-disturbing activities include, but are not limited to, demolition, construction, clearing, grading, filling, and excavation. (Washington Department of Ecology, 1992)

Local government: Any county, city, or town having its own incorporated government for local affairs (Washington Department of Ecology, 1992).

Municipal separate storm sewer systems: Any conveyance or system of conveyance that is owned or operated by the State or local government entity, is used for collecting and conveying storm water, and is not part of a publicly owned treatment works (POTW), as defined in EPA 40 CFR Part III (Washington Department of Ecology, 1992).

Onsite disposal system (OSDS): Sewage disposal system designed to treat wastewater at a particular site. Septic tank systems are common OSDS. (Washington Department of Ecology, 1992)

Organophosphate: Pesticide chemical that contains phosphorus; used to control insects. Organophosphates are short-lived, but some can be toxic when first applied.

Postdevelopment peak runoff: Maximum instantaneous rate of flow during a storm, after development is complete (Washington Department of Ecology, 1992).

Retrofit: The creation or modification of an urban runoff management system in a previously developed area. This may include wet ponds, infiltration systems, wetland plantings, streambank stabilization, and other BMP techniques for improving water quality and creating aquatic habitat. A retrofit can consist of the construction of a new BMP in a developed area, the enhancement of an older urban runoff management structure, or a combination of improvement and new construction. (Schueler et al., 1992)

Soil absorption field: A subsurface area containing a trench or bed with clean stones and a system of distribution piping through which treated sewage may seep into the surrounding soil for further treatment and disposal.

Turbidity: A cloudy condition in water due to suspended silt or organic matter.

Urban runoff: That portion of precipitation that does not naturally percolate into the ground or evaporate, but flows via overland flow, underflow, or channels or is piped into a defined surface water channel or a constructed infiltration facility (Washington Department of Ecology, 1992).

Vegetated buffer: Strips of vegetation separating a waterbody from a land use with potential to act as a nonpoint pollution source; vegetated buffers (or simply buffers) are variable in width and can range in function from a vegetated filter strip to a wetland or riparian area.

Watershed: The land area that drains into a receiving waterbody.

Wetlands: Areas that are inundated or saturated by surface or ground water at a frequency and duration to support, and that under normal circumstances do support, a prevalence of vegetation typically adapted for life in saturated soil conditions; wetlands generally include swamps, marshes, bogs, and similar areas. (This definition is consistent with the Federal definition at 40 CFR 230.3; December 24, 1989. As amendments are made to the wetland definition, they will be considered applicable to this guidance.)

Xeriscaping: A horticultural practice that combines water conservation techniques with landscaping; also known as dry landscaping (Clemson University Cooperative Extension Service, 1991).

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CHAPTER 5: Management Measures for Marinas and Recreational Boating

I. INTRODUCTION

A. What "Management Measures" Are

This chapter specifies management measures to protect coastal waters from sources of nonpoint pollution from marinas and recreational boating. "Management measures" are defined in section 6217 of the Coastal Zone Act Reauthorization Amendments of 1990 (CZARA) as economically achievable measures to control the addition of pollutants to our coastal waters, which reflect the greatest degree of pollutant reduction achievable through the application of the best available nonpoint pollution control practices, technologies, processes, siting criteria, operating methods, or other alternatives.

These management measures will be incorporated by States into their coastal nonpoint programs, which under CZARA are to provide for the implementation of management measures that are "in conformity" with this guidance. Under CZARA, States are subject to a number of requirements as they develop and implement their coastal nonpoint pollution control programs in conformity with this guidance and will have some flexibility in doing so. The application of these management measures by States to activities causing nonpoint pollution is described more fully in *Coastal Nonpoint Pollution Control Program: Program Development and Approval Guidance*, published jointly by the U.S. Environmental Protection Agency (EPA) and the National Oceanic and Atmospheric Administration (NOAA).

B. What "Management Practices" Are

In addition to specifying management *measures*, this chapter also lists and describes management *practices* for illustrative purposes only. While State programs are required to specify management *measures* in conformity with this guidance, State programs need not specify or require the implementation of the particular management *practices* described in this document. However, as a practical matter, EPA anticipates that the management measures generally will be implemented by applying one or more management practices appropriate to the source, location, and climate. The practices listed in this document have been found by EPA to be representative of the types of practices that can be applied successfully to achieve the management measures. EPA has also used some of these practices, or appropriate combinations of these practices, as a basis for estimating the effectiveness, costs, and economic impacts of achieving the management measures. (Economic impacts of the management measures are addressed in a separate document entitled *Economic Impacts of EPA Guidance Specifying Management Measures for Sources of Nonpoint Pollution in Coastal Waters.*)

EPA recognizes that there is often site-specific, regional, and national variability in the selection of appropriate practices, as well as in the design constraints and pollution control effectiveness of practices. The list of practices for each management measure is not all-inclusive and does not preclude States or local agencies from using other technically sound practices. In all cases, however, the practice or set of practices chosen by a State needs to achieve the management measure.

C. Scope of This Chapter

This chapter addresses categories of sources of nonpoint pollution from marinas and recreational boating that affect coastal waters. This chapter specifies 15 management measures grouped under two broad headings: (1) siting and design and (2) operation and maintenance.

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Each category of sources is addressed in a separate section of this guidance. Each section contains (1) the management measure(s); (2) an applicability statement that describes, when appropriate, specific activities and locations for which the measure is suitable; (3) a description of the management measure's purpose; (4) the basis for the management measure's selection; (5) information on management practices that are suitable, either alone or in combination with other practices, to achieve the management measure; (6) information on the effectiveness of the management measure and/or of practices to achieve the measure; and (7) information on costs of the measure and/or practices to achieve the measure.

D. Relationship of This Chapter to Other Chapters and to Other EPA Documents

1. Chapter 1 of this document contains detailed information on the legislative background for this guidance, the process used by EPA to develop this guidance, and the technical approach used by EPA in this guidance.

2. Chapter 7 of this document contains management measures to protect wetlands and riparian areas that serve a nonpoint source abatement function. These measures apply to a broad variety of sources, including marinas and recreational boating sources.

3. Chapter 8 of this document contains information on recommended monitoring techniques to (1) ensure proper implementation, operation, and maintenance of the management measures and (2) assess over time the success of the measures in reducing pollution loads and improving water quality.

4. EPA has separately published a document entitled *Economic Impacts of EPA Guidance Specifying Management Measures for Sources of Nonpoint Pollution in Coastal Waters.*

5. NOAA and EPA have jointly published guidance entitled *Coastal Nonpoint Pollution Control Program: Program Development and Approval Guidance*. This guidance contains details on how State Coastal Nonpoint Pollution Control Programs are to be developed by States and approved by NOAA and EPA. It includes guidance on the following:

   - The basis and process for EPA/NOAA approval of State Coastal Nonpoint Pollution Control Programs;
   - How NOAA and EPA expect State programs to provide for the implementation of management measures "in conformity" with this management measures guidance;
   - How States may target sources in implementing their Coastal Nonpoint Pollution Control Programs;
   - Changes in State coastal boundaries; and
   - Requirements concerning how States are to implement their Coastal Nonpoint Pollution Control Programs.

E. Problem Statement

Marinas and recreational boating are increasingly popular uses of coastal areas. The growth of recreational boating, along with the growth of coastal development in general, has led to a growing awareness of the need to protect waterways. In the Coastal Zone Management Act (CZMA) of 1972, as amended, Congress declared it to be national policy that State coastal management programs provide for public access to the coasts for recreational purposes. Clearly, boating and adjunct activities (e.g., marinas) are an important means of public access. When these facilities are poorly planned or managed, however, they may pose a threat to the health of aquatic systems and may pose other environmental hazards. Ensuring the best possible siting for marinas, as well as the best available design and construction practices and appropriate operation and maintenance practices, can greatly reduce nonpoint source (NPS) pollution from marinas.

Because marinas are located right at the water's edge, there is often no buffering of the release of pollutants to waterways. Adverse environmental impacts may result from the following sources of pollution associated with marinas and recreational boating:

- Poorly flushed waterways where dissolved oxygen deficiencies exist;
- Pollutants discharged from boats;
- Pollutants transported in storm water runoff from parking lots, roofs, and other impervious surfaces;
- The physical alteration or destruction of wetlands and of shellfish and other bottom communities during the construction of marinas, ramps, and related facilities; and
- Pollutants generated from boat maintenance activities on land and in the water.

The management measures described in this chapter are designed to reduce NPS pollution from marinas and recreational boating. Effective implementation will avoid impacts associated with marina siting, prevent the introduction of nonpoint source pollutants, and/or reduce the delivery of pollutants to water resources.

Pollution prevention should be at the fore of any NPS management strategy. It is expected that each coastal State's decision on implementation of these management measures will be based on a management strategy that balances the need for protecting the coastal environment and the need to provide adequate public access to coastal waters.

F. Pollutant Types and Impacts

A marina can have significant impacts on the concentrations of pollutants in the water, sediment, and tissue of organisms within the marina itself. Although sources of pollutants outside the marina are part of the problem, marina design, operation, and location appear to play crucial roles in determining whether local water quality is impacted (NCDEM, 1991).

Marina construction may alter the type of habitat found at the site. Alterations can have both negative and positive effects. For example, a soft-bottom habitat (i.e., habitat characterized by burrowing organisms and deposit feeders) could be replaced with a habitat characterized by fouling organisms attached to the marina pilings and bulkhead. These fouling organisms, however, may attract other organisms, including invertebrates and juvenile fish.

The presence of a marina is not necessarily an indicator of poor water quality. In fact, many marinas have good water quality. Despite this, they may still have degraded biological resources and contaminated sediments resulting from bioaccumulation in organisms and adhesion of pollutants to sediments. A brief summary of some of the impacts that can be associated with marina and boating activities is presented below.

1. Toxicity in the Water Column

Pollutants from marinas can result in toxicity in the water column, both lethal and sublethal, related to decreased levels of dissolved oxygen and elevated levels of metals and petroleum hydrocarbons. These pollutants may enter the water through discharges from boats or other sources, spills, or storm water runoff.

Low Dissolved Oxygen. The organics in sewage discharged from recreational boats require dissolved oxygen (DO) to decompose. The biological oxygen demand (BOD) of a waterbody is a measure of the DO required to decompose sewage and other organic matter (Milliken and Lee, 1990). Accumulation of organic material in sediment will result in a sediment oxygen demand (SOD) that can negatively impact water column DO. The effect of boat sewage on

DO can be intensified in temperate regions because the peak boating season coincides with the highest water temperatures and thus the lowest solubilities of oxygen in the water and the highest metabolism rates of aquatic organisms. (As temperature increases, dissolved oxygen levels decrease.) Cardwell and Koons (1981) recorded significant decreases in DO in several northwestern marinas in the late summer and early fall, which are the peak times of marina use. Nixon et al. (1973) measured lower DO levels in an area of marina development than in an adjacent undeveloped bay of similar size. An intensive study in several North Carolina marinas showed significant decreases in DO concentration compared to ambient concentrations in the receiving waterbody. These decreases in DO were thought to result from high SOD within the marinas and poor flushing resulting from improper marina design (NCDEM, 1990).

Metals. Metals and metal-containing compounds have many functions in boat operation, maintenance, and repair. Lead is used as a fuel additive and ballast and may be released through incomplete fuel combustion and boat bilge discharges (NCDEM, 1991). Arsenic is used in paint pigments, pesticides, and wood preservatives. Zinc anodes are used to deter corrosion of metal hulls and engine parts. Copper and tin are used as biocides in antifoulant paints. Other metals (iron, chrome, etc.) are used in the construction of marinas and boats.

Many of these metals/compounds are found in marina waters at levels that are toxic to aquatic organisms. Copper is the most common metal found at toxic concentrations in marina waters (NCDEM, 1990, 1991). Dissolved copper was detected at toxic concentrations at several marinas within the Chesapeake Bay (Hall et al., 1987). The input of copper via bottom paints and scrapings has been shown to be quite significant (Young et al., 1974). Tin in the form of butyltin, an extremely potent biocide, has been detected at toxic levels within marina waters nationwide (Stephenson et al., 1986; Maguire, 1986; Grovhoug et al., 1986; Stallard et al., 1987). The use of butyltins in bottom paint is now regulated, and butyltins cannot be used on nonaluminum recreational boats under 25 meters in length. High levels of zinc, chromium, and lead were also detected in waters within North Carolina marinas (NCDEM, 1990). Table 5-1 presents results of a recent study of boatyard hull pressure-washing wastewater in the Puget Sound area that revealed concentrations of metals and other pollutants that are of concern to environmental regulators (METRO, 1992a).

Petroleum Hydrocarbons. McMahon (1989) found elevated concentrations of hydrocarbons in marina waters and attributed them to refueling activities and bilge or fuel discharge from nearby boats.

2. Increased Pollutant Levels in Aquatic Organisms

Aquatic organisms can concentrate pollutants in the water column through biological activity. Copper and zinc concentrations in oysters were significantly higher in oysters in South Carolina and North Carolina marinas than at reference sites (NCDEM, 1991; SCDHEC, 1987). Increased levels of copper, cadmium, chromium, lead, tin, zinc, and PCBs were found in mussels from southern California marina waters (CARWQCB, 1989; Young et al., 1979). Three months after planting, concentrations of lead, zinc, and copper in oysters transplanted to several Australian marinas were two to three times higher than those of control sites (McMahon, 1989). Concentrations of copper in a green algae and the fouling community were significantly higher in a Rhode Island marina area than in adjacent control areas (Nixon et al., 1973). Several polynuclear aromatic hydrocarbons were detected in oyster tissue at marinas in South Carolina (Marcus and Stokes, 1985; Wendt et al., 1990).

3. Increased Pollutant Levels in Sediments

Many of the contaminants found in the storm water runoff of marinas do not dissolve well in water and accumulate to higher concentrations in sediments than in the overlying water. Contaminated sediments may, in turn, act as a source from which these contaminants can be released into the overlying waters. Benthic organisms—those organisms that live on the bottom or in the sediment—are exposed to pollutants that accumulate in the sediments and may be affected by this exposure or may avoid the contaminated area.

Metals. Copper is the major contaminant of concern because most common antifouling paint preparations contain cuprous oxide as the active biocide component (METRO, 1992a). In most cases metals have a higher affinity for sediments than for the water column and therefore tend to concentrate there. A recent Puget Sound area study of

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wastewater from boat hull pressure washing found that suspended solids accounted for 96 percent of the copper, 94 percent of the lead, and 83 percent of the zinc in the wastewater (see Table 5-1 for concentrations). Most of the metal concentrations were associated with particles less than 60 microns in size, resulting in their settling out of solution slowly (METRO, 1992a). Stallard et al. (1987) noted that the sediments of nearly every California marina tested had high concentration of butyltins. Marina sites in North Carolina had significantly higher levels of arsenic, cadmium, chromium, copper, lead, mercury, nickel, and zinc than did reference sites (NCDEM, 1991). McMahon (1989) found significantly higher concentrations of copper, lead, zinc, and mercury in the sediments at a marina site than in the parent waterbody. Within the marina, higher levels of copper and lead were found near a maintenance area drain and fuel dock, suggesting the drain as a source of copper and lead and the fuel dock as a possible source of lead. Sediments at most stations within Marina Del Rey were sufficiently contaminated with copper, lead, mercury, and zinc to affect fish and/or invertebrates, especially at the larval or juvenile stage (Soule et al., 1991). Researchers thought that this contamination might account for the absence of more sensitive species and the low diversity within the marina. However, the extent of the sediment contamination resulting from marina-related activities was unclear.

Petroleum Hydrocarbons. Petroleum hydrocarbons, particularly polynuclear aromatic hydrocarbons (PAHs), tend to adsorb to particulate matter and become incorporated into sediments. They may persist for years, resulting in exposure to benthic organisms. Voudrias and Smith (1986) reported that sediments from two Virginia creeks with marinas contained significantly higher levels of hydrocarbons than did control sites. The North Carolina Division of Environmental Management (NCDEM, 1990) found PAHs in the sediments of six marinas, all of which had fuel docks. Nearby reference areas did not appear to be affected. Marcus et al. (1988) found an increase in PAHs in the sediments of two South Carolina marinas. Sources of petroleum hydrocarbons were identified as the origin of

Table 5-1. Boatyard Pressure-washing Wastewater Contaminants and Regulatory Limits in the Puget Sound Area (METRO, 1992)

				Permit Limit Values			
					Boatyard NPDES		
						Receiving Waters[f]	
Analytical Parameter	Units	Untreated Sample (average)[a]	Untreated Sample (high)	Sanitary Sewers (Metro)	Sanitary Sewers	Marine	Fresh
pH	pH	7.2	6.7 - 8.2	5.5 - 12.0	—[c]	—[d]	—[d]
Turbidity	ntu	469	1700	—[c]	—[c]	—[d]	—[d]
Suspended Solids	mg/L	800	3100	—[c]	—[c]	—[d]	—[d]
Oil/Grease	mg/L	—[b]	—[b]	100	—[c]	—[d]	—[d]
Copper	mg/L	55	190	8.0	2.4	0.006	0.018
Lead	mg/L	1.7	14	4.0	1.2	0.280	0.068
Zinc	mg/L	6.0	22	10.0	3.3	0.190	0.130
Tin	mg/L	0.49	1.4	—[e]	—[e]	—[e]	—[e]
Arsenic	mg/L	0.08	0.1	4.0	3.6	0.136	0.720

[a] Values are based on analysis of 18 samples.
[b] Oil and grease not detected by visible inspections.
[c] No limit set or known for this parameter.
[d] No monitoring requirements, but limits will be based on water-quality criteria.
[e] Tin regulated by restrictions on the application of tributyltin paints.
[f] Limit values based on 8/13/91 draft of the Boatyard General NPDES Permit.

sediment contamination within several Australian marinas; however, a well-flushed marina in this study did not have an increase in sediment hydrocarbons (McMahon, 1989). This finding supports the supposition that sufficient flushing within a marina basin prevents build-up of pollutants in marina sediments.

4. Increased Levels of Pathogen Indicators

Studies conducted in Puget Sound, Long Island Sound, Narragansett Bay, North Carolina, and Chesapeake Bay have shown that boats can be a significant source of fecal coliform bacteria in areas with high boat densities and low hydrologic flushing (NCDEM, 1990; Sawyer and Golding, 1990; Milliken and Lee, 1990; Gaines and Solow, 1990; Seabloom et al., 1989; Fisher et al., 1987). Fecal coliform levels in marinas and mooring fields become elevated near boats during periods of high boat occupancy and usage. NOAA identified boating activities (the presence of marinas, shipping lanes, or intracoastal waterways) as a contributing source in the closure to harvesting of millions of acres of shellfish-growing waters on the east coast of the United States (Leonard et al., 1989).

5. Disruption of Sediment and Habitat

Boat operation and dredging can destroy habitat; resuspend bottom sediment (resulting in the reintroduction of toxic substances into the water column); and increase turbidity, which affects the photosynthetic activity of algae and estuarine vegetation. Paulson and Da Costa (1991) demonstrated that propeller-induced flows can contribute significantly to bottom scour in shallow embayments and may have adverse effects on water clarity and quality. The British Waterways Board (1983) noted that propeller-driven boats may impact the aquatic environment and result in bank erosion. Waterways with shallow water environments would be affected as follows:

(1) The propeller would cut off or uproot water plants growing up from the bottom, and

(2) The propeller agitation of the water (propwash) would disturb the sediments, creating turbidity that would reduce the light available for photosynthesis of plants, impact feeding and clog the breathing mechanisms of aquatic animals, and smother animals and plants.

EPA (1974) noted a resuspension of solids from the bottom and disturbance to aquatic macrophytes following boating activity. Changes in turbidity were dependent on water depth, motor power, operational time and type, and nature of sediment deposits. The increase in turbidity was generally accompanied by an increase in organic carbon and phosphorus concentrations. However, the possible contribution of these nutrients to eutrophication was not determined. The biological communities of rivers may be impacted by boat traffic, which can increase turbidity; resuspend sediments that move into backwaters; create changes in waves, velocity, and pressure; and increase shoreline erosion (USFWS, 1982).

Dredging may alter the marina and the adjacent water by increasing turbidity, reducing the oxygen content of the water, burying benthic organisms, causing disruption and removal of bottom habitat, creating stagnant areas, and altering water circulation (Chmura and Ross, 1978). Some of these impacts (e.g., turbidity and reduced DO) are temporary and without long-term adverse effects. Dredging is addressed under CWA section 404 and associated regulations and is therefore not discussed further in this chapter.

6. Shoaling and Shoreline Erosion

Shoaling and shoreline erosion result from the physical transport of sediment due to waves and/or currents. These waves and currents may be natural (wind-induced, rainfall runoff, etc.) or human-induced (alterations in current regimes, boat wakes, etc.).

The British Waterways Board (1983) noted that when vessel-generated waves reach the shallow margins of a waterway, they can erode the banks and the bed, tending to wash away fringing plants and their associated animal life. The Waterways Board also found that a substantial volume of the sediment that results in shoaling comes from bank erosion and that removal of this material by dredging is a costly recurrent expense, especially where boat traffic causes extensive bank erosion. Factors influencing vessel-generated shoreline erosion include the distance of the boat from shore, boat speed, side slopes, sediment type, and depth of the waterway (Camfield et al., 1980; Sorensen, 1986; Zabawa and Ostrom, 1980).

G. Other Federal and State Marina and Boating Programs

1. NPDES Storm Water Program

The storm water permit program is a two-phase program enacted by Congress in 1987 under section 402(p) of the Clean Water Act. Under Phase I, National Pollutant Discharge Elimination System (NPDES) permits are required to be issued for municipal separate storm sewers serving large or medium-sized populations (greater than 250,000 or 100,000 people, respectively), and for storm water discharges associated with industrial activity such as certain types of marinas. Permits are also to be issued, on a case-by-case basis, if EPA or a State determines that a storm water discharge contributes to a violation of a water quality standard or is a significant contributor of pollutants to waters of the United States. EPA published a rule implementing Phase I on November 16, 1990.

a. Which marinas are regulated by the NPDES Storm Water Program?

Under the NPDES Storm Water Program, discharge permits are required for point source discharges of storm water from certain types of marinas. A point source discharge of storm water is a flow of rainfall runoff in some kind of discrete conveyance (a pipe, ditch, channel, swale, etc.).

If a marina is primarily in the business of renting boat slips, storing boats, cleaning boats, and repairing boats, and generally performs a range of other marine services, it is classified under the storm water program (using the Standard Industrial Classification (SIC) system developed by the Office of Management and Budget) as a SIC 4493. Marinas classified as SIC 4493 are the type that may be regulated under the storm water program and may be required to obtain a storm water discharge permit.

A marina that is classified as a SIC 4493 is required to obtain an NPDES storm water discharge permit if vehicle maintenance activities such as vehicle (boat) rehabilitation, mechanical repairs, painting, fueling, and lubrication or equipment cleaning operations are conducted at the marina. The storm water permit will apply only to the point source discharges of storm water from the maintenance areas at the marinas. Operators of these types of marinas should consult the water pollution control agency of the State in which the marina is located to determine how to obtain a storm water discharge permit.

b. Which marinas are not regulated by the NPDES Storm Water Program?

Marinas classified as SIC 4493 that are *not* involved in equipment cleaning or vehicle maintenance activities are not covered under the storm water program. Likewise, a marina, regardless of its classification and the types of activities conducted, that has no point source discharges of storm water, is also not regulated under the NPDES storm water program. In addition, some marinas are classified SIC code 5541 - marine service stations and are also not regulated under the NPDES Storm Water Program. These types of marinas are primarily in the business of selling fuel *without vehicle maintenance or equipment cleaning operations.*

c. What marina activities are covered by this guidance?

EPA has not yet promulgated regulations that would designate additional storm water discharges, beyond those regulated in Phase I, that will be required to be regulated in Phase II. Therefore, marina discharges that are not covered under Phase I, including those discharges that potentially may be ultimately covered by Phase II of the storm water permits program, are covered by this management measures guidance and will be addressed by the Coastal Nonpoint Pollution Control Programs. Any storm water discharge at a marina that ultimately is issued an NPDES permit will become exempt from this guidance and from the Coastal Nonpoint Pollution Control Program at the time that the permit is issued.

2. Other Regulatory Programs

The management measures for marinas do not address discharge of sanitary waste from vessels. They do, however, specify a measure to require that new marinas be designed to include pumpout stations and other facilities to handle sanitary waste from marine toilets, also referred to as marine sanitation devices (MSDs), and another measure to ensure that these facilities are properly maintained.

Vessels are not required to be equipped with an MSD. If a boat does have an MSD, however, the MSD has to meet certain standards set by EPA as required by CWA section 312. In addition to EPA standards for MSDs, EPA may allow a State to prohibit all discharges (treated or untreated) from MSDs, thus declaring the area a "no-discharge zone." Any State may apply to the EPA Administrator for designation of a "no-discharge zone" in some or all of the waters of the State; however, EPA must ensure that these waters meet certain tests before granting the application.

The siting and permitting process to which marinas are subject varies from State to State. State and Federal agencies both play a role in this process. Under section 10 of the Rivers and Harbors Act of 1899, the U.S. Army Corps of Engineers (USACE) regulates all work and structures in navigable waters of the United States. Under section 404 of the Clean Water Act, USACE permits are issued or denied to regulate discharges of dredged or fill materials in navigable waters of the United States, including wetlands.

All coastal States with Federally-approved coastal zone management programs can review Federal permit applications, and some States regulate dredge and fill, marshlands, or wetlands permitting for marina development. All States with Federally-approved coastal programs have the authority to object to section 10/section 404 permits if the proposed action is inconsistent with the State's coastal zone management program. Some States require permits for the use of State water bottomlands. States have authority under the Clean Water Act to issue section 401 water quality certifications for Federally-permitted actions as part of their water quality standards program.

The Food and Drug Administration (FDA) has established fecal coliform standards for certified shellfish-growing waters. Each coastal State regulates its own shellfish sanitation program under the National Shellfish Sanitation Program. States must participate if they wish to export shellfish across State lines. Various approaches are used to comply.

Some States also have a State coastal zone management permit providing them authority over development activities in areas located within their defined coastal zone. Alternatively, or in addition to this permitting authority, some States have regulatory planning authority in given areas of the coast, allowing them to influence the siting of marinas, if not their actual design and construction.

Finally, Massachusetts has developed a Harbor Planning Program, and other States (e.g., Connecticut, Rhode Island, New York, and Oregon) are developing similar programs. Municipalities participating in the program develop Harbor Management Plans. The plans must be consistent with approved coastal zone management plans, and they offer benefits such as giving municipalities greater influence over licensing of State tidelands and priority consideration for grants. The plans recommend comprehensive, long-term management programs that help municipalities balance conservation and development, address pollution impacts on a cumulative rather than piecemeal basis, and resolve conflicts over water-dependent and non-water-dependent uses of the waterfront.

H. Applicability of Management Measures

The management measures in this chapter are intended to be applied by States to control impacts to water quality and habitat from marina siting, construction (both new and expanding marinas), and operation and maintenance, as well as boat operation and maintenance. Under the Coastal Zone Act Reauthorization Amendments of 1990, States are subject to a number of requirements as they develop coastal nonpoint source (NPS) programs in conformity with the management measures and will have some flexibility in doing so. The application of these management measures by States is described more fully in *Coastal Nonpoint Pollution Control Program: Program Development and Approval Guidance*.

The management measures for marinas are applicable to the facilities and their associated shore-based services that support recreational boats and boats for hire. The following operations/facilities are covered by the management measures of this chapter:

- Any facility that contains 10 or more slips, piers where 10 or more boats may tie up, or any facility where a boat for hire is docked;
- Boat maintenance or repair yards that are adjacent to the water;
- Any Federal, State, or local facility that involves recreational boat maintenance or repair that is on or adjacent to the water;
- Public or commercial boat ramps;
- Any residential or planned community marina with 10 or more slips; and
- Any mooring field where 10 or more boats are moored.

Many States already use a 5- to 10-slip definition for marinas. The 10-slip definition for marinas is also based on Federal legislation that implements MARPOL (the International Convention for the Prevention of Pollution from Ships). This legislation requires adequate waste disposal facilities for ships at facilities with 10 or more slips. This guidance is not intended to address shipyards where extensive repair and maintenance of larger vessels occur. Such facilities are subject to NPDES point source and storm water permitting requirements.

Certain types of changes or additions to existing marinas may produce insignificant differences in impacts from such marinas, while other types of changes and expansions may have a far greater effect. Activities that alter the design, capacity, purpose, or use of the marina are subject to the siting and design management measures. The States are to define: (1) activities that significantly change the physical configuration or construction of the marina, (2) activities that significantly change the number of vessels accommodated, or (3) the operational changes that significantly change the potential impacts of the marina. Potential changes to marinas may be treated in the same manner as new marinas; i.e., the changes to the marina would be subject to applicable siting and design management measures.

The management measures for siting and design are applicable to new marinas. Application of the management measures to expanding marinas should be done on a case-by-case basis and should hinge on the potential for the expansion to impact water quality and important habitat. For example, an expanding marina would not be required to implement the flushing, water quality assessment, or shoreline stabilization management measures if the expansion involved only an increase in the number of parking spaces. The storm water runoff management measure is the only siting and design measure that is always applicable to existing and expanding marinas, as well as new marinas.

One method that has been used successfully by several States to determine whether an alteration/expansion is significant is to set a marina perimeter when the marina is constructed. Thereafter, alterations that occur within that perimeter (such as dock reconfiguration) are considered not significant. Another method that States have used is to set a limit, such as a 25 percent increase in the number of slips or a set number of slips (e.g., an increase of more than five slips is considered significant). Rhode Island has successfully implemented a combination of these methods (Rhode Island Coastal Resources Management Program, Section 300.4).

Changes to a marina may also result from catastrophic natural disasters such as hurricanes and severe flooding. It is possible, in smaller marinas, that efforts to rebuild need not be subject to all siting and design management measures.

II. SITING AND DESIGN

Siting and design are among the most significant factors affecting a marina's potential for water quality impacts. The location of a marina—whether it is open (located directly on a river, bay, or barrier island) or semi-enclosed (located on an embayment or other protected area)—affects its circulation and flushing characteristics. Circulation and flushing can also be influenced by the basin configuration and orientation to prevailing winds. Circulation and flushing play important roles in the distribution and dilution of potential contaminants. The final design is usually a compromise that will provide the most desirable combination of marina capacity, services, and access, while minimizing environmental impacts, dredging requirements, protective structures, and other site development costs. The objective of the marina siting and design management measures is to ensure that marinas and ancillary structures do not cause direct or indirect adverse water quality impacts or endanger fish, shellfish, and wildlife habitat both during and following marina construction.

Many factors influence the long-term impact a marina will have on water quality within the immediate vicinity of the marina and the adjacent waterway. Initial marina site selection is the most important factor. Selection of a site that has favorable hydrographic characteristics and requires the least amount of modification can reduce potential impacts. Because marina development can result in reduced levels of dissolved oxygen, many waters with average dissolved oxygen concentrations barely at or below State standards may be unsuitable for marina development.

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A. Marina Flushing Management Measure

Site and design marinas such that tides and/or currents will aid in flushing of the site or renew its water regularly.

1. Applicability

This management measure is intended to be applied by States to new and expanding[1] marinas. Under the Coastal Zone Act Reauthorization Amendments of 1990, States are subject to a number of requirements as they develop coastal nonpoint source programs in conformity with this measure and will have some flexibility in doing so. The application of management measures by States is described more fully in *Coastal Nonpoint Pollution Control Program: Program Development and Approval Guidance*, published jointly by the U.S. Environmental Protection Agency (EPA) and the National Oceanic and Atmospheric Administration (NOAA) of the U.S. Department of Commerce.

2. Description

The term *flushing* or *residence time* is often misused in that a single number (e.g., 10 days) is sometimes given to describe the flushing time of an estuary or harbor. In actuality, the flushing time ranges from zero days at the boundary to possibly several weeks, depending on location within the marina waterbody.

Maintaining water quality within a marina basin depends primarily on flushing as determined by water circulation within the basin (Tsinker, 1992). If a marina is not properly flushed, pollutants will concentrate to unacceptable levels in the water and/or sediments, resulting in impacts to biological resources (McMahon, 1989; NCDEM, 1990, 1991). In tidal waters, flushing is primarily due to tidal advective mixing and is controlled by the movement of the tidal prism into and out of the marina waterbody. A large tidal prism relative to the mean total volume of the waterbody indicates a large potential for flushing because more of the "old" water has a chance to become mixed with the "new" water outside the boundary or opening to the waterbody.

In nontidal coastal waters, such as the Great Lakes, wind drives circulation in the adjacent waterbody, causing a velocity shear between the marina basin and the adjacent waterbody and thereby producing one or more circulation cells (vortices). Such cells can have a flushing effect on water within a marina. The current created by local wind conditions is influenced by its persistence in terms of velocity and direction. The depth of the affected water layer is controlled by temperature and how the salinity changes with depth. Several hours of consistent wind are required for full development of wind-driven currents. These currents can be 2 percent of the wind's velocity and are generally downwind in most shallow areas (Tobiasson and Kollmeyer, 1991). In many situations wind-driven currents will provide adequate flushing of marina basins.

The degree of flushing necessary to maintain water quality in a marina should be balanced with safety, vessel protection, and sedimentation. Wave energy should be dissipated adequately to ensure that boater safety and protection of vessels are not at risk. The protected nature of marina basins can result in high sedimentation rates in waters containing high concentrations of suspended solids. Methods for assessing and mitigating sedimentation rates are available (NRC, 1987).

[1] Refer to Section I.H (General Applicability) for additional information on expansions of existing marinas.

3. Management Measure Selection

The measure was selected because it has been shown that adequate flushing will greatly reduce or eliminate the potential for stagnation of water in a marina and will help maintain biological productivity and aesthetics (Tsinker, 1992; SCCC, 1984). Presented below are some illustrative examples of flushing guidelines in different coastal regions and different conditions. In areas where tidal ranges do not exceed 1 meter, as in the southeastern United States, a flushing reduction (the amount of a conservative substance that is flushed from the basin) of 90 percent over a 24-hour period has been recommended. For example, a flushing analysis for a proposed marina/canal on the St. Johns River, Florida, was conducted to predict how an effluent would disperse and to determine the configuration that would provide for maximum flushing of a hypothetical conservative pollutant (Tetra Tech, 1988). The selected design provided the recommended flushing reduction of 90 percent over a 24-hour period. This study showed that employing modeling to demonstrate how to achieve the recommended flushing rate is effective at avoiding adverse water quality and other environmental impacts. In the Northwest, a minimum flushing reduction of 70 percent per day was judged to be adequate (Cardwell and Koons, 1981). The 70 percent value, which represents the overall mean flushing rate for the marina basin, was based on the prevailing 1.82-meter tidal range for a 24-hour period. However, if the marina was in a protected area, such as an estuary or embayment, where tidal ranges never attain 1.82 meters, then a minimum flushing reduction of approximately 85 percent per day was recommended.

4. Practices

As discussed more fully at the beginning of this chapter and in Chapter 1, the following practices are described for illustrative purposes only. State programs need not require implementation of these practices. However, as a practical matter, EPA anticipates that the management measure set forth above generally will be implemented by applying one or more management practices appropriate to the source, location, and climate. The practices set forth below have been found by EPA to be representative of the types of practices that can be applied successfully to achieve the management measure described above.

■ a. *Site and design new marinas such that the bottom of the marina and the entrance channel are not deeper than adjacent navigable water unless it can be demonstrated that the bottom will support a natural population of benthic organisms.*

Existing water depths can affect the entire marina layout and design. Therefore, if depth information is not available, bathymetric surveys should be conducted in the proposed marina basin area as well as in those areas that will be used as channels, whether existing or proposed (Schluchter and Slotta, 1978). Flushing rates in marinas can be maximized by proper design of the entrance channel and basins. For example, in areas of minimal or no tides, marina basin and channel depths should be designed to gradually increase toward open water to promote flushing (USEPA, 1985a). Otherwise, isolated deep holes where water can stagnate may be created (SCCC, 1984).

Good flushing alone does not guarantee that a marina's deepest waters will be renewed on a regular basis. Several studies have concluded that deep canals and holes deeper than adjacent waters are not adequately flushed by tidal action or by wind-generated forces and thus cause stagnant or semi-stagnant conditions (Walton, 1983; Barada and Partington, 1972). Lower layers in canals and basins can act as traps for fine sediment and organic detritus and exhibit low dissolved oxygen concentrations. Lower-layer stagnation can occur in holes of depths less than 10 feet (Murawski, 1969). The low DO concentrations, resulting from an oxygen demand exerted by resuspended sediments and decaying organic matter, can impact aquatic life in the warmer months when the normal DO concentration is lower because of higher temperatures (Sherk, 1971). Fine sediments trapped in deep holes may form a thin surface ooze, which gives poor internal oxygen circulation and leads to oxygen reduction both within the sediments and in the overlying water (USEPA, 1976).

■ b. *Design new marinas with as few segments as possible to promote circulation within the basin.*

Flushing efficiency for a marina is inversely proportional to the number of segments. For example, a one-segment marina will not flush as well as a marina in open water, a two-segment marina will not flush as well as a one-

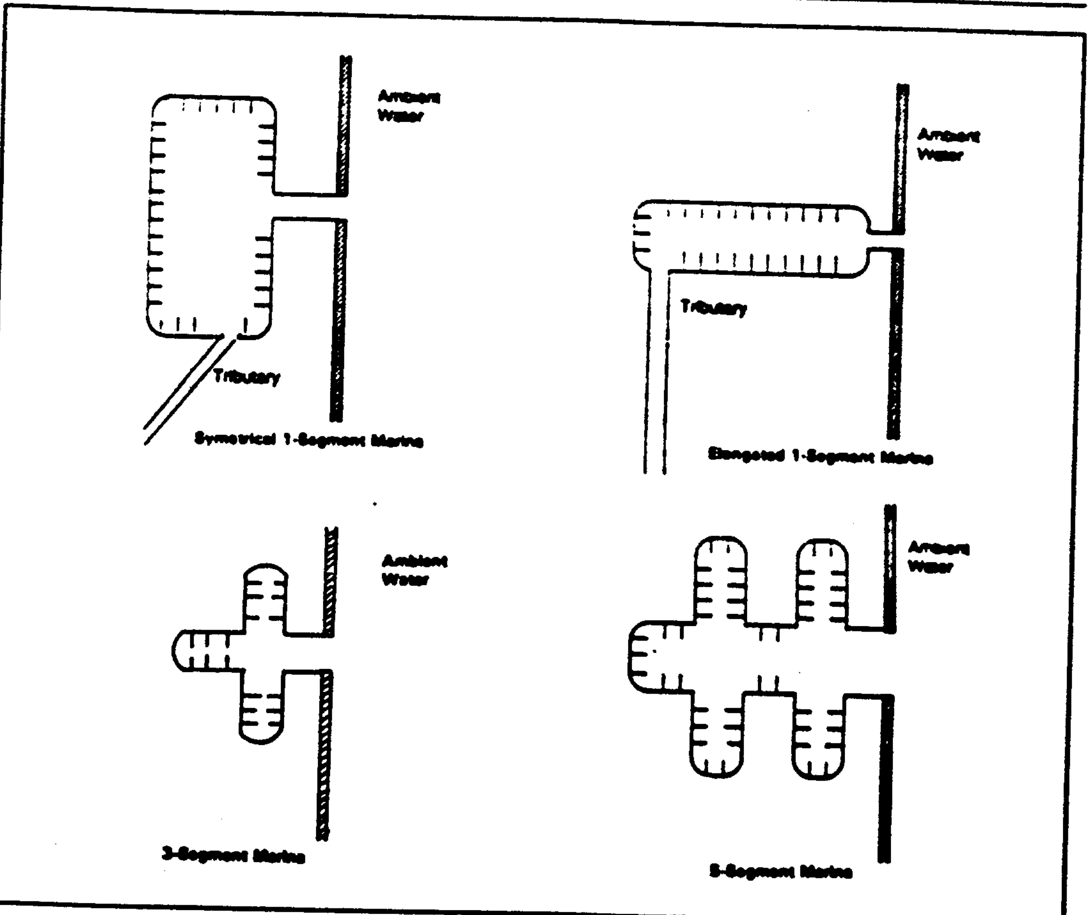

Figure 5-1. Example marina designs (adapted from DNREC, 1990).

segment marina, and so forth. Figure 5-1 presents examples of marinas with one segment and more than one segment. The physical configuration of the proposed marina as determined by the orientation of the marina toward the natural water flow can have a significant effect on the flushing capacity of the waterway. The ideal situation is one in which the distance between the exchange boundary and the inner portion of the basin is minimized. As the shape of the basin becomes more elongated (i.e., more than one segment) with respect to total surface area, the tidal advective or other dispersive mixing processes become more confined along a single flow path, and it takes longer for a water particle originating in the inner part of the basin to travel the greater distance to the boundary.

The marina's aspect ratio (the ratio of its length to its breadth) should be used as a guideline for marina basin design with respect to flushing. This ratio should be greater than 0.33 and less than 3.0, preferably between 0.5 and 2.0 (Cardwell and Koons, 1981). For rectangular marinas with one entrance connected directly to the source waterbody, the length-to-breadth ratio should be between 0.5 and 3.0 to eliminate secondary circulation cells where mixing and tidal flushing are reduced (McMahon, 1989).

Marina configurations that promote flushing exhibit, in general, better dissolved oxygen conditions than those with restrictions or stagnant areas such as improper entrance channel design, bends, and square corners (NCDEM, 1990). These areas also tend to trap sediment and debris. If debris are allowed to collect and settle to the bottom, an oxygen demand will be imposed on the water and water quality will suffer. Therefore, square corners should be avoided in critical downwind or similar areas where this is most likely to be a problem. If square corners are unavoidable because of other considerations, then points of access should be provided in those corners to allow for easy cleanout of accumulated debris.

In tidal waters, marina design should replace conventional rectangular boat basin geometry with curvilinear geometry to eliminate the stagnation effects of sharp-edged corners and to exploit the natural hydraulic patterns of flow and prevent the occurrence of areas where flushing is negligible (Cardwell and Koons, 1981). By combining these elements in the design of a marina, analytical studies have suggested that a strong internal basin circulation system could develop, resulting in acceptable water quality levels (Layton, 1991).

c. *Consider other design alternatives in poorly flushed waterbodies (open marina basin over semi-enclosed design; wave attenuators over a fixed structure) to enhance flushing.*

In selecting a marina site and developing a design, consideration of the need for efficient flushing of marina waters should be a prime factor along with safety and vessel protection. For example, sites located on open water or at the mouth of creeks and tributaries usually have higher flushing rates. These sites are generally preferable to sites located in coves or toward the heads of creeks and tributaries, locations that tend to have lower flushing rates.

In poorly flushed waterbodies, special arrangements may be necessary to ensure adequate overall flushing. In these areas, selection of an open marina design and/or the use of wave attenuators should be considered. Open marina designs have no fabricated or natural barriers, which tend to restrict the exchange of water between ambient water and water within the marina area. Wave attenuators improve flushing rates because water exchange is not restricted. They are also attractive because they do not interfere with the bottom ecology or aesthetic view. Other advantages include their easy removal and minimization of potential interference with fish migration and shoreline processes (Rogers et al., 1982).

The effectiveness of wave attenuators is usually dependent on their mass (Tobiasson and Kollmeyer, 1991). The greater the horizontal and draft dimensions, the greater their displacement and effectiveness. Floating wave attenuators have limitations on their use in extreme wave fields, and site-specific studies should be performed as to their suitability.

d. *Design and locate entrance channels to promote flushing.*

Entrance channel alignment should follow the natural channel alignment as closely as possible to increase flushing. Any bends that are necessary should be gradual (Dunham and Finn, 1974). In areas where the tidal range is small, it is recommended that the marina's entrance be designed as wide as possible to promote flushing while still providing adequate protection from waves (USEPA, 1985a). In areas where the tidal range is large, however, a single narrow entrance channel, if properly designed, has proven to provide adequate flushing (Layton, 1991).

Entrance channel design and placement can alleviate potential water quality problems. In tidal and nontidal waters, marina flushing rates are enhanced by wind action when entrance channels are aligned parallel to the direction of prevailing winds because wind-generated currents can mix basin water and facilitate circulation between the basin and the adjacent waterway (Christensen, 1986).

Shoaling may be significant in areas of significant bed load transport if the entrance channel is located perpendicular to the waterway. Increased shoaling could require extensive maintenance dredging of the channel or create a sill at the entrance to the marina basin. Shoaling at the marina entrance can lead to water quality problems by reducing flushing and water circulation within the basin (Tetra Tech, 1988; USEPA, 1985a). In Panama City, Florida, a study of bathymetric surveys before and after the construction of an artificial inlet showed that the areas of deposition and erosion in the natural bay rapidly changed as a result of alterations of channel positions and depths (Johnston, 1981).

The orientation and location of a solitary entrance can impact marina flushing rates and should be given consideration along with other factors impacting flushing. When a marina basin is square or rectangular, a single entrance at the center of a marina produces better flushing than does a single corner-located asymmetric entrance (Nece, 1981). This results in part because the jet entering the marina on the flood tide is able to circumnavigate a greater length of the sub-basin perimeter associated with each of the two gyres than it could in a single-gyre basin with an asymmetric entrance. If the marina basin is circular, an off-center entrance channel will promote better circulation. Off-center entrance channels also promote better circulation in circular canals.

e. Establish two openings, where appropriate, at opposite ends of the marina to promote flow-through currents.

Where water-level fluctuations are small, alternatives in addition to the ones previously discussed should be considered to ensure adequate water exchange and to increase flushing rates (Dunham and Finn, 1974). An elongated marina situated parallel to a tidal river can be adequately flushed using two entrances to establish a flow-through current so that wind-generated currents or tidal currents move continuously through the marina. In situations where both openings cannot be used for boat traffic, a smaller outlet onto an adjacent waterbody can be opened solely to enhance flushing. In other situations a buried pipeline has been used to promote flushing.

f. Designate areas that are and are not suitable for marina development; i.e., provide advance identification of waterbodies that do and do not experience flushing adequate for marina development.

For example, the physical characteristics of some small tidal creeks result in poor flushing and increased susceptibility to water quality problems (Klein, 1992). These characteristics include:

- Bottom configuration — Flushing is retarded when a depression exists that is lower than the entrance to the waterway.
- Entrance configuration — A constricted entrance will decrease flushing.
- Tributary inflow — Higher freshwater inflow will increase flushing.
- Tidal range — Increased tidal range will increase flushing.
- Shape of the waterway — As the configuration of a waterway becomes more convoluted and irregular, flushing tends to decrease.

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B. Water Quality Assessment Management Measure

Assess water quality as part of marina siting and design.

1. Applicability

This management measure is intended to be applied by States to new and expanding[2] marinas. Under the Coastal Zone Act Reauthorization Amendments of 1990, States are subject to a number of requirements as they develop coastal nonpoint source programs in conformity with this measure and will have some flexibility in doing so. The application of management measures by States is described more fully in *Coastal Nonpoint Pollution Control Program: Program Development and Approval Guidance*, published jointly by the U.S. Environmental Protection Agency (EPA) and the National Oceanic and Atmospheric Administration (NOAA) of the U.S. Department of Commerce.

2. Description

Assessments of water quality may be used to determine whether a proposed marina design will result in poor water quality. This may entail predevelopment and/or postdevelopment monitoring of the marina or ambient waters, numerical or physical modeling of flushing and water quality characteristics, or both. Cost impacts may preclude a detailed water quality assessment for marinas with 10 to 49 slips (See *Economic Impacts of EPA Guidance Specifying Management Measures for Sources of Nonpoint Pollution in Coastal Waters.*) A preconstruction inspection and assessment can still be expected, however. Historically, water quality assessments have focused on two parameters: dissolved oxygen (DO) and pathogen indicators. The problems resulting from low DO in surface waters have been recognized for over a century. The impacts of low DO concentrations are reflected in an unbalanced ecosystem, fish mortality, and odor and other aesthetic nuisances. DO levels may be used as a surrogate variable for the general health of the aquatic ecosystem (Thomann and Mueller, 1987). Coastal States use pathogen indicators, such as fecal coliform bacteria (*Escherichia coli*) and enterococci, as a surrogate variable for assessing risk to public health through ingestion of contaminated water or shellfish (USEPA, 1988) and through bathing (USEPA, 1986).

Dissolved Oxygen. Three important factors support the use of DO as an indicator of water quality associated with marinas. First, low DO is considered to pose a significant threat to aquatic life. For example, fish and invertebrate kills due to low DO are well known and documented (Cardwell and Koons, 1981). Second, DO is among the few variables that have been measured historically with any consistency. A historical water quality baseline is extremely useful for predicting the impacts of a proposed marina. Third, DO is fundamentally important in controlling the structure—and, in some areas, the productivity—of biological communities.

Pathogen Indicators. Marinas in the vicinity of harvestable shellfish beds represent potential sources for bacterial contamination of the shellfish. Siting and construction of a marina or other potential source of human sewage contiguous to beds of shellfish may result in closure of these beds. Also, nearby beaches and waters used for bathing should be considered.

Fecal coliform bacteria, *Escherichia coli*, and enterococci are used as indicators of the pathogenic organisms (viruses, bacteria, and parasites) that may be present in sewage. These indicator organisms are used because no reliable and

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[2] Refer to Section I.H (General Applicability) for additional information on expansions of existing marinas.

cost-effective test for pathogenic organisms exists. Water quality assessments can be used to ensure that water quality standards supporting a designated use are not exceeded. For example, in waters approved for shellfish harvesting, a marina water quality assessment could be used to document potential fecal coliform concentrations in the water column in excess of the standard of 14 organisms MPN (most probable number) per 100 milliliters of water. This standard should not be exceeded in areas where the exceedance would result in the closure of harvestable or productive shellfish beds. Many States have adopted EPA's 1986 ambient water quality criteria for bacteria, which recommend *E. coli* and enterococci as indicators of pathogens for freshwater and marine bathing.

3. Management Measure Selection

Selection of this measure was based on the widespread use and proven effectiveness of water quality assessments in the siting and design of marinas. The North Carolina Department of Environmental Management conducted a postdevelopment study to characterize the water quality conditions of several marinas and to provide data that can be used to evaluate future marina development (NCDEM, 1990). The sampling program demonstrated that marina water quality monitoring studies are effective at assessing potential water quality impacts from coastal marinas. Water quality assessments have been used successfully at a variety of other proposed marina locations nationwide to determine potential water quality impacts (USEPA, 1992b). Many States require water quality assessments of proposed marina development (Appendix 5A). Marinas with 10 to 49 slips may not be able to afford monitoring or modeling. (See *Economic Impacts of EPA Guidance Specifying Management Measures for Sources of Nonpoint Pollution in Coastal Waters*.) In such instances a preconstruction inspection and assessment can still be performed. Dredging requires a River and Harbor Act section 10 permit from the U.S. Army Corps of Engineers (USACE). If there is discharge into waters of the United States after dredging, then a CWA section 404 permit is required. A CWA section 401 Water Quality Certification is required from the State before a section 404 permit is issued by the USACE.

4. Practices

As discussed more fully at the beginning of this chapter and in Chapter 1, the following practices are described for illustrative purposes only. State programs need not require implementation of these practices. However, as a practical matter, EPA anticipates that the management measure set forth above generally will be implemented by applying one or more management practices appropriate to the source, location, and climate. The practices set forth below have been found by EPA to be representative of the types of practices that can be applied successfully to achieve the management measure described above.

Two effective techniques are available to evaluate water quality conditions for proposed marinas. In the first technique, a water quality monitoring program that includes predevelopment, during-development, and postdevelopment phases can be used to assess the water quality impacts of a marina. In the second approach, effective assessment can be accomplished through numerical modeling that includes predevelopment and postconstruction model applications.

Numerical modeling can be used to study impacts associated with several alternatives and to select an optimum marina design that avoids and minimizes impacts to both water quality and habitats existing at the site (e.g., Rive St. Johns Canal study and Willbrook Island marina). A combination of field surveys and numerical modeling studies may be necessary to identify all environmental concerns and to avoid or minimize marina impacts on both water quality conditions and nearby shellfish habitat.

■ a. *Use a water quality monitoring methodology to predict postconstruction water quality conditions.*

A primary objective for use of a water quality assessment is to ensure that the 24-hour average dissolved oxygen concentration and the 1-hour (or instantaneous) minimum dissolved oxygen concentration both inside the proposed marina and in adjacent ambient waters will not violate State water quality standards or preclude designated uses.

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The first step in a marina water quality assessment should be the evaluation and the characterization of existing water quality conditions. Before an analysis of the potential impacts of future development is made, it should be determined whether current water quality is acceptable, marginal, or substandard. The best way to assess existing water quality is to measure it. Acceptable water quality data may already have been collected by various government organizations. Candidate organizations include the U.S. Geological Survey, the USACE, State and local water quality control and monitoring agencies, and engineering and oceanographic departments of local universities.

The second step in a marina water quality assessment is to set design standards in terms of water quality. In most States, the water quality is graded based on DO content, and a standard exists for the 24-hour average concentration and an instantaneous minimum concentration. A State's water quality standard for DO during the critical season may be used to set limits of acceptability for good water quality.

The best way to assess marina impacts on water quality is to design a sampling strategy and physically measure dissolved oxygen levels. During the sampling, sediment oxygen demand and other data that may be used to estimate dissolved oxygen levels using numerical modeling procedures can be collected (USEPA, 1992c, 1992d). A postdevelopment field program may include dye-release and/or drogue-release studies (to verify circulation patterns) and a water quality monitoring program. Data collected from such studies may be used to assist in the prediction of water quality or circulation at other potential marina sites.

Sampling programs are effective methods to evaluate the potential water quality impacts from proposed marinas. The main objective of a preconstruction sampling program is to characterize the water surrounding the area in the vicinity of the proposed marina. Another objective of a preconstruction sampling program is to provide necessary information for modeling investigations (e.g., Tetra Tech, 1988).

■ *b. Use a water quality modeling methodology to predict postconstruction water quality conditions.*

Water quality monitoring can be expensive, and therefore a field monitoring approach may not be practical. The use of a numerical model may be the most economical alternative. However, all models require some field data for proper calibration. A better and more cost-effective approach would be a combination of both water quality monitoring and numerical modeling (Tetra Tech, 1988).

Modeling techniques are used to predict flushing time and pollutant concentrations in the absence of site-specific data. A distinct advantage of numerical models over monitoring studies is the ability to easily perform sensitivity analyses to establish a set of design criteria. Limits of water quality acceptability, flushing rates, and sedimentation rates must be known before quantifying the limit of geometric parameters to comply with these standards. Numerical models can be used to evaluate different alternative designs to determine the configuration that would provide for maximum flushing of pollutants. Models can also be used to perform sensitivity analysis on the selected optimum design.

In 1982, preconstruction numerical modeling studies were conducted to investigate whether a proposed marina in South Carolina would meet the State water quality standards after construction. Modeling results indicated that the proposed Wexford Marina would meet water quality standards (Cubit Engineering, 1982). The marina was approved and constructed. Follow-up monitoring studies were conducted to evaluate preconstruction model predictions (USEPA, 1986). The monitoring results indicated that shellfish harvesting standards were being met, thereby validating the preconstruction modeling study.

EPA Region 4 recently completed an in-depth report on marina water quality models (USEPA, 1992c). The primary focus of the study was to provide guidance for selection and application of computer models for analyzing the potential water quality impacts (both DO and pathogen indicators) of a marina. EPA reviewed a number of available methods and classified them into three categories: simple methods, mid-range models, and complex models. Simple methods are screening techniques that provide only information on the average conditions in the marina. Screening methods do not provide spatial or time-varying water quality predictions, and therefore it is recommended that these methods be used with open marina designs and/or marinas sited in areas characterized by good flushing rates and good water quality conditions (USEPA, 1992c). In addition, simple models are not suitable where marina flushing is controlled by the prevailing wind, requiring the application of more advanced models, such as WASP4.

In poorly flushed areas and in marinas with a complex design, a more advanced method will identify those areas where water quality standards may be violated. The complex methods are also capable of predicting spatial and time-variant water quality conditions and provide the complete water quality picture inside a proposed marina. In general, advanced models are more effective and more appropriate than simple screening methods in assessing environmental impacts associated with marina siting and design (USEPA, 1992c).

Costs associated with applying a numerical model or conducting a water quality monitoring program range from 0.1 to 2.0 percent of the total marina development project cost. Table 5-2 provides cost information by marina, size, State, and year built. These factors should all be considered when comparing a particular cost associated with a specific item. For example, costs associated with the water quality monitoring program for Barbers Point Harbor and Marina complex were estimated at $56,000. On the other hand, the cost of the water quality monitoring program for the Beacons Reach marina, North Carolina, was $3,000. It was only when a full environmental assessment was conducted (e.g., North Point and Barbers Point marina complex) that costs were higher. In addition, several models have been recommended as appropriate tools to assess potential water quality impacts from coastal marinas (USEPA, 1992c, 1992d). The cost associated with applying the simple model is on the order of $1,000, whereas the cost associated with the advanced model is in the range of $25,000 to $100,000. Siting and design practices to reduce environmental impacts were frequently part of a larger design/environmental study. Costs for a total environmental assessment of a proposed marina ranged from 1 percent to 5 percent of the total project cost.

c. *Perform preconstruction inspection and assessment.*

A preconstruction inspection and assessment may be affordable in place of detailed water quality monitoring or modeling for marinas with 10 to 49 slips. The River and Harbor Act of 1899 section 10 and Clean Water Act section 404 permit application process requires applicants to present to the USACE information necessary for a water quality assessment. An expert knowledgeable in water quality and hydrodynamics may assess potential impacts using available information and site inspection.

Table 5-2. Cost Summary of Selected Marina Siting Practices (USEPA, 1992b)

Marina/Project Name and Location	Years	Scope of Work	Cost (x $1000)
North Point Marina Illinois (1,493 slips)	1963-1989	Full environmental assessment	100
		Construction cost	39,000
Point Roberts Marina Washington (1,000 slips)	1976-1978	Environmental studies (physical and numerical modeling, littoral drift, and biological studies)	300
		Postconstruction water quality monitoring program (including dye release and drogue)	10
		Construction cost	6,000
Barbers Point Harbor and Marina Complex (Retrofit) Hawaii	1981-1985	Physical model	650
		Numerical model (both 2D and 3D)	100
		Botanical survey	15
		Baseline water quality monitoring program	56
		Total construction	140,000
Marina Water Quality Modeling Study	1990	Numerical model applications to 3 Southeast marinas	30
		Data collection	22
Rive St. Johns Canal Florida	1988	Littoral studies and data collection	20
		Numerical model study	30
North Carolina Coastal Marina Water Quality Assessment	1989	Water quality monitoring program[a]	3
		Dye study[b]	3
		Numerical modeling studies	0.5
Wilbrook Island Marina (200 slips) South Carolina	1990	Water quality modeling study	10
Coastal Water Quality Assessment (NCDEM) North Carolina	1989	Monitoring program[c]	3
		Numerical modeling application[b]	0.5
		Dye study (flushing)[c]	3
Wexford Marina South Carolina	1982 and 1986	Numerical model application	—[d]
		Numerical model application	—[d]

[a] Cost estimate is per marina site.
[b] Simple screening model.
[c] This program was conducted by NCDEM personnel.
[d] Not available.

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Habitat Assessment Management Measure

Site and design marinas to protect against adverse effects on shellfish resources, wetlands, submerged aquatic vegetation, or other important riparian and aquatic habitat areas as designated by local, State, or Federal governments.

1. Applicability

This management measure is intended to be applied by States to new and expanding[3] marinas where site changes may impact on wetlands, shellfish beds, submerged aquatic vegetation (SAV), or other important habitats. The habitats of nonindigenous nuisance species, such as some clogging vegetation or zebra mussels, are not considered important habitats. Under the Coastal Zone Act Reauthorization Amendments of 1990, States are subject to a number of requirements as they develop coastal nonpoint source programs in conformity with this measure and will have some flexibility in doing so. The application of management measures by States is described more fully in *Coastal Nonpoint Pollution Control Program: Program Development and Approval Guidance*, published jointly by the U.S. Environmental Protection Agency (EPA) and the National Oceanic and Atmospheric Administration (NOAA) of the U.S. Department of Commerce.

2. Description

Coastal marinas are often located in estuaries, one of the most diverse of all habitats. Estuaries contain many plant and animal communities that are of economic, recreational, ecological, and aesthetic value. These communities are frequently sensitive to habitat alteration that can result from marina siting and design. Biological siting and design provisions for marinas are based on the premise that marinas should not destroy important aquatic habitat, should not diminish the harvestability of organisms in adjacent habitats, and should accommodate the same biological uses (e.g., reproduction, migration) for which the source waters have been classified (Cardwell et al., 1980). Important types of habitat for an area, such as wetlands, shellfish beds, and submerged aquatic vegetation (SAV), are usually designated by local, State, and Federal agencies. In most situations the locations of all important habitats are not known. Geographic information systems are used to map biological resources in Delaware and show promise as a method of conveying important habitat and other siting information to marina developers and environmental protection agencies (DNREC, 1990).

3. Management Measure Selection

The selection of this measure was based on its widespread use in siting and design and the fact that proper siting and design can reduce short-term impacts (habitat destruction during construction) and long-term impacts (water quality, sedimentation, circulation, wake energy) on the surrounding environment (USEPA, 1992b). Currently, 50 percent of the coastal States minimize adverse impacts caused by siting and design by requiring a habitat assessment prior to siting a marina, and an additional 40 percent require a habitat assessment under special conditions (Appendix 5A).

[3] See Section I.H (General Applicability) for additional information on expansions of existing marinas.

4. Practices

As discussed more fully at the beginning of this chapter and in Chapter 1, the following practices are described for illustrative purposes only. State programs need not require implementation of these practices. However, as a practical matter, EPA anticipates that the management measure set forth above generally will be implemented by applying one or more management practices appropriate to the source, location, and climate. The practices set forth below have been found by EPA to be representative of the types of practices that can be applied successfully to achieve the management measure described above.

a. *Conduct surveys and characterize the project site.*

The first step in achieving compatibility between coastal development and coastal resources is to properly characterize the proposed project site. The site's physical properties and water quality characteristics must be assessed. To minimize potential impacts, available habitat and seasonal use of the site by benthos, macroinvertebrates, and ichthyofauna should be evaluated. Once these data are assembled, it becomes possible to identify environmental risks associated with development of the site. Through site-design modifications, preservation of critical or unique habitat, and biological/chemical/physical monitoring, it is possible to minimize the direct and indirect impacts associated with a specific waterfront development (USEPA, 1985a). To properly evaluate development applications for projects at the periphery of critical or endangered habitat areas, it may be necessary to conduct on-site visits and surveys to determine the distribution of critical habitat such as spawning substrate and usage by spawning fish.

Based on data compiled primarily by the New Jersey Department of Environmental Protection (NJDEP) prior to construction, it was concluded that a large proposed marina (Port Liberte) could have a serious environmental impact on resident and transient fish and macroinvertebrates. Loss of unique habitat, water quality degradation, and disturbance of contaminated sediments were some of the more severe anticipated impacts. Following a comprehensive NJDEP review process, the developer modified the site plan and phased construction activities, thereby satisfying the concerns of the various environmental regulatory agencies and minimizing potential direct and indirect impacts (Souza et al., 1990). Follow-up monitoring established that the management practices were effective in avoiding impacts to important fishery habitat.

b. *Redevelop coastal waterfront sites that have been previously disturbed; expand existing marinas or consider alternative sites to minimize potential environmental impacts.*

Proper marina site selection is a practice that can minimize adverse impacts on nearby habitats. For example, the selected site for North Point Marina in Illinois was not a suitable environment for either floral or faunal habitat because of high erosion rates, high ground-water conditions, and the high potential for flooding (Braam and Jansen, 1991). Despite the surrounding environment, this site was thought to be suitable for marina development because the site had been previously disturbed. Within existing urban harbors where the shorelines have been modified previously by bulkheading and filling, there will be many opportunities to site recreational boating facilities with minimal adverse environmental consequences (Goodwin, 1988).

Alternative site analysis may be used to demonstrate that a chosen site is the most economic and environmentally suitable. Alternative site/design analysis has been found effective at reducing potential impacts from many proposed marinas. The proposed Rive St. Johns Canal, Willbrook Island, and John Wayne marinas used this practice and demonstrated the effectiveness of analyzing alternative sites and designs to minimize environmental impacts. For example, eight design alternatives were considered for the John Wayne marina. The selected alternative reduced tideland alteration, biological destruction, and stream diversion. This was accomplished by moving the marina basin nearly 1,000 feet north of the original site and reducing the basin capacity (Holland, 1986). Five alternatives were considered for the Rive St. Johns Canal. The selected site avoided impacts to wetland habitats and has better flushing characteristics. The Willbrook study considered five alternatives, and the site selected successfully minimized impacts to submerged aquatic vegetation and wetlands.

c. Employ rapid bioassessment techniques to assess impacts to biological resources.

Rapid bioassessment techniques, when fully developed, will provide cost-effective biological assessments of potential marina development sites. Rapid bioassessment uses biological criteria and is based on comparing the community assemblages of the potential development site to an undisturbed reference condition. Biological criteria or biocriteria describe the reference condition of aquatic communities inhabiting unimpaired waterbodies (USEPA, 1992a). These methods consist of community-level assessments designed to evaluate the communities based on a variety of functional and structural attributes or metrics. Rapid bioassessment protocols for freshwater streams and rivers were published in 1989 for macroinvertebrates and fish to provide States with guidelines for conducting cost-effective biological assessments (USEPA, 1989). Development of similar protocols for application in estuaries and near coastal areas is under way (USEPA, 1992a).

Scores from rapid bioassessments may be used to determine the biological integrity of a site. Sites that are comparable to pristine conditions, with complete assemblages of species, should not be developed as marinas because of the unavoidable impacts associated with such development. The level of effort required to characterize a site will depend on the specific protocol (level of detail required and organisms used) employed. The time needed to perform a rapid bioassessment in freshwater streams varied from 1.5-3 hours to 5-10 hours for benthos and 3 to 17 hours for fish (USEPA, 1989).

d. Assess historic habitat function (e.g., spawning area, nursery area, migration pathway) to minimize indirect impacts.

Washington State issued siting and tidal height provisions (WDF, 1971, 1974) to ensure that bulkheads do not destroy spawning of surf smelt habitat and increase the vulnerability of juvenile salmon. In addition, marina breakwaters may disrupt the migration pattern of migratory fish, such as salmon. The design of marinas should consider the migration, survival, and the harvestability of food fish and shellfish.

e. Minimize disturbance to indigenous vegetation in the riparian area.

A riparian area is defined as:

> Vegetated ecosystems along a waterbody through which energy, materials, and water pass. Riparian areas characteristically have a high water table and are subject to periodic flooding and influence from the adjacent waterbody. These systems encompass wetlands, uplands, or some combination of these two land forms. They will not in all cases have all of the characteristics necessary for them to be classified as wetlands.[4]

Riparian areas are generally more productive habitat, in both diversity and biomass, than adjacent uplands because of their unique hydrologic condition. Many important processes occur in the riparian zone, including the following:

- Because of their linear form along waterways, riparian areas process large fluxes of energy and materials from upstream systems as well as from ground-water seepage and upland runoff.
- They can serve as effective filters, sinks, and transformers of nutrients, eroded soils, and other pollutants.
- They often appear to be nutrient transformers that have a net import of inorganic nutrient forms and a net export of organic forms.

Chapter 7 of this document, which also requires protection of riparian areas when they have significant nonpoint pollution control value, contains a more detailed discussion of riparian functions.

[4] This definition is adapted from the definition offered previously by Mitsch and Gosselink (1986) and Lowrance et al. (1988).

f. Encourage the redevelopment or expansion of existing marina facilities that have minimal environmental impacts instead of new marina development in habitat areas that local, State, or Federal agencies have designated important.

One method to avoid new marina development in areas containing important habitat is the purchase of development rights of existing marinas or important habitat. In the case of preserving an existing marina (thus avoiding the impacts associated with developing new marinas), the government pays the difference (if there is one) between the just value and the water-dependent value and owns the rights to develop the property for other uses. This approach provides instant liquidity for the marina owner, who keeps the profits derived from all marina assets even though the government may have paid 80 to 90 percent of the value of the land. This would in theory offset the inability to sell the marina for non-water-dependent activities and decrease marina development in areas containing important habitat. The purchase of development rights and conservation easements for land containing important habitat or NPS control values is discussed in Chapter 4. In the Broward County (Florida) Comprehensive Plan, expansion of existing marina facilities is preferred over development of new facilities (Bell, 1990).

g. Develop a marina siting policy to discourage development in areas containing important habitat as designated by local, State, or Federal agencies.

Establishing a marina siting policy is an efficient and effective way to control habitat degradation and water pollution impacts associated with marinas. Creating such a policy involves:

- Establishing goals for coastal resource use and protection;
- Cataloging coastal resources; and
- Analyzing existing conditions and problems, as well as future needs.

A siting policy benefits the environment, the public, regulatory agencies, and the marina industry. Examples of such benefits include:

- Impacts to and destruction of environmentally sensitive areas (such as wetlands, fish nursery areas, and shellfish beds) are avoided by directing development to sites more appropriate for marina development;
- Coastal resources (such as submerged aquatic vegetation and beaches) are protected;
- Cumulative impacts from numerous pollution sources are more easily assessed;
- Coastal development and economic growth are balanced with environmental protection, and the continued viability of water-dependent uses is ensured;
- The needs of the marina industry and rights of public access are accounted for;
- The permitting process is streamlined;
- Regulatory efforts are coordinated; and
- Interjurisdictional consistency is improved.

Many States already address coastal resource and development needs through coastal zone management plans, growth management plans, critical area programs, and other means. The following examples illustrate the high level of acceptance such planning has achieved and the variety of program types upon which a marina siting policy could be built:

- Twelve States have established critical area programs that protect public health and safety, the quality of natural features, scenic value, recreational opportunities, and the historical and cultural significance of coastal areas (Myers, 1991).

- North Carolina has a water use classification system to assist in the implementation of land use policies. Coastal areas are designated for preservation, conservation, or development (Clark, 1990).

- Massachusetts has a Harbor Management Program, wherein municipalities devise specific harbor management plans consistent with State goals (Massachusetts Coastal Zone Management, 1988).

- The Narragansett Bay Project, part of EPA's National Estuary Program, recognizes land use planning as the key to accomplishing many goals, including controlling NPS pollution, protecting and restoring habitat, and preserving public access and recreational opportunities (Myers, 1991).

- The Cape Cod Commission found that unplanned growth over the last several decades has limited public access, displaced marinas and boatyards in favor of non-water-dependent uses, encroached on fishermen's access, degraded water quality, destroyed habitat, and created use conflicts (Cape Cod Commission, 1991).

Shoreline Stabilization Management Measure

Where shoreline erosion is a nonpoint source pollution problem, shorelines should be stabilized. Vegetative methods are strongly preferred unless structural methods are more cost effective, considering the severity of wave and wind erosion, offshore bathymetry, and the potential adverse impact on other shorelines and offshore areas.

1. Applicability

This management measure is intended to be applied by States to new and expanding[3] marinas where site changes may result in shoreline erosion. Under the Coastal Zone Act Reauthorization Amendments of 1990, States are subject to a number of requirements as they develop coastal nonpoint source programs in conformity with this measure and will have some flexibility in doing so. The application of management measures by States is described more fully in *Coastal Nonpoint Pollution Control Program: Program Development and Approval Guidance*, published jointly by the U.S. Environmental Protection Agency (EPA) and the National Oceanic and Atmospheric Administration (NOAA) of the U.S. Department of Commerce.

2. Description

The establishment of vegetation as a primary means of shore protection has shown the greatest success in low-wave-energy areas where underlying soil types provide the stability required for plants and where conditions are amenable to the sustaining of plant growth. Under suitable conditions, an important advantage of vegetation is its relatively low initial cost. The effectiveness of vegetation for shore stabilization varies with the amount of wave reduction provided by the physiography and offshore bathymetry of the site or with the degree of wave attenuation provided by structural devices. Identification of the cause of the erosion problem is essential for selecting the appropriate technique to remedy the problem. Methods for determining the potential effectiveness of stabilizing a site with indigenous vegetation are presented in Chapter 7.

Some structural methods to stabilize shorelines and navigation channels are bulkheads, jetties, and breakwaters. They are designed to dissipate incoming wave energy. While structures can provide shoreline protection, unintended consequences may include accelerated scouring in front of the structure, as well as increased erosion of unprotected downstream shorelines.

Among structural techniques, gabions, riprap, and sloping revetments dissipate incoming wave energy more effectively and result in less scouring. Bulkheads are appropriate in some circumstances, but where alternatives are appropriate they should be used first. Costs and design considerations of these and other structural methods for controlling shoreline erosion are presented in Chapter 6.

[3] Refer to Section I.H (General Applicability) for additional information on expansions of existing marinas.

3. Management Measure Selection

Selection of this measure was based on the demonstrated effectiveness of vegetation and structural methods to mitigate shoreline erosion and the resulting turbidity and shoaling (see Chapters 6 and 7). Also, it is in the best interest of marina operators to minimize shoreline erosion because erosion may increase sedimentation and the frequency of dredging in the marina basin and channel(s).

4. Practices

As discussed more fully at the beginning of this chapter and in Chapter 1, the following practices are described for illustrative purposes only. State programs need not require implementation of these practices. However, as a practical matter, EPA anticipates that the management measure set forth above generally will be implemented by applying one or more management practices appropriate to the source, location, and climate. The practices set forth below have been found by EPA to be representative of the types of practices that can be applied successfully to achieve the management measure described above.

Detailed information on practices and the cost and effectiveness of structural and vegetative practices can be found in Chapters 6 and 7, respectively.

E. Storm Water Runoff Management Measure

Implement effective runoff control strategies which include the use of pollution prevention activities and the proper design of hull maintenance areas.

Reduce the average annual loadings of total suspended solids (TSS) in runoff from hull maintenance areas by 80 percent. For the purposes of this measure, an 80 percent reduction of TSS is to be determined on an average annual basis.

1. Applicability

This management measure is intended to be applied by States to new and expanding[6] marinas, and to existing marinas for *at least* the hull maintenance areas.[7] If boat bottom scraping, sanding, and/or painting is done in areas other than those designated as hull maintenance areas, the management measure applies to those areas as well. This measure is not applicable to runoff that enters the marina property from upland sources. Under the Coastal Zone Act Reauthorization Amendments of 1990, States are subject to a number of requirements as they develop coastal nonpoint source programs in conformity with this measure and will have some flexibility in doing so. The application of management measures by States is described more fully in *Coastal Nonpoint Pollution Control Program: Program Development and Approval Guidance*, published jointly by the U.S. Environmental Protection Agency (EPA) and the National Oceanic and Atmospheric Administration (NOAA) of the U.S. Department of Commerce.

2. Description

The principal pollutants in runoff from marina parking areas and hull maintenance areas are suspended solids and organics (predominately oil and grease). Toxic metals from boat hull scraping and sanding are part of, or tend to become associated with, the suspended solids (METRO, 1992a). Practices for the control of these pollutants can be grouped into three types: (1) filtration/infiltration, (2) retention/detention, and (3) physical separation of pollutants. A further discussion of storm water runoff controls can be found in Chapter 4.

The proper design and operation of the marina hull maintenance area is a significant way to prevent the entry of toxic pollutants from marina property into surface waters. Recommended design features include the designation of discrete impervious areas (e.g., cement areas) for hull maintenance activities; the use of roofed areas that prevent rain from contacting pollutants; and the creation of diversions and drainage of off-site runoff away from the hull maintenance area for separate treatment. Source controls that collect pollutants and thus keep them out of runoff include the use of sanders with vacuum attachments, the use of large vacuums for collecting debris from the ground, and the use of tarps under boats that are being sanded or painted.

The perviousness of non-hull maintenance areas should be maximized to reduce the quantity of runoff. Maximizing perviousness can be accomplished by placing filter strips around parking areas. Swales are strongly recommended for the conveyance of storm water instead of drains and pipes because of their infiltration and filtering characteristics.

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[6] Refer to Section I.H (General Applicability) for additional information on expansions of existing marinas.

[7] Hull maintenance areas are areas whose primary function is to provide a place for boats during the scraping, sanding, and painting of their bottoms.

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Technologies capable of treating runoff that has been collected (e.g., wastewater treatment systems and holding tanks) may be used in situations where other practices are not appropriate or pretreatment is necessary. The primary disadvantages of using such systems are relatively high costs and high maintenance requirements. Some marinas are required to pretreat storm water runoff before discharge to the local sewer system (Nielsen, 1991). Washington State strongly recommends that marinas pretreat hull-cleaning wastewater and then discharge it to the local sewer system (METRO, 1992b).

The annual TSS loadings can be calculated by adding together the TSS loadings that can be expected to be generated during an average 1-year period from precipitation events less than or equal to the 2-year/24-hour storm. The 80 percent standard can be achieved, by reducing over the course of the year, 80 percent of these loadings. EPA recognizes that 80 percent cannot be achieved for each storm event and understands that TSS removal efficiency will fluctuate above and below 80 percent for individual storms.

3. Management Measure Selection

The 80 percent removal of TSS was selected because chemical wastewater treatment systems, sand filters, wet ponds, and constructed wetlands can all achieve this degree of pollutant removal if they are designed properly and the site is suitable. Source controls can also reduce final TSS concentrations in runoff. Table 5-3 presents summary information on the effectiveness, cost, and suitability of the practices listed below. The discussion under each practice presents factors to be considered when selecting a specific practice(s) for a particular marina site.

The 80 percent removal of TSS is applicable to the hull maintenance area only. Although pollutants in runoff from the remaining marina property are to be considered in implementing effective runoff pollution prevention and control strategies for all marinas, existing marinas may be unable to economically treat storm water runoff by retention/detention or filtration/infiltration technologies because of treatment system land requirements and the likely need to collect and transfer runoff from marina shoreline areas (at lower elevations) to upland areas for treatment. Also, marina property may be developed to such an extent that space is not available to build the detention/ retention structures. In other situations, the soil type and groundwater levels may not allow sufficient infiltration for trenches, swales, filter strips, etc. The measure applies to all new and existing marina hull maintenance areas because it allows for runoff control of a smaller, more controlled area and also because the runoff from these hull maintenance areas contain higher levels of toxic pollutants (CDEP, 1991; and METRO, 1992a).

In addition, many of the available practices are currently being employed by States to control runoff from marinas and other urban nonpoint sources (Appendix 5A).

4. Practices

As discussed more fully at the beginning of this chapter and in Chapter 1, the following practices are described for illustrative purposes only. State programs need not require implementation of these practices. However, as a practical matter, EPA anticipates that the management measure set forth above generally will be implemented by applying one or more management practices appropriate to the source, location, and climate. The practices set forth below have been found by EPA to be representative of the types of practices that can be applied successfully to achieve the management measure described above.

■ *a. Design boat hull maintenance areas to minimize contaminated runoff.*

Boat hull maintenance areas can be designed so that all maintenance activities that are significant potential sources of pollution can be accomplished over dry land and under roofs (where practical), allowing the collection and proper disposal of debris, residues, solvents, spills, and storm water runoff. Boat hull maintenance areas can be specified with signs, and hull maintenance should not be allowed to occur outside these areas. The use of impervious surfaces (e.g., cement) in hull maintenance areas will greatly enhance the collection of sandings, paint chips, etc. by vacuuming or sweeping.

Table 5-3. Stormwater Management Practice Summary Information

Practice - Characteristics	Pollutants Controlled	Removal Efficiencies (%)	Use with Other Practices	Cost	Retrofit Suitability	References	Pretreatment of Runoff Recommended
Sand Filter	TSS TP TN Fecal Col Metals	60-90 0-80 20-40 40 40-80	Yes	$1 - 11 per ft^3 of runoff	Medium	City of Austin, 1990; Schueler 1991; Tull 1990	Yes
Wet Pond	TSS TP TN COD Pb Zn Cu	50-90 20-90 10-90 10-90 10-95 20-95 38-90	Yes	$340-623 per acre treated; 3-5 of capital cost per year	Medium	Schueler, 1987, 1991; USEPA, 1986	Yes, but not necessary
Constructed Wetlands	TSS TP SP TN NO_3 COD Pb Zn	50-90 0-80 30-65 0-40 5-95 20-80 30-95 30-80	Yes	See Chapter 7	Medium		Yes
Infiltration Basin/Trench	TSS TP TN BOD Bacteria Metals	50-99 50-100 50-100 70-90 75-98 50-100	Yes	<u>Of capital costs</u>: Basins = 3-13 Trenches = 5-15	Medium	Schueler, 1987, 1991	Yes
Porous Pavement	TSS TP TN COD Pb Zn	60-90 60-90 60-90 60-90 60-90 60-90	No	<u>Incremental cost</u>: $40,051-78,288 per acre	Low	Schueler, 1987; SWRPC, 1991; Cahill Associates, 1991	
Vegetated Filter Strip	TSS TP TN COD Metals	40-90 30-80 20-60 0-80 20-80	Combine with practices for MM	<u>Seed</u>: $200-1000 per acre; <u>Seed & mulch</u>: $800-3500 per acre; <u>Sod</u>: $4500-48,000 per acre	High	Schueler et al., 1992	No
Grassed Swale	TSS TP TN Pb Zn Cu Cd	20-40 20-40 10-30 10-20 10-20 50-60 50	Combine with practices for MM	<u>Seed</u>: $4.50-8.50 per linear ft; <u>Sod</u>: $8-50 per linear ft	High	SWRPC, 1991; Schueler, 1987, 1991; Horner, 1988; Wanielista and Yousef, 1988	No

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Table 5-3. (Continued)

Practice - Characteristics	Pollutants Controlled	Removal Efficiencies (%)	Use with Other Practices	Cost	Retrofit Suitability	References	Pretreatment of Runoff Recommended
Swirl Concentrator	TSS BCD		Yes		High	WPCF, 1989; Pisano, 1989; USEPA, 1982	No
Catch Basins	TSS COD	60-97 10-56	Yes	$1100-3000	High	WPCF, 1989; Richards, 1981; SWRPA, 1991	No
Catch Basin with Sand Filter	TSS TN COD Pb Zn	70-90 30-40 40-70 70-90 50-80	High	$10,000 per drainage acre		Shaver, 1991	No
Adsorbents in Drain Inlets	Oil	High	Yes	$85-93 for 10 pillows		Silverman, 1989; Industrial Products and Lab Safety, 1991	No
Holding Tank	All	100 for first flush	Yes			WPCF, 1989	No
Boat Maintenance Area Design	All	Minimizes area of pollutant dispersal	Yes	Low	High	IEP, 1992	No
Oil-grit Separators	TSS	10-25	No		High	Steel and McGhee, 1979; Romano, 1990; Schueler, 1987; WPCF, 1989	No

b. *Implement source control practices.*

Source control practices prevent pollutants from coming into contact with runoff. Sanders with vacuum attachments are effective at collecting hull paint sandings (Schlomann, 1992). Encouraging the use of such sanders can be accomplished by including the price of their rental in boat haul-out and storage fees, in effect making their use by marina patrons free. Vacuuming impervious areas can be effective in preventing pollutants from entering runoff. A schedule (e.g., twice per week during the boating season) should be set and adhered to. Commercial vacuums are available for approximately $765 to $1065 (Dickerson, 1992), and approximately one machine is needed at a marina of 250 slips or smaller. Tarpaulins may be placed on the ground prior to placement of a boat in a cradle or stand and subsequent sanding/painting. The tarpaulins will collect paint chips, sanding, and paint drippings and should be disposed of in a manner consistent with State policy.

c. *Sand Filter*

Sand filters (also known as filtration basins) consist of layers of sand of varying grain size (grading from coarse sand to fine sands or peat), with an underlying gravel bed for infiltration or perforated underdrains for discharge of treated water. Figure 5-2 shows a conceptual design of a sand filter system. Pollutant removal is primarily achieved by "straining" pollutants through the filtering media and by settling on top of the sand bed and/or a pretreatment pool.

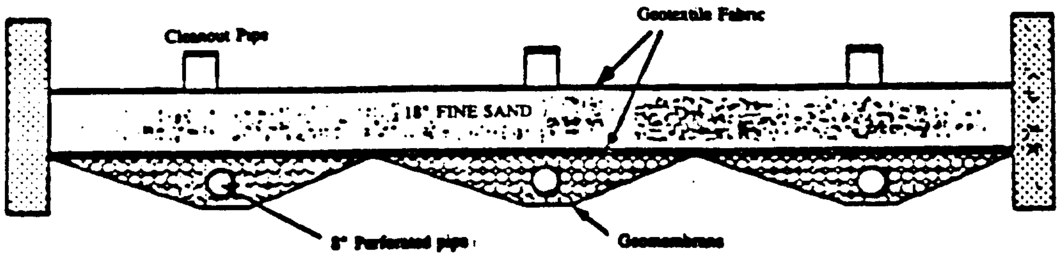

Figure 5-2. Conceptual design of a sand filter system (Austin, Texas, 1991).

Detention time is typically 4 to 6 hours (City of Austin, 1990), although increased detention time will increase effectiveness (Schueler et al., 1992). Sand filters may be used for drainage areas from 3 to 80 acres (City of Austin, 1990). Sand filters may be used on sites with impermeable soils since the runoff filters through filter media, not native soils. The main factors that influence removal rates are the storage volume, filter media, and detention time. Three different designs may be appropriate for marina sites: off-line sedimentation/filtration basins, on-line sand/sod filtration basins, and on-line sand basins. Performance monitoring of these designs produced average removal rates of 85 percent for sediment, 35 percent for nitrogen, 40 percent for dissolved phosphorous, 40 percent for fecal coliform, and 50 percent to 70 percent for trace metals (Schueler et al., 1992).

Sand filters become clogged with particulates over time. In general, clogging occurs near the runoff input to the sand filter. Frequent manual maintenance is required of sand filters, primarily raking, surface sediment removal, and removal of trash, debris, and leaf litter. Sand filters appear to have excellent longevity because of their off-line design and the high porosity of sand as a filtering medium (Schueler et al., 1992). Construction costs have been estimated at $1.30 to $10.50 per cubic foot of runoff treated (Tull, 1990). Significant economies of scale exist as sand filter size increases (Schueler et al., 1992). Maintenance costs are estimated to be approximately 5 percent of construction cost per year (Austin DPW, 1991, in Schueler et al., 1992).

d. Wet Pond

Wet ponds are basins designed to maintain a permanent pool of water and temporary storage capacity for storm water runoff (see Figure 5-3). The permanent pool enhances pollutant removal by promoting the settling of particulates, chemical coagulation and precipitation, and biological uptake of pollutants and is normally 1/2 to 1 inch in depth per impervious acre. Wet ponds are typically not used for drainage areas less than 10 acres (Schueler, 1987). Pond liners are required if the native soils are permeable or if the bedrock is fractured. Design parameters of concern include geometry, wet pond depth, area ratio, volume ratio, and flood pool drawdown time. Ponds may be designed to include shallow wetlands, thereby enhancing pollutant removal. Pollutant removal ranges are presented in Table 5-3. Removal rates of greater than 80 percent for total suspended solids were achieved in many studies (Schueler et al., 1992). Pollutant removal is primarily a function of the ratio of pond volume to watershed size (USEPA, 1986).

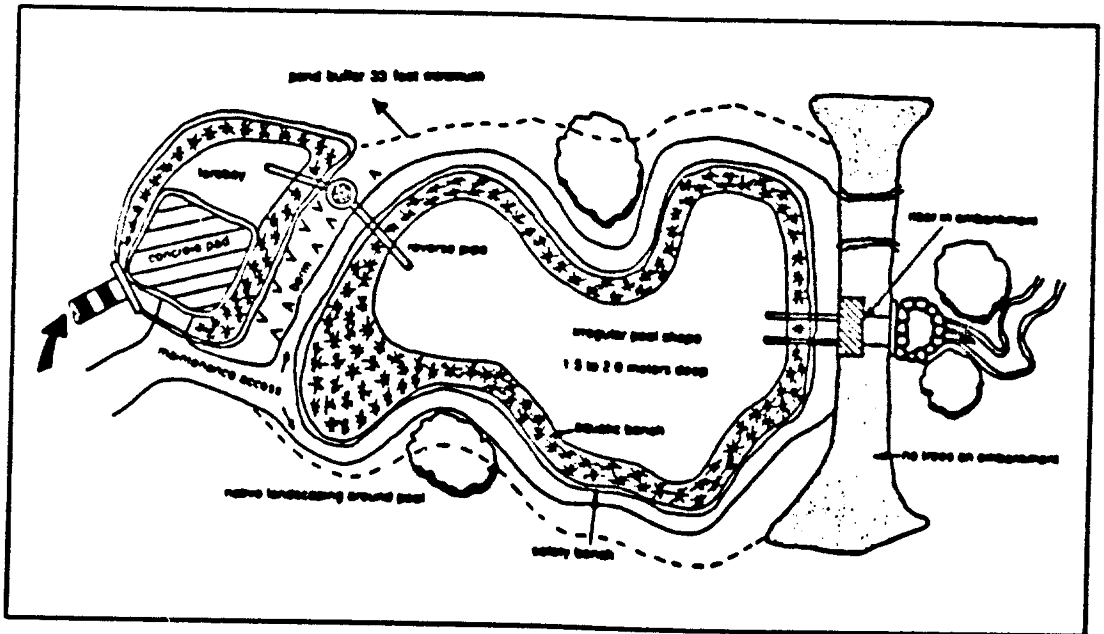

Figure 5-3. Schematic design of an enhanced wet pond system (Schueler, 1991).

A low level of routine maintenance, including tasks such as mowing of side slopes, inspections, and clearing of debris from outlets, is required. Wet ponds can be expected to lose approximately 1 percent of their runoff storage capacity per year as a result of sediment accumulation. To maintain the pollutant removal capacity of the pond, periodic removal of sediment is necessary. A recommended sediment cleanout cycle is every 10 to 20 years (British Columbia Research Corp., 1991). With proper maintenance and replacement of inlet and outlet structures every 25 to 50 years, wet ponds should last in excess of 50 years (Schueler, 1987). A review of capital costs for wet ponds revealed costs of $349 to $823 per acre treated and annual maintenance costs of 3 percent to 5 percent of the capital cost (Schueler, 1987).

e. Constructed Wetland

A complete discussion of created wetlands can be found in Chapter 7. Summary information on pollutant removal efficiencies, cost, etc. is presented in Table 5-3.

f. Infiltration Basin/Trench

Infiltration practices suitable for storm water treatment include basins and trenches. Figures 5-4 and 5-5 show examples of infiltration basins and trenches. Like porous pavement, infiltration practices reduce runoff by increasing ground-water recharge. Prior to infiltration, runoff is stored temporarily at the surface, in the case of infiltration basins, or in subsurface stone-filled trenches.

Infiltration devices should drain within 72 hours of a storm event and should be dry at other times. The maximum contributing drainage area should not exceed 5 acres for an individual infiltration trench and should range from 2 to 15 acres for an infiltration basin (Schueler et al., 1992).

Pretreatment to remove coarse sediments and PAHs is necessary to prevent clogging and diminished infiltration capacity over time. The application of infiltration devices is severely restricted by soils, water table, slope, and

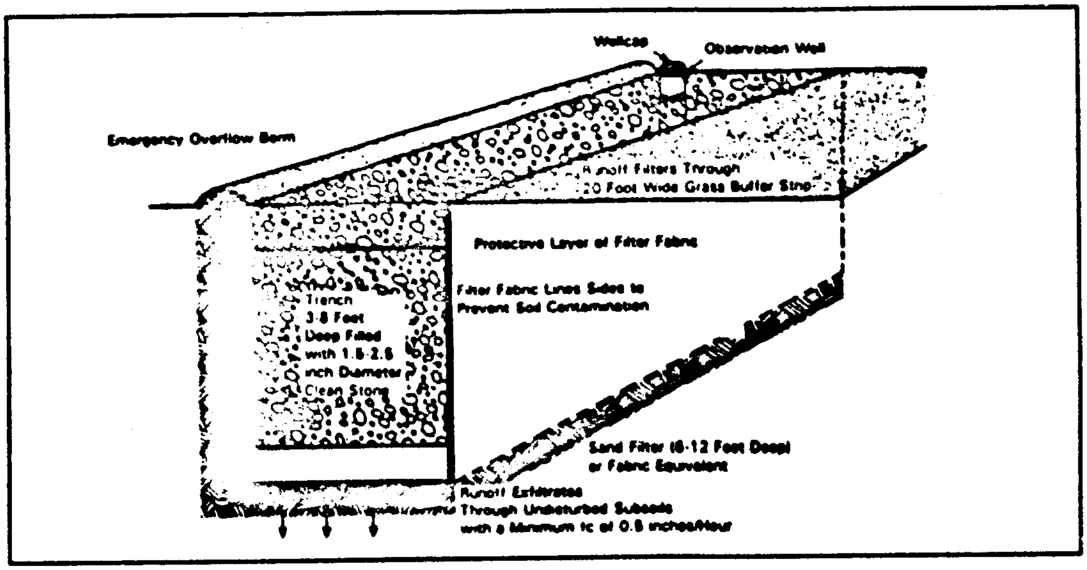

Figure 5-4. Schematic design of a conventional infiltration trench (Schueler, 1987).

contributing area conditions. The sediment load from marina hull maintenance areas may limit the applicability of infiltration devices in these areas. Infiltration devices are not practical in soils with field-verified infiltration rates of less than 1/2 inch per hour (Schueler et al., 1992). Soil borings should be taken well below the proposed bottom of the trench to identify any restricting layers and the depth of the water table. Removal of soluble pollutants in

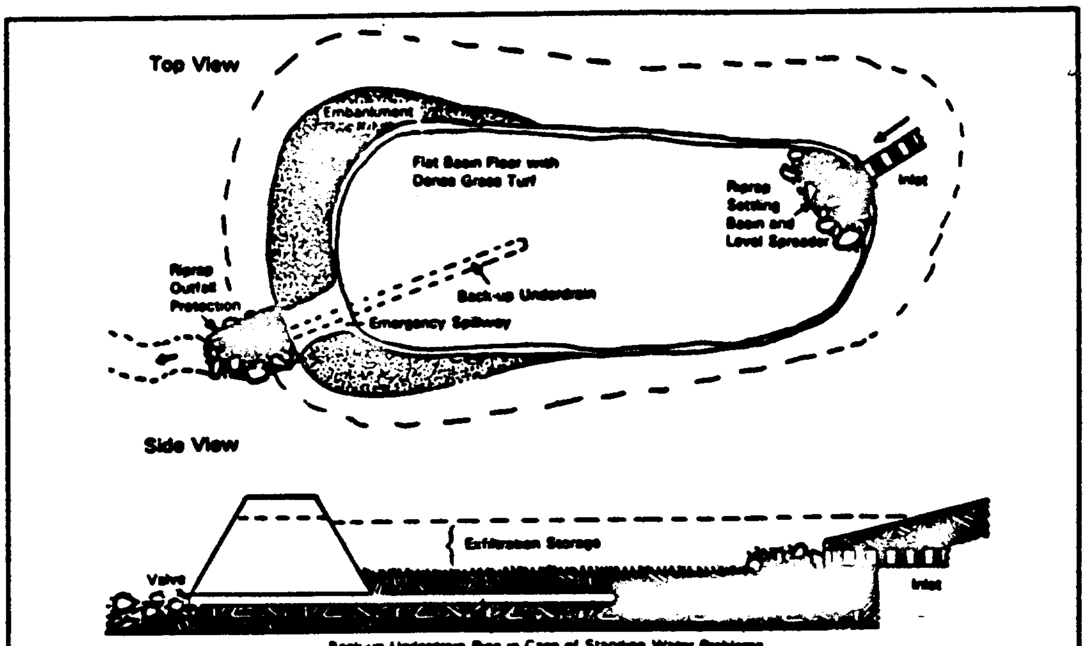

Figure 5-5. Schematic design of an infiltration basin (Schueler, 1987).

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infiltration devices relies heavily on soil adsorption, and removal efficiencies are lowered in sandy soils with limited binding capacity. Schueler (1987) reported a sediment removal efficiency of 95 percent, 60 percent to 75 percent removal of nutrients, and 95 percent to 99 percent removal of metals using a 2-year design storm. Other effectiveness data are presented in Table 5-3.

Infiltration basins and trenches have had high failure rates in the past (Schueler et al., 1992). A geotechnical investigation and design of a sound and redundant pretreatment system should be required before construction approval. Routine maintenance requirements include inspecting the basin after every major storm for the first few months after construction and annually thereafter to determine whether scouring or excessive sedimentation is reducing infiltration. Infiltration basins must be mowed twice annually to prevent woody growth. Tilling may be required in late summer to maintain infiltration capacities in marginal soils (Schueler, 1987). Field studies indicate that regular maintenance is not done on most infiltration trenches/basins, and 60 percent to 70 percent were found to require maintenance. Based on longevity studies, replacement or rehabilitation may be required every 10 years (Schueler et al., 1992). Proper maintenance of pretreatment structures may result in increased longevity. Reported costs for infiltration devices (Table 5-3) varied considerably based on runoff storage volume. Annual maintenance costs varied from 3 percent to 5 percent of capital cost for infiltration basins and from 5 percent to 10 percent for infiltration trenches.

g. Chemical and Filtration Treatment Systems

Chemical treatment of wastewater is the addition of certain chemicals that causes small solid particles to adhere together to form larger particles that settle out or can be filtered. Filtration systems remove suspended solids by forcing the liquid through a medium, such as folded paper in a cartridge filter (METRO, 1992b). A recent study showed that such treatment systems can remove in excess of 90 percent of the suspended solids and 80 percent of most toxic metals associated with hull pressure-washing wastewater (METRO, 1992a). The degree of treatment necessary may be dependent on whether the effluent can be discharged to a sewage treatment system. The cost of a homemade system for a small boatyard to treat 100 gallons a day was estimated at $1,560. The cost of larger commercial systems capable of treating up to 10,000 gallons a day was estimated at $3000 to $50,000 plus site preparation. The solid waste generated by these treatment systems may be considered hazardous waste and may be subject to disposal restrictions.

h. Vegetated Filter Strip

A complete discussion of vegetated filter strips can be found in Chapter 7. Summary information on pollutant removal efficiencies, cost, etc. is presented in Table 5-3.

i. Grassed Swale

Grassed swales are low-gradient conveyance channels that may be used in marinas in place of buried storm drains. To effectively remove pollutants, the swales should have relatively low slope and adequate length and should be planted with erosion-resistant vegetation. Swales are not practical on very flat grades or steep slopes or in wet or poorly drained soils (SWRPC, 1991). Grassed swales can be applied in areas where maximum flow rates are not expected to exceed 1.5 feet per second (Horner et al., 1988). The main factors influencing removal efficiency are vegetation type, soil infiltration rate, flow depth, and flow travel time. Properly designed and functioning grassed swales provide pollutant removal through filtering by vegetation of particulate pollutants, biological uptake of nutrients, and infiltration of runoff. Schueler (1987) suggests the use of check dams in swales to slow the water velocity and provide a greater opportunity for settling and infiltration. Swales are designed to deal with concentrated flow under most conditions, resulting in low pollutant removal rates (SWRPC, 1991). Removal rates are most likely higher under low-flow conditions when sheet flow occurs. This may help to explain that the reported percent removal for TSS varied from 0 to greater than 90 percent (W-C, 1991). Wanielista and Yousef (1986) stated that swales are a useful component in a storm water management system and removal efficiencies can be improved by designing swales to infiltrate and retain runoff. Swales should be used only as part of a storm water management system and may be used with the other practices listed under this management measure.

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Maintenance requirements for grassed swales include mowing and periodic sediment cleanout. Surveys by Horner et al. (1988) and in the Washington area indicate that the vast majority of swales operate as designed with relatively minor maintenance. The primary maintenance problem was the gradual build-up of soil and grass adjacent to roads, which prevents the entry of runoff into swales. The cost of a grassed swale will vary depending on the geometry of the swale (height and width) and the method of establishing the vegetation (see Table 5-3). Construction costs for grassed swales are typically less than those for curb-and-gutter systems. Regular maintenance costs for conventional swales are minimal. Cleanout of sediments trapped behind check dams and spot vegetation repair may be required (Schueler et al., 1992).

j. Porous Pavement

Porous pavement has a layer of porous top course covering an additional layer of gravel. A crushed stone-filled ground-water recharge bed is typically installed beneath these top layers. The runoff infiltrates through the porous asphalt layer and into the underground recharge bed. The runoff then exfiltrates out of the recharge bed into the underlying soils or into a perforated pipe system (see Figure 5-6). When operating properly, porous pavement can replicate predevelopment hydrology, increase ground-water recharge, and provide excellent pollutant removal (up to 80 percent of sediment, trace metals, and organic matter). The use of porous pavement is highly constrained and requires deep and permeable soils, restricted traffic, and suitable adjacent land uses. Pretreatment of runoff is necessary to remove coarse particulates and prevent clogging and diminished infiltration capacity.

The major advantages of porous pavement are (1) it may be used for parking areas and therefore does not use additional site space and (2) when operating properly, it provides high long-term removal of solids and other pollutants. However, significant problems exist in the use of porous pavement. Porous pavement sites have a high failure rate (75 percent) (Schueler et al., 1992). High sediment loads and oil result in clogging and eventual failure of the system. Therefore, porous pavement is not recommended for treatment of runoff from hull cleaning/maintenance areas. Porous pavement is appropriate for low-intensity parking areas where restrictions on use (no heavy trucks) and maintenance (no deicing chemicals, sand, or improper resurfacing) can be enforced. Quarterly vacuum sweeping and/or jet hosing is needed to maintain porosity. Field data, however, indicate that this routine maintenance practice is not frequently followed (Schueler et al., 1992).

The cost of porous pavement should be measured as the incremental cost, or the cost beyond that required for conventional asphalt pavement (up to 50 percent more). To determine the full value of porous pavement, however, the savings from reducing land consumption and eliminating storm systems such as curbs, inlets, and pipes should be considered (Cahill Associates, 1991). Also, the additional cost of directing pervious area runoff around porous pavement should be considered. Maintenance of porous pavement consists of quarterly vacuum sweeping and may be 1 percent to 2 percent of the original construction costs (Schueler et al., 1992). Other maintenance costs include rehabilitation of clogged systems. In a Maryland study, 75 percent of the porous pavement systems surveyed had partially or totally clogged within 5 years. Failure was attributed to inadequate construction techniques, low permeable soils and/or restricting layers, heavy vehicular traffic, and resurfacing with nonporous pavement materials (Schueler et al., 1992).

k. Oil-Grit Separators

Oil-grit separators (see Figure 5-7) may be used to treat water from small areas where other measures are infeasible and are applicable where activities contribute large loads of grease, oil, mud, sand, and trash to runoff (Steel and McGhee, 1979). Oil-grit separators are mainly suitable for oil droplets 150 microns in diameter or larger. Little is known regarding the oil droplet size in storm water; however, droplets less than 150 microns in diameter may be more representative of storm water (Romano, 1990). Basic design criteria include providing 200-400 cubic feet of oil storage per acre of area directed to the structure. The depth of the oil storage should be approximately 3-4 feet, and the depth of grit storage should be approximately 1.5-2.5 feet minimum under the oil storage. Application is limited to highly impervious catchments that are 2 acres or smaller.

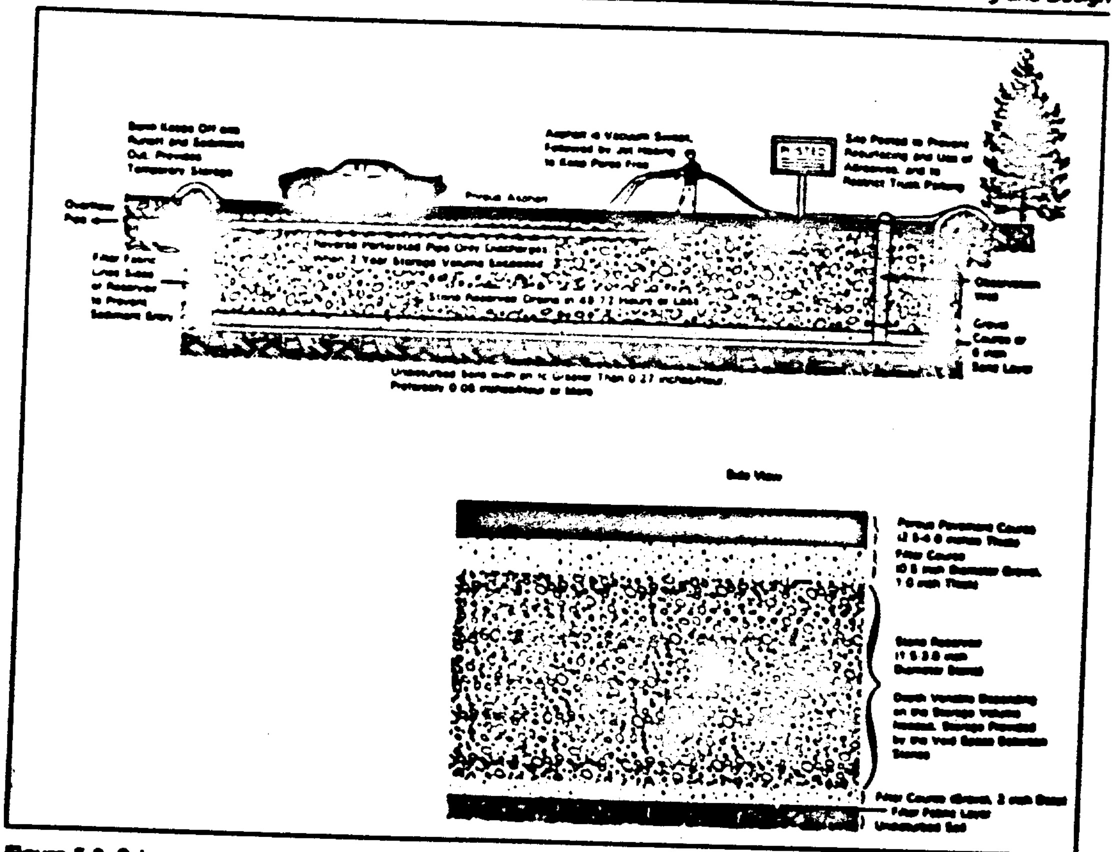

Figure 5-6. Schematic design of a porous pavement system (Schueler, 1987).

Actual pollutant removal occurs only when the chambers are cleaned out. Re-suspension limits long-term removal efficiency if the structure is not cleaned out. Periodic inspections and maintenance of the structure should be done at least twice a year (Schueler, 1987). With proper maintenance, the oil/grit separator should have at least a 50-year life span.

I. Holding Tanks

Simply put, holding tanks act as underground detention basins that capture and hold storm water until it can receive treatment. There are generally two classes of tanks: first flush tanks and settling tanks (WPCF, 1989). First flush tanks are used when the time of concentration of the impervious area is 15 minutes or less. The contents of the tank are transported via pumpout or gravity to another location for treatment. Excess runoff is discharged via the upstream overflow outlet when the tank is filled. Settling tanks are used when a pronounced first flush is not expected. A settling tank is similar to a primary settling tank in that only treated flow is discharged. The load to the clarifier overflow is usually restricted to about 0.2 ft^3/sec/ac of impervious area. If the inflow exceeds this, upstream overflows are activated. Settling tanks require periodic cleaning.

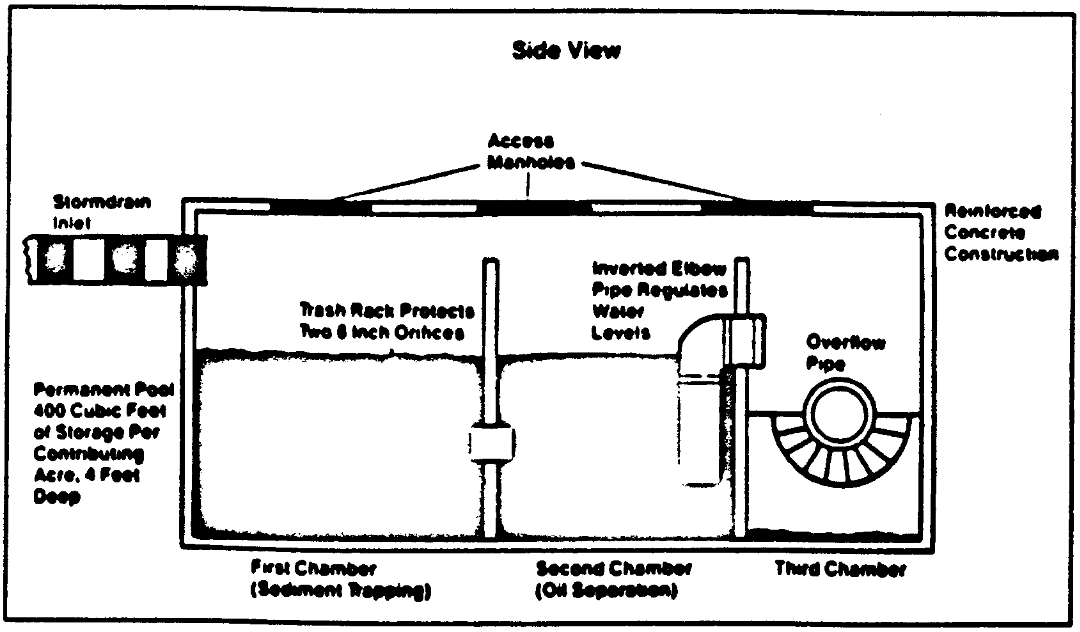

Figure 5-7. Schematic design of a water quality inlet/oil grit separator (Schueler, 1987).

m. Swirl Concentrator

A swirl concentrator is a small, compact solids separation device with no moving parts. During wet weather the unit's outflow is throttled, causing the unit to fill and to self-induce a swirling vortex. Secondary flow currents rapidly separate first flush settleable grit and floatable matter (WPCF, 1989). The pollutant matter is concentrated for treatment, while the cleaner, treated flow discharges to receiving waters. Swirl concentrators are intended to operate under high-flow regimes and may be used in conjunction with settling tanks. EPA published a design manual for swirl and helical bend pollution control devices (USEPA, 1982). However, monitoring data reveal that swirls built in accordance with this manual should be operated at lesser flows than the design indicates to achieve the desired efficiency (Pisano, 1989). Total suspended solids and BOD concentration removal efficiencies in excess of 60 percent have been reported, particularly under first flush conditions (WPCF, 1989). In another report removal effectiveness of total suspended solids from current U.S. swirls varied from a low of 5.2 percent to a high of 36.7 percent excluding first flush, 32.6 percent to 80.6 percent for first flush only, and 16.4 percent to 33.1 percent for entire storm events (Pisano, 1989). Removal efficiencies are dependent on the initial concentrations of pollutants, flow rate, size of structure, when the sumps in the catchments were cleaned, and other parameters (WPCF, 1989; and Pisano, 1989).

n. Catch Basins

Catch basins with flow restrictors may be used to prevent large pulses of storm water from entering surface waters at one time. They provide some settling capacity because the bottom of the structure is typically lowered 2 to 4 feet below the outlet pipe. Above- and below-ground storage is used to hold runoff until the receiving pipe can handle the flow. Temporary surface ponding may be used to induce infiltration and reduce direct discharge. Overland flow can be induced from sensitive areas to either sink discharge points or other storage locations. Catch basins with flow restrictors are not very effective at pollutant removal by themselves (WPCF, 1989) and should be used in conjunction with other practices. Removal efficiencies for larger particles and debris are high and make catch basins attractive as pretreatment systems for other practices. The traps of catch basins require periodic cleaning and maintenance.

Cleaning catch basins can result in large pulses of pollutants in the first subsequent storm if the method of cleaning results in the disturbance and breaking up of residual matter and some material is left in the catch basin (Richards et al., 1981). With proper maintenance, a catch basin should have at least a 50-year life span (Schueler et al., 1992).

o. Catch Basin with Sand Filter

A catch basin with sand filter consists of a sedimentation chamber and a chamber filled with sand. The sedimentation chamber removes coarse particles, helps to prevent clogging of the filter medium, and provides sheet flow into the filtration chamber. The sand chamber filters smaller-sized pollutants. Catch basins with sand filters are effective in highly impervious areas, where other practices have limited usefulness. The effectiveness of the sediment chamber for removal of the different particles depends on the particles' settling velocity and the chamber's length and depth. The effectiveness of the filtration medium depends on its depth.

Catch basins with sand filters should be inspected at least annually, and periodically the top layer of sand with deposition of sediment should be removed and replaced. In addition, the accumulated sediment in the sediment chamber should be removed periodically (Shaver, 1991). With proper maintenance and replacement of the sand, a catch basin with sand filter should have at least a 50-year life span (Schueler et al., 1992).

p. Adsorbents in Drain Inlets

While there is some tendency for oil and grease to sorb to trapped particles, oil and grease will not ordinarily be captured by catch basins, holding tanks, or swirl concentrators. Adsorbent material placed in these structures in a manner that will allow sufficient contact between the adsorbent and the storm water will remove much of the oil and grease load of runoff (Silverman and Stenstrom, 1989). In addition, the performance of oil-grit separators could be enhanced through the use of adsorbents. An adsorbent/catch basin system that treats the majority of the grease and oil in storm water runoff could be designed, and annual replacement of the adsorbent would be sufficient to maintain the system in most cases (Silverman et al., 1989). Manufacturers report that their products are able to sorb 10 to 25 times their weight in oil (Industrial Products, 1991; Lab Safety, 1991). The cost of 10 pillows, 24 inches by 14 inches by 5 inches (total weight 24 pounds), is approximately $85 to $93 (Lab Safety, 1991).

Fueling Station Design Management Measure

Design fueling stations to allow for ease in cleanup of spills.

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1. Applicability

This management measure is intended to be applied by States to new and expanding[1] marinas where fueling stations are to be added or moved. Under the Coastal Zone Act Reauthorization Amendments of 1990, States are subject to a number of requirements as they develop coastal nonpoint source programs in conformity with this measure and will have some flexibility in doing so. The application of management measures by States is described more fully in *Coastal Nonpoint Pollution Control Program: Program Development and Approval Guidance*, published jointly by the U.S. Environmental Protection Agency (EPA) and the National Oceanic and Atmospheric Administration (NOAA) of the U.S. Department of Commerce.

2. Description

Spillage is a source of petroleum hydrocarbons in marinas (USEPA, 1985a). Most petroleum-based fuels are lighter than water and thus float on the water's surface. This property allows for their capture if petroleum containment equipment is used in a timely manner.

3. Management Measure Selection

Selection of this measure is based on the preference for pollution prevention in the design of marinas rather than reliance on control of material that is released without forethought as to how it will be cleaned up. The possibility of spills during fueling operations always exists. Therefore, arrangements should be made to contain pollutants released from fueling operations to minimize the spread of pollutants through and out of the marina.

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4. Practices

As discussed more fully at the beginning of this chapter and in Chapter 1, the following practices are described for illustrative purposes only. State programs need not require implementation of these practices. However, as a practical matter, EPA anticipates that the management measure set forth above generally will be implemented by applying one or more management practices appropriate to the source, location, and climate. The practices set forth below have been found by EPA to be representative of the types of practices that can be applied successfully to achieve the management measure described above.

a. Locate and design fueling stations so that spills can be contained in a limited area.

The location and design of the fueling station should allow for booms to be deployed to surround a fuel spill. Pollutant reduction effectiveness and the cost of the design of fueling areas are difficult to quantify. When designing a new marina, the additional costs of ensuring that the design incorporates effective cleanup considerations should be minimal.

[1] Refer to Section I.H (General Applicability) for additional information on expansions of existing marinas.

b. Design a Spill Contingency Plan.

A Spill Contingency Plan must be developed for fuel storage and dispensation areas. The plan must meet local and State requirements and must include spill emergency procedures, including health and safety, notification, and spill containment and control procedures. Marina personnel must be properly trained in spill containment and control procedures.

c. Design fueling stations with spill containment equipment.

Appropriate containment and control materials must be stored in a clearly marked, easily accessible cabinet or locker. The cabinet or locker must contain absorbent pads and booms, fire extinguishers, a copy of the Spill Contingency Plan, and other equipment deemed suitable. Easily used effective oil spill containment equipment is readily available from commercial suppliers. Booms that can be strung around the spill, absorb up to 25 times their weight in petroleum products, and remain floating after saturation are available at a cost of approximately $160 for four booms 8 inches in diameter and 10 feet long with a weight of 40 pounds (Lab Safety, 1991). Oil-absorbent sheets, rolls, and pillows are also available at comparable prices.

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C. Sewage Facility Management Measure

Install pumpout, dump station, and restroom facilities where needed at new and expanding marinas to reduce the release of sewage to surface waters. Design these facilities to allow ease of access and post signage to promote use by the boating public.

1. Applicability

This management measure is intended to be applied by States to new and expanding[9] marinas in areas where adequate marine sewage collection facilities do not exist. Marinas that do not provide services for vessels that have marine sanitation devices (MSDs) do not need to have pumpouts, although dump stations for portable toilets and restrooms should be available. This measure does not address direct discharges from vessels covered under CWA section 312. Under the Coastal Zone Act Reauthorization Amendments of 1990, States are subject to a number of requirements as they develop coastal nonpoint source programs in conformity with this measure and will have some flexibility in doing so. The application of management measures by States is described more fully in *Coastal Nonpoint Pollution Control Program: Program Development and Approval Guidance*, published jointly by the U.S. Environmental Protection Agency (EPA) and the National Oceanic and Atmospheric Administration (NOAA) of the U.S. Department of Commerce.

2. Description

Three types of onshore collection systems are available: fixed point systems, portable/mobile systems, and dedicated slipside systems. Information on the installation and operation of sewage pumpout stations is available from the State of Maryland (MDDNR, 1991).

EPA Region I determined that, in general, a range of one pumpout facility per 300-600 boats with holding tanks (type III MSDs) should be sufficient to meet the demand for pumpout services in most harbor areas (USEPA, 1991b). EPA Region 4 suggested one facility for every 200 to 250 boats with holding tanks and provided a formula for estimating the number of boats with holding tanks (USEPA, 1985a). The State of Michigan has instituted a no-discharge policy and mandates one pumpout facility for every 100 boats with holding tanks.

According to the 1989 American Red Cross Boating Survey, there were approximately 19 million recreational boats in the United States (USCG, 1990). About 95 percent of these boats were less than 26 feet in length. A very large number of these boats used a portable toilet, rather than a larger holding tank. Given the large percentage of smaller boats, facilities for the dumping of portable toilet waste should be provided at marinas that service significant numbers of boats under 26 feet in length.

Two of the most important factors in successfully preventing sewage discharge are (1) providing "adequate and reasonably available" pumpout facilities and (2) conducting a comprehensive boater education program (USEPA, 1991b). The Public Education Management Measure presents additional information on this subject. One reason that pumpout use in Puget Sound is higher than that in other areas could be the extensive boater education program established in that area.

[9] Refer to Section I.H (General Applicability) for additional information on expansions of existing marinas.

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Chemicals from holding tanks may retard the normal functioning of septic systems. Information on septic systems can be found in Chapter 4. Neither the chemicals nor the concentration of marine wastes has proven to be a problem for properly operating public sewage treatment plants.

3. Management Measure Selection

Measure selection is based on the need to reduce discharges of sanitary waste and the fact that most coastal States and many localities already require the installation of pumpout facilities and restrooms at all or selected marinas (Appendix 5A). Other States encourage the installation and use of pumpouts through grant programs and boater education.

In a Long Island Sound study, only about 5 percent of the boats were expected to use pumpouts. Given the low documented usage by boaters at marinas with pumpouts, the time, inconvenience, and cost associated with pumpouts were determined to be more of a deterrent to use than was lack of availability of facilities (Tanski, 1989). A Puget Sound study found that 35 percent of the boats responding to a survey had holding tanks (type III MSDs). Eighty percent of these boats had y-valves that allowed illegal discharge. About half of these boats used pumpouts. The boaters surveyed felt that the most effective methods to ensure proper disposal of boat waste would be the improvement of waste-disposal facilities and boater education (Cheyne and Carter, 1989). Another Puget Sound study found that the problem of marine sewage waste could best be addressed through containment of wastes onboard the vessel and subsequent onshore disposal through the provision of adequate numbers of clean, accessible, economical, and easily used pumpout stations (Seabloom et al., 1989). Designation and advertisement of no-discharge zones can also increase boater use of pumpout facilities (MDDNR, 1991).

4. Practices

As discussed more fully at the beginning of this chapter and in Chapter 1, the following practices are described for illustrative purposes only. State programs need not require implementation of these practices. However, as a practical matter, EPA anticipates that the management measure set forth above generally will be implemented by applying one or more management practices appropriate to the source, location, and climate. The practices set forth below have been found by EPA to be representative of the types of practices that can be applied successfully to achieve the management measure described above.

a. *Fixed-Point Systems*

Fixed-point collection systems include one or more centrally located sewage pumpout stations (see Figure 5-8). These stations are generally located at the end of a pier, often on a fueling pier so that fueling and pumpout operations can be combined. A boat requiring pumpout services docks at the pumpout station. A flexible hose is connected to the wastewater fitting in the hull of the boat, and pumps or a vacuum system move the wastewater to an onshore holding tank, a public sewer system, a private treatment facility, or another approved disposal facility. In cases where the boats in the marina use only small portable (removable) toilets, a satisfactory disposal facility could be a dump station.

b. *Portable Systems*

Portable/mobile systems are similar to fixed-point systems and in some situations may be used in their place at a fueling dock. The portable unit includes a pump and a small storage tank. The unit is connected to the deck fitting on the vessel, and wastewater is pumped from the vessel's holding tank to the pumping unit's storage tank. When the storage tank is full, its contents are discharged into a municipal sewage system or a holding tank for removal by a septic tank pumpout service. In many instances, portable pumpout facilities are believed to be the most logistically feasible, convenient, accessible (and, therefore, used), and economically affordable way to ensure proper disposal of boat sewage (Natchez, 1991). Portable systems can be difficult to move about a marina and this factor should be considered when assessing the correct type of system for a marina. Another portable/mobile pumpout unit that is an emerging technology and is popular in the Great Salt Pond in Block Island, New York, is the radio-

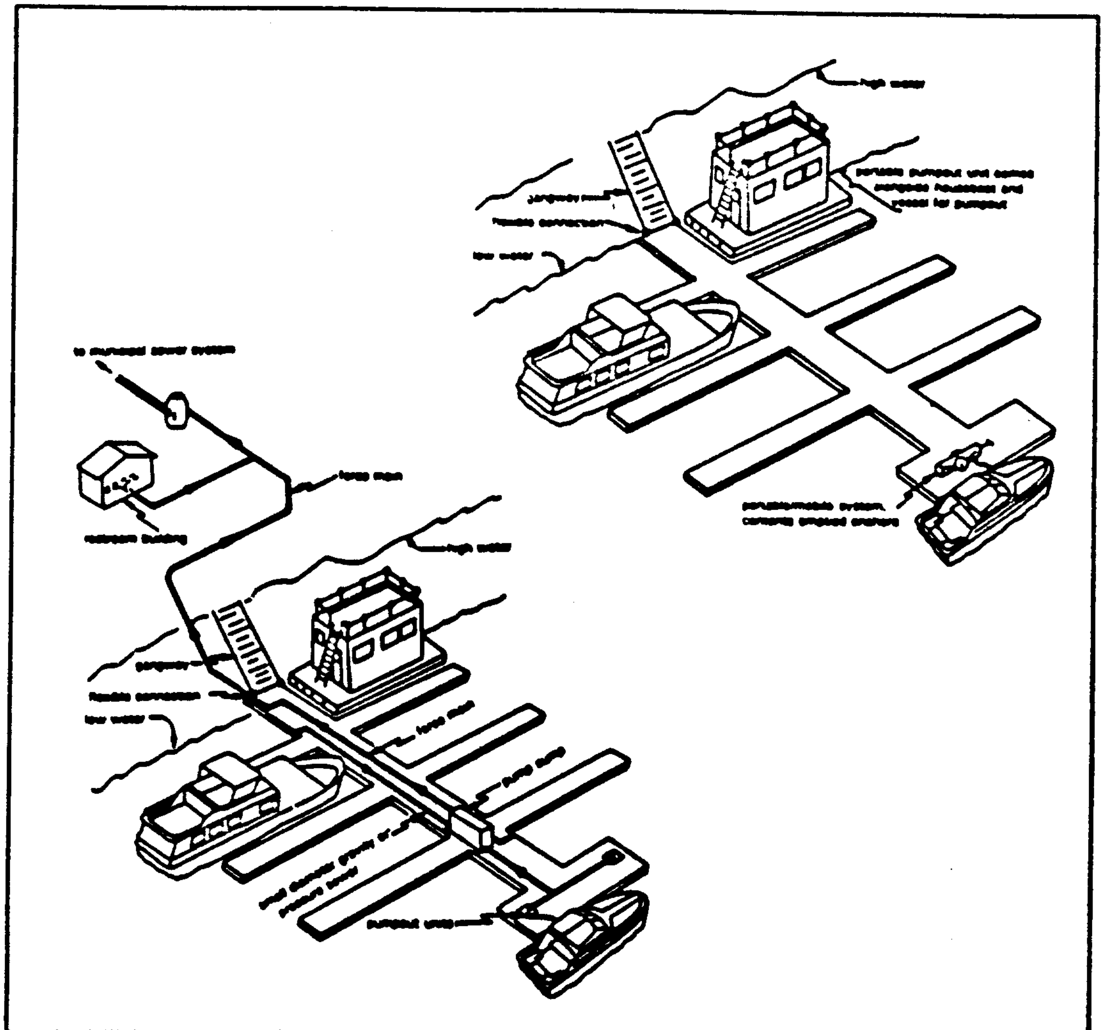

Figure 5-8. Examples of pumpout devices.

dispatched pumpout boat. The pumpout boat goes to a vessel in response to a radio-transmitted request, pumps the holding tank, and moves on to the next requesting vessel. This approach eliminates the inconvenience of lines, docking, and maneuvering vessels in high-traffic areas.

Costs associated with pumpouts vary according to the size of the marina and the type of pumpout system. Table 5-4 presents 1985 cost information for three marina sizes and two types of pumpout systems (USEPA, 1985a). More recent systems are less expensive, with a homemade portable system costing less than $250 in parts and commercial portable units available for between $2,000 and $4,000 (Natchez, 1991).

c. *Dedicated Slipside Systems*

Dedicated slipside systems provide continuous wastewater collection at a slip. Slipside pumpout should be provided to live-aboard vessels. The remainder of the marina can still be served by either marina-wide or mobile pumpout systems.

Table 5-4. Annual Per Slip Pumpout Costs for Three Collection Systems[a] (USEPA, 1985a)

	Marina-Wide	Portable/Mobile	Slipside
Small Marina (200 slips)			
Capital Costs	15[b]	15[c]	102[b]
O&M Costs	110	200	50
Total Cost/Slip/Year	125	215	152
Medium Marina (500 slips)			
Capital Costs	17	10	101
O&M Costs	90	160	40
Total Cost/Slip/Year	107	170	141
Large Marina (2000 slips)			
Capital Costs	16	10	113
O&M Costs	80	140	36
Total Cost/Slip/Year	96	150	149

[a] 1985 data; all figures in dollars.
[b] Based on 12% interest, 15 years amortization.
[c] 12% interest, 15 years on piping; 12% interest, 15 years on portable units.

d. Adequate Signage

Marina operators should post ample signs prohibiting the discharge of sanitary waste from boats into the waters of the State, including the marina basin, and also explaining the availability of pumpout services and public restroom facilities. Signs should also fully explain the procedures and rules governing the use of the pumpout facilities. An example of an easily understandable sign that has been used to advertise the availability of pumpout facilities is presented in Figure 5-9 (Keko, Inc., 1992).

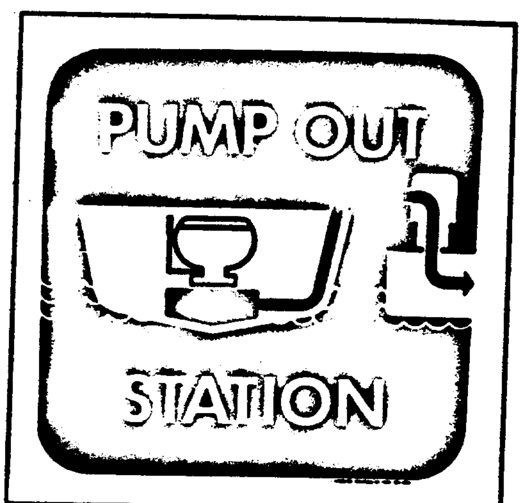

Figure 5-9. Example signage advertising pumpout availability (Keko, Inc., 1992).

III. MARINA AND BOAT OPERATION AND MAINTENANCE

During the course of normal marina operations, various activities and locations in the marina can generate polluting substances. Such activities include waste disposal, boat fueling, and boat maintenance and cleaning; such locations include storage areas for materials required for these activities and hull maintenance areas (METRO, 1992a; Tobiasson and Kollmeyer, 1991). Of special concern are substances that can be toxic to aquatic biota, pose a threat to human health, or degrade water quality.[1] Paint sandings and chippings, oil and grease, fuel, detergents, and sewage are examples (METRO, 1992a; Tobiasson and Kollmeyer, 1991).

It is important that marina operators and patrons take steps to control or minimize the entry of these substances into marina waters. For the most part, this can be accomplished with simple preventative measures such as performing these activities on protected sites, locating servicing equipment where the risk of spillage is reduced (see Siting and Design section of this chapter), providing adequate and well-marked disposal facilities, and educating the boating public about the importance of pollution prevention. The benefit of effective pollution prevention to the marina operator can be measured as the relative low cost of pollution prevention compared to potentially high environmental clean-up costs (Tobiasson and Kollmeyer, 1991).

For those planning to build a marina, attention to the environmental concerns of marina operation during the marina design phase will significantly reduce the potential for generating pollution from these activities. For existing marinas, minor changes in operations, staff training, and boater education should help protect marina waters from these sources of pollution. The management measures that follow address the control of pollution from marina operation and maintenance activities.

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[1]See Section I.F for further discussion.

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A. Solid Waste Management Measure

Properly dispose of solid wastes produced by the operation, cleaning, maintenance, and repair of boats to limit entry of solid wastes to surface waters.

1. Applicability

This management measure is intended to be applied by States to new and expanding[2] marinas. Under the Coastal Zone Act Reauthorization Amendments of 1990, States are subject to a number of requirements as they develop coastal nonpoint source programs in conformity with this measure and will have some flexibility in doing so. The application of management measures by States is described more fully in *Coastal Nonpoint Pollution Control Program: Program Development and Approval Guidance*, published jointly by the U.S. Environmental Protection Agency (EPA) and the National Oceanic and Atmospheric Administration (NOAA) of the U.S. Department of Commerce.

2. Description

Marina operators are responsible for determining what types of wastes will be generated at the marina and ensuring proper disposal. Marina operators are thus responsible for the contents of their dumpsters and the management of solid waste on their property. Hazardous waste should never be placed in dumpsters. Liquid waste should not be mixed with solid waste but rather disposed of properly by other methods (see Liquid Waste Management Measure).

3. Management Measure Selection

This measure was selected because marinas have shown the ability to minimize the entry of solid waste into surface waters through implementation of some or all of the practices. Marinas generate a variety of solid waste through the activities that occur on marina property and at their piers. If adequate disposal facilities are not available there is a potential for disposal of solid waste in surface waters or on shore areas where the material can wash into surface waters. Marina patrons and employees are more likely to properly dispose of solid waste if given adequate opportunity and disposal facilities. Under Federal law, marinas and port facilities must supply adequate and convenient waste disposal facilities for their customers (NOAA, 1988).

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4. Practices

As discussed more fully at the beginning of this chapter and in Chapter 1, the following practices are described for illustrative purposes only. State programs need not require implementation of these practices. However, as a practical matter, EPA anticipates that the management measure set forth above generally will be implemented by applying one or more management practices appropriate to the source, location, and climate. The practices set forth below have been found by EPA to be representative of the types of practices that can be applied successfully to achieve the management measure described above.

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[2] Refer to Section I.H (General Applicability) for additional information on expansions of existing marinas.

a. *Perform boat maintenance/cleaning above the waterline in such a way that no debris falls into the water.*

This subject is also addressed under the Boat Cleaning Management Measure later in this chapter.

b. *Provide and clearly mark designated work areas for boat repair and maintenance. Do not permit work outside designated areas.*

c. *Clean hull maintenance areas regularly to remove trash, sandings, paint chips, etc.*

Vacuuming is the preferred method of collecting these wastes.

d. *Perform abrasive blasting within spray booths or plastic tarp enclosures to prevent residue from being carried into surface waters. If tarps are used, blasting should not be done on windy days.*

e. *Provide proper disposal facilities to marina patrons. Covered dumpsters or other covered receptacles are preferred.*

While awaiting transfer to a landfill, dumpsters in which items such as used oil filters are stored should be covered to prevent rain from leaching material from the dumpster onto the ground.

f. *Provide facilities for the eventual recycling of appropriate materials.*

Recycling of nonhazardous solid waste such as scrap metal, aluminum, glass, wood pallets, paper, and cardboard is recommended wherever feasible. Used lead-acid batteries should be stored on an impervious surface, under cover, and sent to or picked up by an approved recycler. Receipts should be retained for inspection.

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Fish Waste Management Measure

promote sound fish waste management through a combination of fish-cleaning restrictions, public education, and proper disposal of fish waste.

1. Applicability

This management measure is intended to be applied by States to marinas where fish waste is determined to be a source of water pollution. Under the Coastal Zone Act Reauthorization Amendments of 1990, States are subject to a number of requirements as they develop coastal nonpoint source programs in conformity with this measure and will have some flexibility in doing so. The application of management measures by States is described more fully in *Coastal Nonpoint Pollution Control Program: Program Development and Approval Guidance*, published jointly by the U.S. Environmental Protection Agency (EPA) and the National Oceanic and Atmospheric Administration (NOAA) of the U.S. Department of Commerce.

2. Description

Fish waste can result in water quality problems at marinas with large numbers of fish landings or at marinas that have limited fish landings but poor flushing. The amount of fish waste disposed of into a small area such as a marina can exceed that existing naturally in the water at any one time. Fish waste decomposes, which requires oxygen. In sufficient quantity, disposal of fish waste can thus be a cause of dissolved oxygen depression as well as odor problems (DNREC, 1990; McDougal et al., 1986).

3. Management Measure Selection

This measure was selected because marinas have shown the ability to prevent fish-waste-induced water quality or aesthetic problems through implementation of the identified practices. Marinas that cater to patrons who fish a large amount can produce a large amount of fish waste at the marina from fish cleaning. If adequate disposal facilities are not available, there is a potential for disposal of fish waste in areas without enough flushing to prevent decomposition and the resulting dissolved oxygen depression and odor problems. Marina patrons and employees are more likely to properly dispose of fish waste if told of potential consequences and provided adequate and convenient disposal facilities. States require, and many marinas have already implemented, this management measure (Appendix 5A).

4. Practices

As discussed more fully at the beginning of this chapter and in Chapter 1, the following practices are described for illustrative purposes only. State programs need not require implementation of these practices. However, as a practical matter, EPA anticipates that the management measure set forth above generally will be implemented by applying one or more management practices appropriate to the source, location, and climate. The practices set forth below have been found by EPA to be representative of the types of practices that can be applied successfully to achieve the management measure described above.

a. Establish fish-cleaning areas.

Particular areas can be set aside or designated for the cleaning of fish, and receptacles can be provided for the waste. Boaters and fishermen should be advised to use only these areas for fish cleaning, and the waste collected in the receptacles should be disposed of properly.

b. Issue rules governing the conduct and location of fish-cleaning operations.

Marinas can issue rules regarding the cleaning of fish at the marina, depending on the type of services offered by the marina and its clientele. Marinas not equipped to handle fish wastes may prohibit the cleaning of fish at the marina; those hosting fishing competitions or having a large fishing clientele should establish fish-cleaning areas with specific rules for their use and should establish penalties for violation of the rules.

c. Educate boaters regarding the importance of proper fish-cleaning practices.

Boaters should be educated about the problems created by discarding their fish waste into marina waters, proper disposal practices, and the ecological advantages of cleaning their fish at sea and discarding the wastes into the water where the fish were caught. Signs posted on the docks (especially where fish cleaning has typically been done) and talks with boaters during the course of other marina operations can help to educate boaters about marina rules governing fish waste and its proper disposal.

d. Implement fish composting where appropriate.

A law passed in 1989 in New York forbids discarding fish waste, with exceptions, into fresh water or within 100 feet of shore (White et al., 1989). Contaminants in some fish leave few alternatives for disposing of fish waste, so Cornell University and the New York Sea Grant Extension Program conducted a fish composting project to deal with the over 2 million pounds of fish waste generated by the salmonid fishery each year. They found that even with this quantity of waste, if composting was properly conducted the problems of odor, rodents, and maggots were minimal and the process was effective (White et al., 1989). Another method of fish waste composting described by the University of Wisconsin Sea Grant Institute is suitable for amounts of compost ranging from a bucketful to the quantities produced by a fish-processing plant (Frederick et al., 1989).

C. Liquid Material Management Measure

Provide and maintain appropriate storage, transfer, containment, and disposal facilities for liquid material, such as oil, harmful solvents, antifreeze, and paints, and encourage recycling of these materials.

1. Applicability

This management measure is intended to be applied by States to marinas where liquid materials used in the maintenance, repair, or operation of boats are stored. Under the Coastal Zone Act Reauthorization Amendments of 1990, States are subject to a number of requirements as they develop coastal nonpoint source programs in conformity with this measure and will have some flexibility in doing so. The application of management measures by States is described more fully in *Coastal Nonpoint Pollution Control Program: Program Development and Approval Guidance*, published jointly by the U.S. Environmental Protection Agency (EPA) and the National Oceanic and Atmospheric Administration (NOAA) of the U.S. Department of Commerce.

2. Description

This management measure minimizes entry of potentially harmful liquid materials into marina and surface waters through proper storage and disposal. Marina operators are responsible for the proper storage of liquid materials for sale and for final disposal of liquid wastes, such as waste fuel, used oil, spent solvents, and spent antifreeze. Marina operators should decide how liquid waste material is to be placed in the appropriate containers and disposed of and should inform their patrons.

3. Management Measure Selection

This measure was selected because marinas have shown the ability to prevent entry of liquid waste into marina and surface waters. Marinas generate a variety of liquid waste through the activities that occur on marina property and at their piers. If adequate disposal facilities are not available, there is a potential for disposal of liquid waste in surface waters or on shore areas where the material can wash into surface waters. Marina patrons and employees are more likely to properly dispose of liquid waste if given adequate opportunity and disposal facilities. The practices on which the measure is based are available. Many coastal States already have mandatory or voluntary programs that satisfy this management measure (Appendix 5A).

4. Practices

As discussed more fully at the beginning of this chapter and in Chapter 1, the following practices are described for illustrative purposes only. State programs need not require implementation of these practices. However, as a practical matter, EPA anticipates that the management measure set forth above generally will be implemented by applying one or more management practices appropriate to the source, location, and climate. The practices set forth below have been found by EPA to be representative of the types of practices that can be applied successfully to achieve the management measure described above.

■ a. *Build curbs, berms, or other barriers around areas used for the storage of liquid material to contain spills. Store materials in areas impervious to the type of material stored.*

To contain spills, curbs or berms should be installed around areas where liquid material is stored. The berms or curbs should be capable of containing 10 percent of the liquid material stored or 110 percent of the largest container, whichever is greater (WADOE, 1991). There should not be drains in the floor. Implementation of this practice will prevent spilled material from directly entering surface waters. The cost of 6-inch cement curbs placed around a cement pad is $10 to $14 per linear foot (Means, 1990). The cost of a temporary spill dike capable of absorbing 50 liters of material (5 inches in diameter and 30 feet long) is approximately $110 (Lab Safety, 1991).

■ b. *Separate containers for the disposal of waste oil; waste gasoline; used antifreeze; and waste diesel, kerosene, and mineral spirits should be available and clearly labeled.*

Waste oil includes waste engine oil, transmission fluid, hydraulic fluid, and gear oil. A filter should be drained before disposal by placing the filter in a funnel over the appropriate waste collection container. The containers should be stored on an impermeable surface and covered in a manner that will prevent rainwater from entering the containers. Containers should be clearly marked to prevent mixing of the materials with other liquids and to assist in their identification and proper disposal. Waste should be removed from the marina site by someone permitted to handle such waste, and receipts should be retained for inspection.

Care should be taken to avoid combining different types of antifreeze. Standard antifreeze (ethylene glycol, usually identifiable by its blue or greenish color) should be recycled. If recycling is not available, propylene-glycol-based anti-freeze should be used because it is less toxic when introduced to the environment. Propylene glycol is often a pinkish hue (Gannon, 1990). Many States, including Maryland, Washington, and Oregon, have developed programs to encourage the proper disposal of used antifreeze.

Fifty-five-gallon closed-head polyethylene or steel drums approved for shipping hazardous and nonhazardous materials are available commercially at a cost of approximately $50 each. Open-head steel drums (approximately $60 each) with self-closing steel drum covers (approximately $90 each) may also be used (Lab Safety, 1991). A package of five labels that may be affixed to drums (10 inches by 10 inches) costs approximately $10.

■ c. *Direct marina patrons as to the proper disposal of all liquid materials through the use of signs, mailings, and other means.*

If individuals within a marina collect, contain, and dispose of their own liquid waste, signs and education programs (see Public Education Management Measure) should direct them to proper recycling and disposal options.

Petroleum Control Management Measure

Reduce the amount of fuel and oil from boat bilges and fuel tank air vents entering marina and surface waters.

1. Applicability

This management measure is intended to be applied by States to boats that have inboard fuel tanks. Under the Coastal Zone Act Reauthorization Amendments of 1990, States are subject to a number of requirements as they develop coastal nonpoint source programs in conformity with this measure and will have some flexibility in doing so. The application of management measures by States is described more fully in *Coastal Nonpoint Pollution Control Program: Program Development and Approval Guidance*, published jointly by the U.S. Environmental Protection Agency (EPA) and the National Oceanic and Atmospheric Administration (NOAA) of the U.S. Department of Commerce.

2. Description

Fuel and oil are commonly released into surface waters during fueling operations through the fuel tank air vent, during bilge pumping, and from spills directly into surface waters and into boats during fueling. Oil and grease from the operation and maintenance of inboard engines are a source of petroleum in bilges.

3. Management Measure Selection

This measure was selected because (1) the practices have shown the ability to minimize the introduction of petroleum from fueling and bilge pumping and thus prevent a visible sheen on the water's surface and (2) New York State requires the installation of fuel/air separators on new boats. Boaters and fuel station attendants often inadvertently spill fuel when "topping off" fuel tanks. They know the tank is full when fuel comes out of the mandatory air vent. This is preventable by the use of attachments on the air vent that suppress overflowing. Boat bilges have automatic and manual pumps that empty directly to marina or surface waters. When activated, these pumps often cause direct discharge of oil and grease from operation and maintenance of inboard engines. Oil-absorbing bilge pads contain oil and grease and prevent their discharge.

4. Practices

As discussed more fully at the beginning of this chapter and in Chapter 1, the following practices are described for illustrative purposes only. State programs need not require implementation of these practices. However, as a practical matter, EPA anticipates that the management measure set forth above generally will be implemented by applying one or more management practices appropriate to the source, location, and climate. The practices set forth below have been found by EPA to be representative of the types of practices that can be applied successfully to achieve the management measure described above.

a. ***Use automatic shut-off nozzles and promote the use of fuel/air separators on air vents or tank stems of inboard fuel tanks to reduce the amount of fuel spilled into surface waters during fueling of boats.***

During the fueling of inboard tanks fuel can be spilled into surface waters due to overfilling the fuel tank. An automatic shut-off nozzle is partially effective in reducing the potential for overfilling, but often during fueling operations fuel overflows from the air vent on the fuel tank of the boat. Attachments for vents on fuel tanks, which act as fuel/air separators, are available commercially. These devices release air and vapor but contain overflowing fuel. The State of New York passed a law in 1990 that requires that all boats sold in New York after January 1, 1994, have air vents on their fuel tanks that are designed to prevent fuel overflows or spills. The commercial cost of these devices is approximately $85 per unit. Marinas can make these units available in their retail stores and post notices describing their spill prevention benefits and availability.

■ b. *Promote the use of oil-absorbing materials in the bilge areas of all boats with inboard engines. Examine these materials at least once a year and replace as necessary. Recycle them if possible, or dispose of them in accordance with petroleum disposal regulations.*

Marina operators can advertise the availability of such oil-absorbing material or can include the cost of installation of such material in yearly dock fees. Marina operators can also insert a clause in their leasing agreements that boaters will use oil-absorbing material in their bilges. Pillows/pads that absorb oils and petroleum-based products and not water are available. These pillows/pads absorb up to 12 times their weight in oil and cost approximately $40 for a package of 10 (Lab Safety, 1991).

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E. Boat Cleaning Management Measure

For boats that are in the water, perform cleaning operations to minimize, to the extent practicable, the release to surface waters of (a) harmful cleaners and solvents and (b) paint from in-water hull cleaning.

1. Applicability

This management measure is intended to be applied by States to marinas where boat topsides are cleaned and marinas where hull scrubbing in the water has been shown to result in water or sediment quality problems. Under the Coastal Zone Act Reauthorization Amendments of 1990, States are subject to a number of requirements as they develop coastal nonpoint source programs in conformity with this measure and will have some flexibility in doing so. The application of management measures by States is described more fully in *Coastal Nonpoint Pollution Control Program: Program Development and Approval Guidance*, published jointly by the U.S. Environmental Protection Agency (EPA) and the National Oceanic and Atmospheric Administration (NOAA) of the U.S. Department of Commerce.

2. Description

This measure minimizes the use and release of potentially harmful cleaners and bottom paints to marina and surface waters. Marina employees and boat owners use a variety of boat cleaners, such as teak cleaners, fiberglass polishers, and detergents. Boats are cleaned over the water or onshore adjacent to the water. This results in a high probability of some of the cleaning material entering the water. Boat bottom paint is released into marina waters when boat bottoms are cleaned in the water.

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3. Management Measure Selection

This measure was selected because marinas have shown the ability to prevent entry of boat cleaners and harmful solvents as well as the release of bottom paint into marina and surface waters. The practices on which the measure is based are available, minimize entry of harmful material into marina waters, and still allow boat owners to clean their boats.

4. Practices

As discussed more fully at the beginning of this chapter and in Chapter 1, the following practices are described for illustrative purposes only. State programs need not require implementation of these practices. However, as a practical matter, EPA anticipates that the management measure set forth above generally will be implemented by applying one or more management practices appropriate to the source, location, and climate. The practices set forth below have been found by EPA to be representative of the types of practices that can be applied successfully to achieve the management measure described above.

■ a. ***Wash the boat hull above the waterline by hand. Where feasible, remove the boat from the water and perform cleaning where debris can be captured and properly disposed of.***

b. Detergents and cleaning compounds used for washing boats should be phosphate-free and biodegradable, and amounts used should be kept to a minimum.

c. Discourage the use of detergents containing ammonia, sodium hypochlorite, chlorinated solvents, petroleum distillates, or lye.

d. Do not allow in-the-water hull scraping or any process that occurs underwater to remove paint from the boat hull.

The material removed from boat hulls treated with antifoulant paint contains high levels of toxic metals (see Table 5-1).

Public Education Management Measure

Public education/outreach/training programs should be instituted for boaters, as well as marina owners and operators, to prevent improper disposal of polluting material.

1. Applicability

This management measure is intended to be applied by States to all environmental control authorities in areas where marinas are located. Under the Coastal Zone Act Reauthorization Amendments of 1990, States are subject to a number of requirements as they develop coastal nonpoint source programs in conformity with this measure and will have some flexibility in doing so. The application of management measures by States is described more fully in *Coastal Nonpoint Pollution Control Program: Program Development and Approval Guidance*, published jointly by the U.S. Environmental Protection Agency (EPA) and the National Oceanic and Atmospheric Administration (NOAA) of the U.S. Department of Commerce.

2. Description

The best method of preventing pollution from marinas and boating activities is to educate the public about the causes and effects of pollution and methods to prevent it. One of the primary reasons for the success of existing programs is the widespread support for these efforts. Measuring the efficiency of the separate practices of public education and outreach programs can be extremely difficult. Programs need to be examined in terms of long-term impacts.

Creating a public education program should involve user groups and the community in all phases of program development and implementation. The program should be suited to a specific area and should use creative promotional material to spread its message. General information on how to educate and involve the public can be found in *Managing Nonpoint Pollution: An Action Plan Handbook for Puget Sound Watersheds* (PSWQA, 1989) and *Dealing with Annex V - Reference Guide for Ports* (NOAA, 1988).

3. Management Measure Selection

Measure selection is based on low cost (Table 5-5), proven effectiveness, availability, and widespread use by many States (Appendix 5A).

4. Practices

As discussed more fully at the beginning of this chapter and in Chapter 1, the following practices are described for illustrative purposes only. State programs need not require implementation of these practices. However, as a practical matter, EPA anticipates that the management measure set forth above generally will be implemented by applying one or more management practices appropriate to the source, location, and climate. The practices set forth below have been found by EPA to be representative of the types of practices that can be applied successfully to achieve the management measure described above.

Table 5-5. Approximate Costs for Educational and Promotional Material (NOAA, 1988)

Item	Quantity	Cost
Brochures	10,000	2,100
Posters	5,000	500
Decals	6,000	900
Coloring Books	3,000	1,000
Stickers	20,000	450
Signs (wood)	20	800
Litter bags	8,000	1,400
Litter bags (beach cleanup)	2,000	free
Slide shows	5	250
Photo displays	9	1,000
Sweatshirts	288	2,200
Hats	432	1,100
Notices	40	25
Videotaped programs (copies)	4	200
Radio PSAs (copies, 7 announcements)	25	250
TV Public Service Announcements (copies)	6	200
Advertisements, newspaper	2	350
Advertisements, TV	2 weeks	200
Total		12,925

NOTE: Additional costs (about $2500) were involved in the development of the TV and radio public service announcements and brochures and in the acquisition of the rights to some art and photographic materials.

a. Signage

Interpretive and instructional signs placed at marinas and boat-launching sites are a key method of disseminating information to the boating public. The Chesapeake Bay Commission recommended that Bay States develop and implement programs to educate the boating public to stimulate increased use of pumpout facilities (CBC, 1989). The commission found that "boater education on this issue can be substantially expanded at modest expense."

Appropriate signage to direct boaters to the nearest pumpout facility to alert boaters to its presence would very likely stimulate increased used of pumpout facilities. Signs can be provided to marinas and posted in areas where recreational boats are concentrated. Ten-inch-square aluminum signs are available commercially for approximately $12 each (Lab Safety, 1991).

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b. Recycling/Trash Reduction Programs

A New Jersey marina issued reusable tote bags with the marina's name printed on the side. The bags were used repeatedly to transport groceries and to store recyclable materials for proper disposal (Bleier, 1991). Newport, Oregon, instituted a recycling program that was not immediately successful but has since achieved increased boater compliance (Bleier, 1991). The Louisiana and New Hampshire Sea Grant Programs both instituted successful public education programs designed to reduce the amount of marine debris discarded into surface waters (Doyle and Barnaby, 1990). The $17,000 cost of the New Hampshire demonstration program included project organization, distribution of a season's supply of trash bags, advertising material, and project monitoring. More than 90 percent of the 91 participating boats indicated that they had made a commitment to reducing marine pollution.

c. Pamphlets or Flyers, Newsletters, Inserts in Billings

The Washington State Parks and Recreation Commission designed a multifaceted public education program and is working with local governments and boating groups to implement the program and evaluate its effectiveness. The program encourages the use of MSDs and pumpout facilities, discourages impacts to shellfish areas, and provides information to boaters and marina operators about environmentally sound operation and maintenance activities. The Commission has prepared written materials, given talks to boating groups, participated in events such as boat shows, and developed signs for placement at marinas and boat launches. Printed material includes a map of pumpout facilities, a booklet on boat pollution, a pamphlet on plastic debris, and articles on the effects of boating activities. Written material can be made available at marinas, supply stores, or other places frequently visited by boaters. Approximate costs of some educational and promotional materials used in a Newport, Oregon, program are presented in Table 5-5 (NOAA, 1988). Written material describing the importance of boater cooperation in solving the problems associated with marine discharges could be included with annual boat registration forms, and cooperative programs involving State environmental agencies and boaters' organizations could be established.

d. Meetings/Presentations

Presentations at local marinas or other locations are a good way to discuss issues with boaters and marina owners and operators. The New Moon Project in Puget Sound is a public education program that is attempting to increase use of portable sewage pumpouts. This effort has included workshops and seminars for boaters, marina operators, and harbor masters. The presentations have produced interest from marina operators who want to participate and boaters who want additional material (NYBA, 1990). Presentations can also present the positive aspects of marinas and successful case studies of pollution prevention and control.

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[illegible]

Ensure that sewage pumpout facilities are maintained in operational condition and encourage their use.

1. Applicability

This management measure is intended to be applied by States to marinas where marine sewage disposal facilities exist. Under the Coastal Zone Act Reauthorization Amendments of 1990, States are subject to a number of requirements as they develop coastal nonpoint source programs in conformity with this measure and will have some flexibility in doing so. The application of management measures by States is described more fully in *Coastal Nonpoint Pollution Control Program: Program Development and Approval Guidance*, published jointly by the U.S. Environmental Protection Agency (EPA) and the National Oceanic and Atmospheric Administration (NOAA) of the U.S. Department of Commerce.

2. Description

The purpose of this measure is to reduce the release of untreated sewage into marina and surface waters.

3. Management Measure Selection

This measure was selected because it is effective in preventing failure of pumpouts and discourages improper disposal of sanitary wastes. Also, many pumpouts are not properly maintained, limiting their use. The Maryland Department of Natural Resources (MDDNR, 1991) provides operation and maintenance information on pumpouts to marina owners and operators in an effort to increase availability and use of pumpouts. Many other States inspect pumpout facilities to ensure that they are in operational condition (Appendix 5A).

4. Practices

As discussed more fully at the beginning of this chapter and in Chapter 1, the following practices are described for illustrative purposes only. State programs need not require implementation of these practices. However, as a practical matter, EPA anticipates that the management measure set forth above generally will be implemented by applying one or more management practices appropriate to the source, location, and climate. The practices set forth below have been found by EPA to be representative of the types of practices that can be applied successfully to achieve the management measure described above.

■ a. *Arrange maintenance contracts with contractors competent in the repair and servicing of pumpout facilities.*

■ b. *Develop regular inspection schedules.*

■ c. *Maintain a dedicated fund for the repair and maintenance of marina pumpout stations. (Government-owned facilities only)*

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d. Add language to slip leasing agreements mandating the use of pumpout facilities and specifying penalties for failure to comply.

e. Place dye tablets in holding tanks to discourage illegal disposal.

Boating activities that result in excessive fecal coliform bacteria levels can be addressed through the placement of a dye tablet in the holding tanks of all boats entering the adversely impacted waterbody. This practice was employed in Avalon Harbor, California, after moored boats were determined to be the source of problem levels of fecal coliform bacteria. Upon entering the harbor, a harbor patrol officer boards each vessel and places dye tablets in all sanitary devices. The officer then flushes the devices to ensure that the holding tanks do not leak. During the first 3 years of implementation, this practice detected 135 violations of the no-discharge policy and was extremely successful at reducing pollution levels (Smith et al., 1991). One tablet in approximately 60 gallons of water will give a visible dye concentration of one part per million. The cost of the tablets is approximately $30 per 200 tablets (Forestry Suppliers, 1992).

Boat Operation Management Measure

Restrict boating activities where necessary to decrease turbidity and physical destruction of shallow-water habitat.

1. Applicability

This management measure is intended to be applied by States in non-marina surface waters where evidence indicates that boating activities are impacting shallow-water habitats. Under the Coastal Zone Act Reauthorization Amendments of 1990, States are subject to a number of requirements as they develop coastal nonpoint source programs in conformity with this measure and will have some flexibility in doing so. The application of management measures by States is described more fully in *Coastal Nonpoint Pollution Control Program: Program Development and Approval Guidance*, published jointly by the U.S. Environmental Protection Agency (EPA) and the National Oceanic and Atmospheric Administration (NOAA) of the U.S. Department of Commerce.

2. Description

Boat operation can resuspend bottom sediment, resulting in the reintroduction of toxic substances into the water column. It can increase turbidity, which affects the photosynthetic activity of algae and submerged aquatic vegetation (SAV). SAV provides habitat for fish, shellfish, and waterfowl and plays an important role in maintaining water quality through assimilating nutrients. It also reduces wave energy, protecting shorelines and bottom habitats from erosion. Replacing SAV once it has been uprooted or eliminated from an area is difficult, and the science of replacing it artificially is not well-developed. It is therefore important to protect existing SAV. Boat operation may also cut off or uproot SAV, damage corals and oyster reefs, and cause other habitat destruction. The definition of shallow-water habitat should be determined by State policy and should be dependent upon the ecological importance and sensitivity to direct and indirect disruption of the habitats found in the State.

3. Management Measure Selection

This measure was selected because some areas are not suitable for boat traffic due to their shallow water depth and the ecological importance and sensitivity to disruption of the types of habitats in the area. Excluding boats from such areas will minimize direct habitat destruction. Establishing no-wake zones will minimize the indirect impacts of increased turbidity (e.g., decreased light availability).

4. Practices

As discussed more fully at the beginning of this chapter and in Chapter 1, the following practices are described for illustrative purposes only. State programs need not require implementation of these practices. However, as a practical matter, EPA anticipates that the management measure set forth above generally will be implemented by applying one or more management practices appropriate to the source, location, and climate. The practices set forth below have been found by EPA to be representative of the types of practices that can be applied successfully to achieve the management measure described above.

a. Exclude motorized vessels from areas that contain important shallow-water habitat.

Many areas of shallow SAV exhibit troughs (areas of no vegetation) due to the action of boat propellers. This can result in increased erosion of the SAV due to the loss of bottom cover cohesion. SAV should be protected from boat or propeller damage because of its high habitat value.

b. Establish and enforce no-wake zones to decrease turbidity.

No-wake zones should be used in place of speed zones in shallow surface waters for reducing the turbidity caused by boat traffic. Motorboats traveling at relatively slow speeds of 6 to 8 knots in shallow waters can be expected to produce waves at or near the maximum size that can be produced by the boats. The height of a wave is directly proportional to the depth of water in which the wave will disturb the bottom (e.g., a taller wave will disturb the bottom of water deeper than a shorter wave). Bottom sediments composed of fine material will be resuspended and result in turbidity. In areas of high boat traffic, boat-induced turbidity can reduce the photosynthetic activity of SAV. Chapter 6 contains additional information on how to implement this practice.

IV. GLOSSARY

Bathymetric: Pertaining to the depth of a waterbody.

Bed load transport: Sediment transport along the bottom of a waterbody due to currents.

Benthic: Associated with the sea bottom.

Biocriteria: Biological measures of the health of an environment, such as the incidence of cancer in benthic fish species.

BOD: Biochemical oxygen demand; the quantity of dissolved oxygen used by microorganisms in the biochemical oxidation of organic matter and oxidizable inorganic matter by aerobic biological action.

Circulation cell: See *gyre*.

Conservative pollutant: A pollutant that remains chemically unchanged in the water.

Critical habitat: A habitat determined to be important to the survival of a threatened or endangered species, to general environmental quality, or for other reasons as designated by the State or Federal government.

DO: Dissolved oxygen; the concentration of free molecular oxygen in the water column.

Drogue-release study: A study of currents and circulation patterns using objects, or drogues, placed in the water at the surface or at specified depths.

Dye-release study: A study of dispersion using nontoxic dyes.

Exchange boundary: The boundary between one waterbody, e.g., a marina, and its parent waterbody; usually the marina entrance(s).

Fecal coliform: Bacteria present in mammalian feces, used as an indicator of the presence of human feces, bacteria, viruses, and pathogens in the water column.

Fixed breakwater: A breakwater constructed of solid, stationary materials.

Floating breakwater: A breakwater constructed to possess a limited range of movement.

Flushing time: Time required for a waterbody, e.g., a marina, to exchange its water with water from the parent waterbody.

Gyre: A mass of water circulating as a unit and separated from other circulating water masses by a boundary of relatively stationary water.

Hydrographic: Pertaining to ground or surface water.

Ichthyofauna: Fish.

Macrophytes: Plants visible to the naked eye.

Mathematical modeling: Predicting the performance of a design based on mathematical equations.

Micron: Micrometer; one-one millionth (0.000001) of a meter.

NCDEM DO model: A mathematical model for calculating dissolved oxygen concentrations developed by the North Carolina Division of Environmental Management (NCDEM).

No-discharge zone: An area where the discharge of polluting materials is not permitted.

NPDES: National Pollutant Discharge Elimination System. A permitting system for point source polluters regulated under section 402 of the Clean Water Act.

Numerical modeling: See *mathematical modeling.*

Nutrient transformers: Biological organisms, usually plants, that remove nutrients from water and incorporate them into tissue matter.

Organics: Carbon-containing substances such as oil, gasoline, and plant matter.

PAH: Polynuclear aromatic hydrocarbon; multiringed carbon molecules resulting from the burning of fossil fuels, wood, etc.

Physical modeling: Using a small-scale physical structure to simulate and predict the performance of a full-scale structural design.

Rapid bioassessment: An assessment of the environmental degradation of a waterbody based on a comparison between a typical species assemblage in a pristine waterbody and that found in the waterbody of interest.

Removal efficiency: The capacity of a pollution control device to remove pollutants from wastewater or runoff.

Residence time: The length of time water remains in a waterbody. Generally the same as *flushing time.*

Riparian: For the purposes of this report, riparian refers to areas adjoining coastal waterbodies, including rivers, streams, bays, estuaries, coves, etc.

Sensitivity analysis: Modifying a numerical model's parameters to investigate the relationship between alternative [marina] designs and water quality.

Shoaling: Deposition of sediment causing a waterbody or location within a waterbody to become more shallow.

Significant: A quantity, amount, or degree of importance determined by a State or local government.

SOD: Sediment oxygen demand; biochemical oxygen demand of microorganisms living in sediments.

Suspended solids: Solid materials that remain suspended in the water column.

Tidal prism: The difference in the volume of water in a waterbody between low and high tides.

Tidal range: The difference in height between mean low tide and mean high tide.

Velocity shear: Friction created by two masses of water moving in different directions or at different speeds in the same direction.

WASP4 model: A generalized modeling system for contaminant fate and transport in surface waters; can be applied to BOD, DO, nutrients, bacteria, and toxic chemicals.

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Appendix 5A

Summary of Coastal States Marina Programs

APPENDIX 5A: SUMMARY OF COASTAL STATES MARINA PROGRAMS

STATE	Marina water quality (WQ) study required	Critical habitat assessment required prior to marina siting	Stormwater runoff regulations included in the State code for marinas	Pumpouts mandated? Enforced? How many units? Criteria	Authority for oversite of expansions*	Boat maintenance materials handling	Public education programs for boaters	Speed zones or no-wake zones for erosion
AL	Only where marinas basins are constructed out of upland.	Yes	No	Yes for new or expanding marinas	Dept. of Env. Mgmt. reviews	No	Yes, but minimal	Only for safety purposes
AK	No; just a USACE permit and local ordinances	Yes; very important for commercial fish species	No	No	Yes	No	No, but Coast Guard has pollution prevention program	Yes
CA	Yes; the CA Envir. Quality Act, similar to NEPA, is implemented on a regional level	Under the CA Coastal Act; Env. Impact Report written	At the local level; not at the State level	Water Resources Ctrl Board; yes, at least one pump-out facility in marina	CA Envir. Quality Act; must perform EIR, handled at the local level	Encouraged	Yes; very extensive, Dept. of Boating and Waterways	Local jurisdictions provide local control
CT	Yes for large projects or if circulation may be affected	Yes; developers are given guidance	Yes for new and expanding but not small marinas	Yes	Encouraged	Yes	Yes	Only for safety purposes

*The U.S. Army Corps of Engineers reviews all construction activity in navigable waters.

APPENDIX 5A: SUMMARY OF COASTAL STATES MARINA PROGRAMS, Continued

STATE	Marina water quality (WQ) study required	Critical habitat assessment required prior to marina siting	Stormwater runoff regulations included in the State code for marinas	Pumpouts mandated? Enforced? How many units? Criteria	Authority for over-site of expansions*	Boat maintenance materials handling	Public education programs for boaters	Speed zones or no-wake zones for erosion
DE	Yes for new marinas	Yes for new marinas and expansions	Yes	>100 slips must have pumpout; <25 not required; 25-100 allowed to share	Yes	BMPs required	Yes	Yes
FL	Yes	Yes	Yes for new development, not marina-specific	Yes for new marinas	Yes	Minimal	Yes	Yes
GA	No unless problem is found	Yes for shellfish	Yes only for dry stack storage	Yes	Yes	Yes	No; trade association does this	Yes
HA	Yes	Yes	No	No	Yes if expansion is part of a new plan	No	Yes	Only for safety purposes
ME	No	Sometimes	No	Yes	Yes	Yes	Yes	No

*The U.S. Army Corps of Engineers reviews all construction activity in navigable waters.

APPENDIX 5A: SUMMARY OF COASTAL STATES MARINA PROGRAMS, Continued

STATE	Marina water quality (WQ) study required	Critical habitat assessment required prior to marina siting	Stormwater runoff regulations included in the State code for marinas	Pumpouts mandated? Enforced? How many units? Criteria	Authority for oversite of expansions*	Boat maintenance materials handling	Public education programs for boaters	Speed zones or no-wake zones for erosion
MD	Yes in some cases; monitoring may be required	Sometimes	Yes for new development, not marina-specific	Yes	Yes	Encouraged	Yes	Yes
MA	Yes in some cases	Sometimes	No	Yes	Yes	Yes	Yes	Only for safety purposes
MI	No	Yes	No	Yes	Yes	Encouraged	No	Yes at local level
MS	Yes in some cases	Sometimes	No	Yes	Yes	No	Yes	Yes
NH	No	No	Yes, treated the same as other development	Yes	Yes	No	No	Yes
NJ	Yes	Yes	Yes, treated the same as other development	Yes for >25 slips	Yes	Yes	Yes	Only for safety purposes

*The U.S. Army Corps of Engineers reviews all construction activity in navigable waters.

APPENDIX 5A: SUMMARY OF COASTAL STATES MARINA PROGRAMS, Continued

STATE	Marina water quality (WQ) study required	Critical habitat assessment required prior to marina siting	Stormwater runoff regulations included in the State code for marinas	Pumpouts mandated? Enforced? How many units? Criteria	Authority for oversite of expansions*	Boat maintenance materials handling	Public education programs for boaters	Speed zones or no-wake zones for erosion
NY	No	Sometimes	Yes, treated the same as other development	No, except on case-by-case permit condition	Yes	Yes	Yes	Yes; no-wake at local level
NC	Yes	Yes	Yes, treated the same as other development	Yes for >25 slips	Yes for >20% increase	Yes	Yes	Only for safety purposes
OR	Not required at the state level	Encouraged by U.S. Fish and Wildlife Service	Yes, treated the same as other development	Yes; have no-discharge zones already	Yes	Not mandatory; very common to see liquid waste receptacles	Yes, by the Oregon State Marine Board	Yes
RI	Yes in degraded water	Yes	Yes	Yes; at least 1 pumpout for every 500 vessels over 25 feet	Yes	Yes	Yes	Yes
SC	Yes	Sometimes	Yes	Yes for new and expanding	Yes	Yes	Yes	Yes

*The U.S. Army Corps of Engineers reviews all construction activity in navigable waters.

APPENDIX 5A: SUMMARY OF COASTAL STATES MARINA PROGRAMS, Continued

STATE	Marina water quality (WQ) study required	Critical habitat assessment required prior to marina siting	Stormwater runoff regulations included in the State code for marinas	Pumpouts mandated? Enforced? How many units? Criteria	Authority for over-site of expansions*	Boat maintenance materials handling	Public education programs for boaters	Speed zones or no-wake zones for erosion
TX	No	No	No	No	Not available	No	No	Addressed at local level
VA	Yes	Yes	Yes, treated the same as other development	Yes for new and expanding	Yes	No	Yes	Addressed at local level
WA	Required by some local governments; as required for general NPDES permitting for boatyards	Yes	Yes	No, but could be imposed at the local level	Requires approval by the WA Department of Ecology	Yes	Yes	Yes

*The U.S. Army Corps of Engineers reviews all construction activity in navigable waters.

CHAPTER 6: Management Measures for Hydromodification: Channelization and Channel Modification, Dams, and Streambank and Shoreline Erosion

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I. INTRODUCTION

A. What "Management Measures" Are

This chapter specifies management measures to protect coastal waters from sources of nonpoint pollution related to hydromodification activities. "Management measures" are defined in section 6217 of the Coastal Zone Act Reauthorization Amendments of 1990 (CZARA) as economically achievable measures to control the addition of pollutants to our coastal waters, which reflect the greatest degree of pollutant reduction achievable through the application of the best available nonpoint pollution control practices, technologies, processes, siting criteria, operating methods, or other alternatives.

These management measures will be incorporated by States into their coastal nonpoint programs, which under CZARA are to provide for the implementation of management measures that are "in conformity" with this guidance. Under CZARA, States are subject to a number of requirements as they develop and implement their Coastal Nonpoint Pollution Control Programs in conformity with this guidance and will have some flexibility in doing so. The application of these management measures by States to activities causing nonpoint pollution is described more fully in *Coastal Nonpoint Pollution Control Program: Program Development and Approval Guidance*, published jointly by the U.S. Environmental Protection Agency (EPA) and the National Oceanic and Atmospheric Administration (NOAA).

B. What "Management Practices" Are

In addition to specifying management *measures*, this chapter also lists and describes management *practices* for illustrative purposes only. While State programs are required to specify management *measures* in conformity with this guidance, State programs need not specify or require the implementation of the particular management *practices* described in this document. However, as a practical matter, EPA anticipates that the management measures generally will be implemented by applying one or more management practices appropriate to the source, location, and climate. The practices listed in this document have been found by EPA to be representative of the types of practices that can be applied successfully to achieve the management measures. EPA has also used some of these practices, or appropriate combinations of these practices, as a basis for estimating the effectiveness, costs, and economic impacts of achieving the management measures. (Economic impacts of the management measures are addressed in a separate document entitled *Economic Impacts of EPA Guidance Specifying Management Measures for Sources of Nonpoint Pollution in Coastal Waters.*)

EPA recognizes that there is often site-specific, regional, and national variability in the selection of appropriate practices, as well as in the design constraints and pollution control effectiveness of practices. The list of practices for each management measure is not all-inclusive and does not preclude States or local agencies from using other technically sound practices. In all cases, however, the practice or set of practices chosen by a State needs to achieve the management measure.

C. Scope of This Chapter

This chapter addresses three categories of sources of nonpoint pollution from hydromodification activities that affect coastal waters:

(1) Channelization and channel modification;
(2) Dams; and
(3) Streambank and shoreline erosion.

Each category of management measures is addressed in a separate section of this guidance. Each section contains (1) the management measure; (2) an applicability statement that describes, when appropriate, specific activities and locations for which the measure is suitable; (3) a description of the management measure's purpose; (4) the basis for the management measure's selection; (5) information on management practices that are suitable, either alone or in combination with other practices, to achieve the management measure; (6) information on the effectiveness of the management measure and/or of practices to achieve the measure; and (7) information on costs of the measure and/or practices to achieve the measure.

D. Relationship of This Chapter to Other Chapters and to Other EPA Documents

1. Chapter 1 of this document contains detailed information on the legislative background for this guidance, the process used by EPA to develop this guidance, and the technical approach used by EPA in the guidance.

2. Chapter 7 of this document contains management measures to protect wetlands and riparian areas that serve an NPS pollution abatement function. These measures apply to a broad variety of sources, including sources related to hydromodification activities.

3. Chapter 8 of this document contains information on recommended monitoring techniques to (1) ensure proper implementation, operation, and maintenance of the management measures and (2) assess over time the success of the measures in reducing pollution loads and improving surface water quality.

4. EPA has separately published a document entitled *Economic Impacts of EPA Guidance Specifying Management Measures for Sources of Nonpoint Pollution in Coastal Waters.*

5. NOAA and EPA have jointly published guidance entitled *Coastal Nonpoint Pollution Control Program: Program Development and Approval Guidance.* This guidance contains details on how State Coastal Nonpoint Pollution Control Programs are to be developed by States and approved by NOAA and EPA. It includes guidance on the following:

   - The basis and process for EPA/NOAA approval of State Coastal Nonpoint Pollution Control Programs;
   - How NOAA and EPA expect State programs to provide for the implementation of management measures" in conformity" with this management measures guidance;
   - How States may target sources in implementing their Coastal Nonpoint Pollution Control Programs;
   - Changes in State coastal boundaries; and
   - Requirements concerning how States are to implement the Coastal Nonpoint Pollution Control Programs.

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II. CHANNELIZATION AND CHANNEL MODIFICATION MANAGEMENT MEASURES

One form of hydromodification is *channelization* or *channel modification*. These terms (used interchangeably) describe river and stream channel engineering undertaken for the purpose of flood control, navigation, drainage improvement, and reduction of channel migration potential (Brookes, 1990). Activities such as straightening, widening, deepening, or relocating existing stream channels and clearing or snagging operations fall into this category. These forms of hydromodification typically result in more uniform channel cross sections, steeper stream gradients, and reduced average pool depths.

The terms *channelization* and *channel modification* are also used in this chapter to refer to the excavation of borrow pits, canals, underwater mining, or other practices that change the depth, width, or location of waterways or embayments in coastal areas. Excavation of marina basins is addressed separately in Chapter 5 of this guidance.

The term *flow alteration* describes a category of hydromodification activities that result in either an increase or a decrease in the usual supply of fresh water to a stream, river, or estuary. Flow alterations include diversions, withdrawals, and impoundments. In rivers and streams, flow alteration can also result from undersized culverts, transportation embankments, tide gates, sluice gates, and weirs.

Levees along a stream or river channel are also addressed by this section. A *levee* is defined by the U.S. Army Corps of Engineers (USACE) as an embankment or shaped mound for flood control or hurricane protection (USACE, 1981). Pond banks, and other small impoundment structures, often referred to as levees in the literature, are not considered to be levees as defined in this section. Additionally, a *dike* is not used in this guidance to refer to the same structure as a levee, but rather is defined as a channel stabilization structure sited in a river or stream perpendicular to the bank.

For the purpose of this guidance, no distinction will be made between the terms *river* and *stream* because no definition of either could be found to quantitatively distinguish between the two. Likewise, no distinction will be made for word combinations of these two terms; for example, *streambank* and *riverbank* will be considered to be synonymous.

The following definitions for common terms associated with channelization activities apply to this chapter (USACE, 1983). Other definitions are provided in the Glossary at the end of the chapter.

Channel: A natural or constructed waterway that continuously or periodically passes water.

Channel stabilization: Structures placed below the elevation of the average surface water level (lower bank) to control bank erosion or to prevent bank or channel failure.

Streambank: The side slopes of a channel between which the streamflow is normally confined.

Lower bank: The portion of the streambank below the elevation of the average water level of the stream.

Upper bank: The portion of the streambank above the elevation of the average water level of the stream.

Streambank stabilization: Structures placed on or near a distressed streambank to control bank erosion or to prevent bank failure.

Based on the above definitions, the difference between channel stabilization and streambank stabilization is that in streambank stabilization, the upper bank is also protected from erosion or failure. This additional protection guards against erosive forces caused by high-water events and by land-based causes such as runoff or improper siting of

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buildings. Levees are placed along streambanks to prevent flooding in adjacent areas during extreme high-water events.

Effects of Channelization and Channel Modification Activities

General Problematic Effects

Channel modification activities have deprived wetlands and estuarine shorelines of enriching sediments, changed the ability of natural systems to both absorb hydraulic energy and filter pollutants from surface waters, and caused interruptions in the different life stages of aquatic organisms (Sherwood et al., 1990). Channel modification activities can also alter instream water temperature and sediment characteristics, as well as the rates and paths of sediment erosion, transport, and deposition. A frequent result of channelization and channel modification activities is a diminished suitability of instream and riparian habitat for fish and wildlife. Hardening of banks along waterways has eliminated instream and riparian habitat, decreased the quantity of organic matter entering aquatic systems, and increased the movement of NPS pollutants from the upper reaches of watersheds into coastal waters.

Channel modification projects undertaken in streams or rivers to straighten, enlarge, or relocate the channel usually require regularly scheduled maintenance activities to preserve and maintain completed projects. These maintenance activities may also result in a continual disturbance of instream and riparian habitat. In some cases, there can be substantial displacement of instream habitat due to the magnitude of the changes in surface water quality, morphology and composition of the channel, stream hydraulics, and hydrology.

Excavation projects can result in reduced flushing, lowered dissolved oxygen levels, saltwater intrusion, loss of streamside vegetation, accelerated discharge of pollutants, and changed physical and chemical characteristics of bottom sediments in surface waters surrounding channelization or channel modification projects. Reduced flushing, in particular, can increase the deposition of finer-grained sediments and associated organic materials or other pollutants.

Levees may reduce overbank flooding and the subsequent deposition of sediment needed to nourish riverine and estuarine wetlands and riparian areas. Levees can cause increased transport of suspended sediment to coastal and near-coastal waters during high-flow events. Levees located close to streambanks can also prevent the lateral movement of sediment-laden waters into adjacent wetlands and riparian areas that would otherwise serve as depositories for sediment, nutrients, and other NPS pollutants. This has been a major factor, for example, in the rapid loss of coastal wetlands in Louisiana (Hynson et al., 1985). Levees also interrupt natural drainage from upland slopes and can cause concentrated, erosive flows of surface waters.

The resulting changes to the distribution, amount, and timing of flows caused by flow alterations can affect a wide variety of living resources. Where tidal flow restrictors cause impoundments, there may be a loss of streamside vegetation, disruption of riparian habitat, changes in the historic plant and animal communities, and decline in sediment quality. Restricted flows can impede the movement of fish or crustaceans. Flow alteration can reduce the level of tidal flushing and the exchange rate for surface waters within coastal embayments, with resulting impacts on the quality of surface waters and on the rates and paths of sediment transport and deposition.

Specific Effects

Depending on preproject site conditions and the extent of hydromodification activity, new and existing channelization and channel modification projects may result in no additional NPS problems, additional NPS problems, or benefits.

The following are major categories of channelization and channel modification effects and examples of associated problems and benefits.

Changed Sediment Supply. One of the more significant changes in instream habitat associated with channelization and channel modification projects is in sediment supply and delivery. Streamside levees have been linked to accelerated rates of erosion and decreased sediment supplies to coastal areas (Hynson et al., 1985). Sherwood and others (1990) evaluated the long-term impacts of channelization projects on the Columbia River estuary and found that changes to the river system resulted in a net increase of 68 million cubic meters of sediment in the estuary. These changes in sediment supply can include problems such as increased sedimentation to some areas (an estuary, for example) or decreased sediment to other areas (such as streamside wetlands or estuarine marshes). Other changes may be beneficial; for example, a diversion that delivers sediment to eroding marshes (Hynson et al., 1985). Another example of a beneficial channel stabilization project might be one that results in increased flushing and the elimination of unwanted sediment in the spawning area of a stream.

Reduced Freshwater Availability. Salinity above threshold levels is considered to be a form of NPS pollution in freshwater supplies. Reduced freshwater availability for municipal, industrial, or agricultural purposes can result from some channelization and channel modification practices. Similarly, alteration of the salinity regime in portions of a channel can result in ecological changes in vegetation in the streamside area. Diversion of fresh water by flood- and hurricane-protection levees has reduced freshwater inputs to adjacent marshes. This has resulted in increased marsh salinities and degradation of the marsh ecosystem (Hynson et al., 1985). A benefit of other diversion projects was a reduction of freshwater inputs to estuarine areas that were becoming too fresh because of overall increases in fresh water from changes in land use within a watershed. Increases in oyster harvests have been attributed to a freshwater diversion in Plaquemines Parish, Louisiana. Over the 6-year period from 1970 to 1976, oyster harvests increased by over 3.5 million pounds (Hynson et al., 1985). Potential problems with diversions include erosion, settlement, seepage, and liquefaction failure (Hynson et al., 1985).

Accelerated Delivery of Pollutants. Channelization and channel modification projects can lead to an increased quantity of pollutants and accelerated rate of delivery of pollutants to downstream sites. Alterations that increase the velocity of surface water or that increase flushing of the streambed can lead to more pollutants being transported to downstream areas at possibly faster rates. Urbanization has been linked to downstream channelization problems in Hawaii (Anderson, 1992). It is believed that the deterioration of Kaneohe Bay may be caused by development within the watershed, which has increased runoff flows to streams entering the Bay. Streams that once meandered and contained natural vegetation to filter out nutrient and sediment are now channelized and contain surface water that is rich in nutrients and other pollutants associated with urban areas (Anderson, 1992). Some excavation projects have resulted in poor surface water circulation along with increased sedimentation and other surface water quality problems within the excavated basin. In some of these cases, additional, carefully designed channel modifications can increase flushing rates, which deliver accumulated pollutants from the basin to points downstream that are able to assimilate or otherwise beneficially use the accumulated materials.

Loss of Contact with Overbank Areas. Instream hydraulic changes can decrease or interfere with surface water contact to overbank areas during floods or other high-water events. Channelization and channel modification activities that lead to a loss of surface water contact in overbank areas also may result in reduced filtering of NPS pollutants by streamside area vegetation and soils. Areas of the overbank that are dependent on surface water contact (i.e., riparian areas and wetlands) may change in character and function as the frequency and duration of flooding change. Erickson and others (1979) reported a major influence on wetland drainage in the Wild Rice Creek Watershed in North and South Dakota. Drainage rates from streamside areas were 2.6 times higher in the channelized area than in undisturbed areas during preliminary project activities and 5.3 times higher following construction. Schoof (1980) reported several other impacts of channelization, including drainage of wetlands, reduction of oxbows and stream meander, clearing of floodplain hardwood, lowering of ground-water levels, and increased erosion. Channel modification projects such as setback levees or compound channel design can provide the overbank flooding to areas needing it while also providing a desired level of flood protection to adjoining lands.

Changes to Ecosystems. Channelization and channel modification activities can lead to loss of instream and riparian habitat and ecosystem benefits such as pathways for wildlife migration and conditions suitable for reproduction and growth. Problematic flow modifications, for example, have resulted in reversal of flow regimes of some California rivers or streams, which has led to the disorientation of anadromous fish that rely on flow to direct them to spawning areas (James and Stokes Associates, Inc., 1976). Eroded sediment may deposit in new areas, covering benthic communities or altering instream habitat (Sherwood et al., 1990). Orlova and Popova (1976) researched the effects on fish population resulting from altering the hydrologic regime with hydraulic structures such as channels. The effects assessed by Orlova and Popova (1976) include:

- Deterioration of spawning habitat and conditions, resulting in lower recruitment of river species;
- Increases in stocks of summer spawning river species; and
- Changes in types and amounts of food organisms.

Many channel or streambank stabilization structures provide increased instream habitat for certain aquatic species. For example, Sandheinrich and Atchison (1986) reported increases in densities of epibenthic insects within revetments and stone dike areas and more suitable substrate for bottom-dwelling insects in revetment areas.

Instream and Riparian Habitat Altered by Secondary Effects. Secondary instream and riparian habitat alteration effects from channelization and channel modification projects include movement of estuarine turbidity maximum zones (zone of higher sediment concentrations caused by salinity and tide-induced circulation) with salinity changes, cultural eutrophication caused by inadequate flushing, and trapping of large quantities of sediment. Wolff and others (1989) analyzed the impacts of flow augmentation on the stream channel and instream habitat following a transbasin water diversion project in Wyoming. The South Fork of Middle Crow Creek, previously ephemeral, was beneficially used as a conveyance to create instream habitat as a part of impact management measures of the transbasin diversion project. Discontinuous channels, high summer water temperature, and flow interruptions and fluctuations were identified as potential limiting factors for the development of such practices for this particular project. Modeling results, however, indicated that as the channel develops, the effects of the first two limiting factors will be negligible. Following 2 years of increased flow in the 5.5-mile section of stream channel (reach) used in this study, the volume of stream channel had increased 32 percent and more channel areas were expected to develop on approximately 67 percent of the stream reach. The total area of beaver ponds had more than doubled. The brook trout with which the beaver ponds were stocked were reported to be surviving and growing.

The examples described above illustrate the range of possible effects that can result from channelization and channel modification projects. These effects can be either beneficial or problematic to the ecology and surrounding riparian habitat. The effects caused by changed sediment supplies provide an excellent example of these varying impacts. In one case, sediment supplies to coastal marshes are insufficient and the marshes are subsiding (problem). In another case, sediment supplies to an estuary are increasing to the point of causing changes to the natural tidal flow (problem). A final example showed decreased sediment in a streambed, which has resulted in better conditions for native spawning fish (benefit). Thus, depending on site-specific conditions and the particular channelization or channel modification practices used, the project will have positive or negative NPS pollution impacts.

Another confounding factor is the potential for one project to have multiple NPS problems and/or benefits. Assuming that a channelization or channel modification project was originally designed to overcome a specific problem (e.g., channel deepening for navigation, streambank stabilization for erosion control, or levee construction for flood control), the project was intended to be beneficial. Unfortunately, planners of many channelization and channel modification projects have, in the past, been myopic when considering the range of impacts associated with the project. The purpose of the management measures in this section is to recommend proper evaluation of potential projects and reevaluation of existing projects to reduce NPS impacts and maximize potential benefits.

Proper evaluation of channelization and channel modification projects should consider three major points.

(1) **Existing conditions.** New and existing channelization and channel modification projects should be evaluated for potential effects (both problematic and beneficial) based on existing stream and watershed conditions. Site-specific stream conditions, such as flow rate, channel dimensions, typical surface water quality, or slope, should be evaluated in conjunction with streamside conditions, such as soil and vegetation type, slopes, or land use. Characteristics of the watershed also need to be evaluated. This phase of the evaluation will identify baseline conditions for potential projects and can be compared to historical conditions for projects already in place.

(2) **Potential conditions.** Anticipated changes to the base (or existing) conditions in a stream, along the streambank, and within the watershed should be evaluated. By examining potential changes caused by new conditions, long-term impacts can be factored into the design or management of a channelization or channel modification project. Studies like that of Sandheinrich and Atchison (1986) clearly show that short-term benefits from hydromodification activities can change to long-term problems.

(3) **Watershed management.** Evaluation of changes in watershed conditions is paramount in the proper design of a channelization or channel modification project. Since the design of these projects is based on hydrology, changes in watershed hydrology will certainly impact the proper functioning of a channelization or channel modification structure. Additionally, many surface water quality changes associated with a channelization or channel modification project can be attributed to watershed changes, such as different land use, agricultural practices, or forestry practices.

The two management measures presented in this section of the chapter promote the evaluation of channelization and channel modification projects. Channels should be evaluated as a part of the watershed planning and design processes, including watershed changes from new development in urban areas, agricultural drainage, or forest clearing. The purpose of the evaluation is to determine whether resulting NPS changes to surface water quality or instream and riparian habitat can be expected and whether these changes will be good or bad.

Existing channelization and channel modification projects can be evaluated to determine the NPS impacts and benefits associated with the projects. Modifications to existing projects, including operation and maintenance or management, can also be evaluated to determine the possibility of improving some or all of the impacts without changing the existing benefits or creating additional problems.

In both new and existing channelization and channel modification projects, evaluation of benefits and/or problems will be site-specific. Mathematical models are one type of tool used to determine these impacts. Some models provide a simple analysis of a particular situation and are good for screening purposes. Other models evaluate complex interactions of many variables and can be powerful, site-specific evaluation tools. There are also structural and nonstructural practices that can be used to prevent either NPS pollution effects from or NPS impacts to channelization and channel modification projects. Interpretation of design changes, model results predicting changes or impacts, or the effects of structural or nonstructural practices requires sound biological and engineering judgment and experience.

The first three problems listed above are usually associated with the alteration of physical characteristics of surface waters. Accordingly, they are addressed by Management Measure II.A in the section below. The last three problems listed above can be grouped to represent problems resulting from modification of instream and riparian habitat. They are addressed by Management Measure II.B in the subsequent section below.

[illegible]

(1) Evaluate the potential effects of proposed channelization and channel modification on the physical and chemical characteristics of surface waters in coastal areas;

(2) Plan and design channelization and channel modification to reduce undesirable impacts; and

(3) Develop an operation and maintenance program for existing modified channels that includes identification and implementation of opportunities to improve physical and chemical characteristics of surface waters in those channels.

1. Applicability

This management measure is intended to be applied by States to public and private channelization and channel modification activities in order to prevent the degradation of physical and chemical characteristics of surface waters from such activities. This management measure applies to any proposed channelization or channel modification projects, including levees, to evaluate potential changes in surface water characteristics, as well as to existing modified channels that can be targeted for opportunities to improve the surface water characteristics necessary to support desired fish and wildlife. Under the Coastal Zone Act Reauthorization Amendments of 1990, States are subject to a number of requirements as they develop coastal NPS programs in conformity with management measures and will have some flexibility in doing so. The application of this management measure by States is described more fully in *Coastal Nonpoint Pollution Control Program: Program Development and Approval Guidance*, published jointly by the U.S. Environmental Protection Agency (EPA) and the National Oceanic and Atmospheric Administration (NOAA) of the U.S. Department of Commerce.

2. Description

The purpose of this management measure is to ensure that the planning process for new hydromodification projects addresses changes to physical and chemical characteristics of surface waters that may occur as a result of the proposed work. Implementation of this management measure is intended to occur concurrently with the implementation of Management Measure B (Instream and Riparian Habitat Restoration) of this section. For existing projects, the purpose of this management measure is to ensure that the operation and maintenance program uses any opportunities available to improve the physical and chemical characteristics of the surface waters. Changes created by channelization and channel modification activities are problematic if they unexpectedly alter environmental parameters to levels outside normal or desired ranges. The physical and chemical characteristics of surface waters that may be influenced by channelization and channel modification include sediment, turbidity, salinity, temperature, nutrients, dissolved oxygen, oxygen demand, and contaminants.

Implementation of this management measure in the planning process for new projects will require a two-pronged approach:

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(1) Evaluate, with numerical models for some situations, the types of NPS pollution related to instream changes and watershed development.

(2) Address some types of NPS problems stemming from instream changes or watershed development with a combination of nonstructural and structural practices.

The best available technology that can be applied to examine the physical and chemical effects of hydraulic and hydrologic changes to streams, rivers, or other surface water systems are models and past experience in situations similar to those described in the case studies discussed in this chapter. These models, discussed in detail under the practices of this section, can simulate many of the complex physical, chemical, and biological interactions that occur when hydraulic changes are imposed on surface water systems. Additionally, models can be used to determine a combination of practices to mitigate the unavoidable effects that occur even when a project is properly planned. Models, however, cannot be used independently of expert judgment gained through past experience. When properly applied models are used in conjunction with expert judgment, the effects of channelization and channel modification projects (both potential and existing projects) can be evaluated and many undesirable effects prevented or eliminated.

In cases where existing channelization or channel modification projects can be changed to enhance instream or streamside characteristics, several practices can be included as a part of regular operation and maintenance programs. New channelization and channel modification projects that cause unavoidable physical or chemical changes in surface waters can also use one or more practices to mitigate the undesirable changes. The practices include streambank protection, levee protection, channel stabilization, flow restrictors, check dam systems, grade control structures, vegetative cover, instream sediment control, noneroding roadways, and setback levees or flood walls. By using one or more of these practices in combination with predictive modeling, the adverse impacts of channelization and channel modification projects can be evaluated and possibly corrected.

This management measure addresses three of the effects of channelization and channel modification that affect the physical and chemical characteristics of surface waters:

(1) Changed sediment supply;
(2) Reduced freshwater availability; and
(3) Accelerated delivery of pollutants.

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3. Management Measure Selection

Selection of this management measure was based on the following factors:

(1) Published case studies of existing channelization and channel modification projects describe alterations to the physical and chemical characteristics of surface waters (Burch et al., 1984; Erickson et al., 1979; Parrish et al., 1978; Pennington and Dodge, 1982; Petersen, 1990; Reiser et al., 1985; Roy and Messier, 1989; Sandheinrich and Atchison, 1986; Sherwood et al., 1990). Frequently, the postproject conditions are intolerable to desirable fish and wildlife.

(2) The literature also describes instream benefits for fish and wildlife that can result from careful planning of channelization and channel modification projects (Bowie, 1981; Los Angeles River Watershed, 1973; Sandheinrich and Atchison, 1986; Shields et al., 1990; Swanson et al., 1987; USACE, 1981; USACE, 1989).

(3) Increased volumes of runoff resulting from some types of watershed development produce hydraulic changes in downstream areas including bank scouring, channel modifications, and flow alterations (Anderson, 1992; Schueler, 1987).

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4. Practices

As explained more fully at the beginning of this chapter and in Chapter 1, the following practices are described for illustrative purposes only. State programs need not require implementation of practices. However, as a practical matter, EPA anticipates that the management measure set forth above generally will be implemented by applying one or more management practices appropriate to the source, location, and climate. The practices set forth below have been found by EPA to be representative of the types of practices that can be applied successfully to achieve the management measure described above.

■ *a. Use models/methodologies as one means to evaluate the effects of proposed channelization and channel modification projects on the physical and chemical characteristics of surface waters. Evaluate these effects as part of watershed plans, land use plans, and new development plans.*

Mathematical Models for Physical and Chemical Characteristics of Surface Waters, Including Instream Flows

Over the past 20 to 30 years, theoretical and engineering advances have been made in the quantitative descriptions and interactions of physical transport processes; sediment transport, erosion, and deposition; and surface water quality processes. Based on these theoretical approaches and the need for evaluations of proposed surface water resource engineering projects, a variety of simulation models have been developed and applied to provide technical input for complex decision-making. In planning-level evaluations of proposed hydromodification projects, it is critical to understand that the surface water quality and ecological impact of the proposed project will be driven primarily by the alteration of physical transport processes. In addition, it is critical to realize that the most important environmental consequences of many hydromodification projects will occur over a long-term time scale of years to decades.

The key element in the selection and application of models for the evaluation of the environmental consequences of hydromodification projects is the use of appropriate models to adequately characterize circulation and physical transport processes. Appropriate surface water quality and ecosystem models (e.g., salinity, sediment, cultural eutrophication, oxygen, bacteria, fisheries, etc.) are then selected for linkage with the transport model to evaluate the environmental impact of the proposed hydromodification project. Because of the increasing availability of relatively inexpensive computer hardware and software over the past decade, rapid advances have been made in the development of sophisticated two-dimensional (2D) and three-dimensional (3D) time-variable hydrodynamic models that can be used for environmental assessments of hydromodification projects (see Spaulding, 1990; McAnally, 1987). Two-dimensional depth or laterally averaged hydrodynamic models are economical and can be routinely developed and applied for environmental assessments of beneficial and adverse effects on surface water quality by knowledgeable teams of physical scientists and engineers (Hamilton, 1990). Three-dimensional hydrodynamic models, usually considered more of an academic research tool, are also beginning to be more widely applied for large-scale environmental assessments of aquatic ecosystems (e.g., EPA/USACE-WES Chesapeake Bay 3D hydrodynamic and surface water quality model).

The necessity for the application of detailed 2D and 3D hydrodynamic models for large-scale hydromodification projects can be demonstrated using detailed simulation models to hindcast the long-term surface water quality and ecological impact of projects that have actually been constructed over the past 20 to 40 years. Sufficient data are available from a number of large-scale hydromodification projects in the United States and overseas that can provide data sets for the development of hindcasting models to illustrate the capability of the models to simulate the known adverse long-term ecological consequences of projects that have actually been operational for decades. The results of such hindcasting evaluations could provide important guidance for resource managers, who use good professional judgment to understand the level of technical complexity and the costs required for an adequate assessment of the long-term ecological impacts of proposed hydromodification projects. In the Columbia River estuary, for example, Sherwood and others (1990) used historical bathymetric data with a numerical 2D hydrodynamic model (Hamilton, 1990) to document the long-term impact of hydromodification changes on channel morphology, riverflow transport processes, salinity intrusion, residence time, and net accumulation of sediment.

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When models are not suited to evaluate a particular situation, examining existing conditions and using best professional judgment are another way to evaluate the effects of hydromodification activities. For example, in cases where water supplies need to be restored to wetlands that have historically experienced a loss of water contact, models can be used to ensure that the length of time of renewed water exposure is within the tolerance of the wetland plants for inundation, since excessive inundation of wetland plants can be as destructive as loss of water contact. Surface water quality monitoring and procedures such as Rapid Bioassessment Protocols (see Management Measure B in this section for more information) are examples of methods to examine existing conditions.

Table 6-1 lists some of the available models for studying the effects of channelization and channel modification activities. Listed below are examples of channelization and channel modification activities and associated models that can be used in the planning process.

- **Impoundments.** A hydrodynamic model coupled with a surface water quality model (e.g., WASP4) can be applied to determine changes in surface water quality due to an increased detention of storm water runoff caused by the upstream dams. Changes in sediment distribution in the estuary caused by a reduction in the sediment source (due to the trap efficiency of an upstream impoundment) are difficult to determine with modeling.

- **Tidal Flow Restrictions.** Restrictions of tidal flow may include undersized culverts and bridges, tide gates, and weirs. One potential modeling technique to determine the flow through the restriction is the USGS FESWMS-2DH model. Once the flows through the restriction are defined, then WASP4 can be applied to compute surface water quality impacts.

- **Breakwaters, Jetties, and Wave Barriers.** Construction of these coastal structures may alter the surface water circulation patterns and cause sediment accumulation. Physical hydraulic models can be used to qualitatively determine where sediment will accumulate, but they cannot reliably determine the quantities of accumulated sediment. Finite element (CAFE) or finite difference (EFDC) models can be used to determine changes in circulation/flushing caused by the addition or modification of coastal structures. The WASP4 model can be applied to determine surface water quality impacts.

- **Flow Regime Alterations.** Removing or increasing freshwater flows to an estuary can alter the hydraulic characteristics and water chemistry. The WASP4 model can be used to determine surface water quality impacts.

- **Excavation of Uplands for Marina Basins or Lagoon Systems.** Depending on the magnitude and frequency of water-level fluctuations, this activity may result in poorly flushed areas within a marina or lagoon system. Finite element or finite difference models (e.g., CAFE/DISPER and EFDC) can be used to determine a design that will result in adequate flushing. The WASP4 model can be applied to determine surface water quality (e.g., dissolved oxygen or salinity) impacts.

Model Selection

Although a wide range of adequate hydrodynamic and surface water quality models are available, the central issue in the selection of appropriate models for an evaluation of a specific hydromodification project is the appropriate match of the financial and geographical scale of the proposed project with the cost required to perform a credible technical evaluation of the projected environmental impact. It is highly unlikely, for example, that a proposal for a relatively small marina project with planned excavation of an upland area would be expected or required to contain a state-of-the-art hydrodynamic and surface water quality analysis that requires one or more person-years of effort. In such projects, a simplified, desktop approach—requiring less time and money—would most likely be sufficient (McPherson, 1991). In contrast, substantial technical assessment of the long-term environmental impacts would be expected for channelization proposed as part of construction of a major harbor facility or as part of a system of navigation and flood control locks and dams. The assessment should incorporate the use of detailed 2D or 3D hydrodynamic models coupled with sediment transport and surface water quality models.

Table 6-1. Models Applicable to Hydromodification Activities

Model	Description	Source and Contact
CAFE	Circulation Analysis Finite Element.	Developed at MIT in mid-1970s by J.D. Wang and J.J. Connor. E. Eric Adams Massachusetts Institute of Technology Department of Civil Engineering Cambridge, MA
DISPER	Dispersion analysis model that is coupled to the CAFE model.	Developed at MIT in mid-1970s by G.C. Christodoulou. E. Eric Adams Massachusetts Institute of Technology Department of Civil Engineering Cambridge, MA
TABS-2	Generalized numerical modeling system for open-channel flows, sedimentation, and constituent transport.	Developed by U.S. Army Corps of Engineers Waterways Experiment Station 1978-1984. U.S. Army Waterways Experiment Station Hydraulics Laboratory P.O. Box 631 Vicksburg, MS 39180-0631
EFDC	Environmental Fluid Dynamics Code. This is a 3D finite-difference hydrodynamic and salinity model.	Developed by John Hamrick at the Virginia Institute of Marine Science 1990-1991. Dr. John Hamrick 9 Sussex Court Williamsburg, VA 23188
WASP4	Water Quality Analysis Simulation Program. Simulates dissolved oxygen and nutrients.	Developed and updated by EPA Environmental Research Laboratory, Athens, Georgia, 1986-1990. David Disney U.S. EPA Center for Exposure Assessment Modeling College Station Road Athens, GA 30613
FESWMS-2DH	Finite element surface water modeling system for two-dimensional flow in a horizontal plane. Can simulate steady and unsteady surface water flow and is useful for simulating two- dimensional flow where complicated hydraulic conditions exist (e.g., highway crossings of streams and flood rivers).	Developed for U.S. Geological Survey, Reston, VA Dr. David Froehlich Department of Civil Engineering University of Kentucky Lexington, KY
TPA	Tidal Prism Analysis.	U.S. EPA. 1985. *Coastal Marinas Assessment Handbook.* U.S. EPA, Region 4, Atlanta, GA.
CE-QUAL-W2	Consists of directly coupled hydrodynamic and water quality transport models. Can simulate suspended solids and accumulation and decomposition of detritus and organic sediment. Two-dimensional in the x-z plane.	Developed by U.S. Army Corps of Engineers Waterways Experiment Station in 1986. U.S. Army Waterways Experiment Station Hydraulics Laboratory P.O. Box 631 Vicksburg, MS 39180-0631

In general, six criteria can be used to review available models for potential application in a given hydromodification project:

(1) Time and resources available for model application;
(2) Ease of application;
(3) Availability of documentation;
(4) Applicability of modeled processes and constituents to project objectives and concerns;
(5) Hydrodynamic modeling capabilities; and
(6) Demonstrated applicability to size and type of project.

The Center for Exposure Assessment Modeling (CEAM), EPA Environmental Research Laboratory, Athens, Georgia, provides continual support for several hydrodynamic and surface water quality models. Another source of information and technical support is the Waterways Experiment Station, U.S. Army Corps of Engineers, Vicksburg, Mississippi. Although a number of available models are in the public domain, costs associated with setting up and operating these models may exceed the project's available resources. For a simple to moderately difficult application, the approximate level of effort varies from 1 to 12 person-months (Table 6-2).

Model Limitations

Factors that need to be considered in the application of mathematical models to predict impacts from hydromodification projects include:

- Variations in the accuracy of these models when they are applied to the short- and long-term response of natural systems;
- The availability of relevant information to derive the simulations and validate the modeling results;
- The substantial computer time required for long-term simulations of 3D hydrodynamic and surface water quality process models; and
- The need for access to sophisticated equipment such as the CRAY-XMP.

b. Identify and evaluate appropriate BMPs for use in the design of proposed channelization or channel modification projects or in the operation and maintenance program of existing projects. Identify and evaluate positive and negative impacts of selected BMPs and include costs.

Several available surface water management practices can be implemented to avoid or mitigate the physical and chemical impacts generated by hydromodification projects. Many of these practices have been engineered and used for several decades not only to mitigate human-induced impacts but also to rehabilitate hydrologic systems degraded by natural processes.

Table 6-2. Approximate Levels of Effort for Hydrodynamic and Surface Water Quality Modeling

Dimensionality	Surface Water Quality Parameter	Approximate Level of Effort
1D steady state	DO, BOD, nutrient	1-2 person-months
1D, 2D steady state	DO, BOD, nutrient, phytoplankton, toxics	1-4 person-months
1D, 3D time-variable	DO, BOD, nutrient, phytoplankton, toxics	1-12 person-months

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Streambank Protection

In general, the design of streambank protection may involve the use of several techniques and materials. Nonstructural or programmatic management practices for the prevention of streambank failures include:

- Protection of existing vegetation along streambanks;
- Regulation of irrigation near streambanks and rerouting of overbank drainage; and
- Minimization of loads on top of streambanks (such as prevention of building within a defined distance from the streambed).

Several structural practices are used in the protection or the rehabilitation of eroded banks. These practices are usually implemented in combination to provide stability of the stream system, and they can be grouped into direct and indirect methods. Direct methods place protecting material in contact with the bank to shield it from erosion. Indirect methods function by deflecting channel flows away from the bank or by reducing the flow velocities to nonerosive levels (Henderson and Shields, 1984; Henderson, 1986). Indirect bank protection requires less bank grading and tree and snag removal.

Direct methods for streambank protection include stone riprap revetment, erosion control fabrics and mats, revegetation, burlap sacks, cellular concrete blocks, and bulkheads. Indirect methods include dikes, wire or board fences, gabions, and stone longitudinal dikes. The feasibility of these practices depends on the engineering design of the structure, the availability of the protecting material, the extent of the bank erosion, and specific site conditions such as the flow velocity, channel depth, inundation characteristics, and geotechnical characteristics of the bank. The use of vegetation alone or in combination with other structural practices, when appropriate, would further reduce the engineering and maintenance efforts.

Innovative designs of streambank protection tailored to specific environmental goals and site conditions may result in beneficial effects. Several innovative channel profiling and revetment design considerations were reviewed by Henderson and Shields (1984), including composite revetments for deep channels with flow concentrated along the bank line, windrow revetments for actively eroding and irregular banks, and reinforced revetments (stone toe protection) to control underwater activities adjacent to high banks. Composite revetments placed along the Missouri River were built with a combination of stone, gravel, clay, and flood-tolerant vegetation to protect the streambank (USACE, 1981). The different materials were selected to match the erosive potential of the streambank zones. Beneficial environmental impacts that can be achieved by this type of design include higher densities and abundance of riparian vegetation on the top bank, allowing flood-tolerant species to colonize the clay and gravel of the splash zone. The design was reported to provide better access to the channel by wildlife, and it had a greater aesthetic value.

An excavated bench (compound channel) streambank protection design, based on streambed stabilization, was used to control erosion activities on the Yazoo River tributaries in Mississippi. These tributaries were experiencing extensive bed degradation and channel migration. The design consisted of structural protection to the water elevation reached during 90 to 95 percent of the annual storm events, a flattened bench excavated just above the structural protection to provide a suitable growing environment for wood vegetation and shrubs, and a grass-seeded upper bank, which could be succeeded by native species. This practice has been reported to be successful in controlling streambank erosion (Bowie, 1981).

Streambank protection structures may impact the riparian wildlife community if the stabilization effort alters the quality of the riparian habitat. Comparison of protected riprapped and adjacent unprotected streambanks and cultivated nearby areas along the Sacramento River showed that bird species diversity and density were significantly lower on the riprapped banks than on the unaltered sites (Hehnke and Stone, 1978). However, benthic microorganisms appear to benefit from stone revetment. Burress and others (1982) found that the density and diversity of macroinvertebrates were higher in the protected bank areas.

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Levee Protection

Many valuable techniques can be used, when applied correctly, to protect, operate, and maintain levees (Hynson et al., 1985). Evaluation of site-specific conditions and the use of best professional judgment are the best methods for selecting the proper levee protection and operation and maintenance plan. According to Hynson and others (1985), maintenance activities generally consist of vegetation management, burrowing animal control, upkeep of recreational areas, and levee repairs.

Methods to control vegetation include mowing, grazing, burning, and using chemicals. Selection of a vegetation control method should consider the existing and surrounding vegetation, desired instream and riparian habitat types and values, timing of controls to avoid critical periods, selection of livestock grazing periods, and timing of prescribed burns to be consistent with historical fire patterns (Hynson et al., 1985). Additionally, a balance between the vegetation management practices for instream and riparian habitat and engineering considerations should be maintained to avoid structural compromise (Hynson et al., 1985). Animal control methods are most effective when used as a part of an integrated pest management program and might include instream and riparian habitat manipulation or biological controls (Hynson et al., 1985). Recreational area management includes upkeep of planted areas, disposal of solid waste, and repairing of facilities (Hynson et al., 1985).

Channel Stabilization and Flow Restrictors

Channel stabilization using hydraulic structures to stabilize stream channels, as well as to control stream sediment load and transport, is a common practice. In general, these structures function to:

- Retard further downward cutting of the channel bed;
- Retard or reduce the sediment delivery rate;
- Raise and widen the channel beds;
- Reduce the stream grade and flow velocities;
- Reduce movement of large boulders; and
- Control the direction of flow and the position of the stream.

Check Dam Systems

The Los Angeles River Watershed (1973) evaluated the cost-effectiveness of check dam systems as sediment control structures in the Angeles National Forest. In general, the check dam systems were found to be marginally cost-effective and were able to provide some beneficial sediment-reduction functions.

Swanson and others (1987) described the use of 71 check dams in the headwaters area of a perennial stream in northwestern Nevada. Watershed management problems, such as a history of overgrazing, led to riparian habitat degradation in streamside areas and severe gullying. The problem was ameliorated with changes in watershed management practices (livestock exclusion in streamside areas or limited grazing programs) and structural practices (check dams). Loose rock check dams, designed for 25-year floods, were selected for their ability to retard water velocities and trap sediment.

Benefits of this planned channel modification project include both instream and streamside changes. Sediment was trapped behind the dams (average of 0.9 foot in 2 years), and small wetland areas were established behind most dams. Additionally, over one-half of the channel length was vegetated in the deepest areas and the entire channel was at least partially vegetated. Streamside benefits included increased bird and plant diversity and abundance.

Grade Control Structures - Streambank and Channel Stabilization

Grade control structures (GCS) are hydraulic barriers (weirs) installed across streams to stabilize the channel, control headcuts and scour holes, and prevent upstream degradation. These structures can be built with a variety of materials, including sheet piling, stone, gabions, or concrete. Grade control structures are usually installed in combination with other practices to protect streambanks and direct the stream flow. Grade control structure design needs to account for stream morphologic, hydrologic, and hydraulic characteristics to determine the range of stream discharges for which the structure will function. Additionally, the upstream distance influenced by the structure, changes to surface water profiles, and the sediment transport capacity of the targeted stream reach need to be considered.

Shields and others (1990) evaluated the efficiency of GCS installed on Twentymile Creek (northeast Mississippi) to address channel instability. Effects on bank line vegetation were assessed using a before-and-after approach. Benefits of the GCS included local channel aggradation for about 1 mile upstream of each structure, increased streambank vegetation, locally increased fish species diversity downstream from the GCS, and the creation of low-flow velocities and greater pool depths downstream from the GCS. The primary problem associated with the project was the continued general streambed degradation after the structures were installed.

Vegetative Cover

Streambank protection using vegetation is probably the most commonly used practice, particularly in small tributaries. Vegetative cover, also used in combination with other structural practices, is relatively easy to establish and maintain, is visually attractive, and is the only streambank stabilization method that can repair itself when damaged (USACE, 1983). Appropriate native plant species should be used. Vegetation growing under the waterline provides two levels of protection. First, the root system helps to hold the soil together and increases overall bank stability by forming a binding network. Second, the exposed stalks, stems, branches, and foliage provide resistance to the streamflow, causing the flow to lose part of its energy by deforming the plants rather than by removing the soil particles. Above the waterline, vegetation protects against rainfall impact on the banks and reduces the velocity of the overland flow during storm events.

In addition to its bank stabilization potential, vegetation can provide pollutant-filtering capacity. Pollutant and sediment transported by overland flow may be partly removed as a result of a combination of processes including reduction in flow pattern and transport capacity, settling and deposition of particulates, and eventually nutrient uptake by plants.

Instream Sediment Load Control

Instream sediment can be controlled by using several structural practices depending on the management objective and the source of sediment. Streambank protection and channel stabilization practices, including various types of revetments, grade control structures, and flow restrictors, have been effective in controlling sediment production caused by streambank erosion. Significant amounts of instream sediment deposition can be prevented by controlling bank erosion processes and streambed degradation. Channel stabilization structures can also be designed to trap sediment and decrease the sediment delivery to desired areas by altering the transport capacity of the stream and creating sediment storage areas. In regulated streams, alteration of the natural streamflow, particularly the damping of peak flows caused by surface water regulation and diversion projects, can increase streambed sediment deposits by impairing the stream's transport capacity and its natural flushing power. Sediment deposits and reduced flow alter the channel morphology and stability, the flow area, the channel alignment and sinuosity, and the riffle and pool sequence. Such alterations have direct impacts on the aquatic habitat and the fish populations in the altered streams (Reiser et al., 1985).

Noneroding Roadways

Farm, forestry, and other rural road construction; streamside vehicle operation; and stream crossings usually result in significant soil disturbance and create a high potential for increased erosion processes and sediment transport to adjacent streams and surface waters. Road construction involves activities such as clearing of existing native vegetation along the road right-of-way; excavating and filling the roadbed to the desired grade; installation of culverts and other drainage systems; and installation, compaction, and surfacing of the roadbed.

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Although most erosion from roadways occurs during the first few years after construction, significant impacts may result from maintenance operations using heavy equipment, especially when the road is located adjacent to a waterbody. In addition, improper construction and lack of maintenance may increase erosion processes and the risk for road failure. To minimize erosion and prevent sedimentation impacts on nearby waterbodies during construction and operation periods, streamside roadway management needs to combine proper design for site- specific conditions with appropriate maintenance practices. Chapter 3 of this document reviews available practices for rural road construction and management to minimize impacts on waterbodies in coastal zones. Chapter 4 outlines practices and design concepts for construction and management of roads designed for heavier traffic loads and can be applied to planning and installation of roads and highways in coastal areas.

Setback Levees and Flood Walls

Levees and flood walls are longitudinal structures used to reduce flooding and minimize sedimentation problems associated with fluvial systems. They can be constructed without disturbing the natural channel vegetation, cross section, or bottom slope. Usually no immediate instream effects from sedimentation are caused by implementing this type of modification. However, there may be a long-term problem in channel adjustment (USACE, 1989).

Siting of levees and flood walls should be addressed prior to design and implementation of these types of projects. Proper siting of such structures can avoid several types of problems. First, construction activities should not disturb the physical integrity of adjacent riparian areas and/or wetlands. Second, by setting back the structures (offsetting them from the streambank), the relationship between the channel and adjacent riparian areas can be preserved. Proper siting and alignment of proposed structures can be established based on hydraulic calculations, historical flood data, and geotechnical analysis of riverbank stability.

5. Costs for Modeling Practices

Costs for modeling of channelization and channel modification activities range from $1,500 to over $5,000,000 (see Table 6-3). Generally, more expensive modeling requires custom programming, extensive data collection, detailed calibration and verification, and larger computers. The benefits of more expensive modeling include a more detailed analysis of the problem and the ability to include more variables in the model. Less expensive models, in general, have minimal data requirements and require little or no programming, and they can usually be run on smaller computers. The difference in cost roughly corresponds to the detail that can be expected in the final analysis.

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Table 6-3. Costs of Models for Various Applications

Application	Model	Cost ($)
Channel Maintenance	Physical model of estuary, river, or stream "from scratch"	500,000 to 5,000,000
	Existing physical model of estuary, river, or stream	50,000 to 500,000
	3D hydrodynamic and salinity model	50,000 to 200,000
	TABS-2 application for sedimentation	50,000 to 200,000
	TPA application to a marina basin	1,500 to 3,000
	WASP4 application to a marina basin	15,000 to 50,000
Dams and Impoundments	WASP4 application to an estuary or a reservoir	50,000 to 150,000
	CE-QUAL-W2 application to an estuary or a reservoir	50,000 to 100,000
	Estuarine or reservoir sediment transport models	unlimited
Tidal Flow Restrictors	FESWMS-2DH application of tidal flow restriction	15,000 to 30,000
	WASP4 application of tidal flow restriction	50,000 to 150,000
Flow Regime Alterations	WASP4 application of flow regime alteration	50,000 to 150,000
Breakwaters and Wave Barriers	CAFE finite element circulation model	15,000 to 50,000
	EFDC finite difference 3D model	20,000 to 60,000
	WASP4 application to harbor system	15,000 to 50,000
Excavation of Uplands for Marina Basins or Lagoon Systems	CAFE/DISPER models	15,000 to 50,000
	EFDC 3D hydrodynamic model	20,000 to 60,000
	WASP4 application to marina/lagoon	15,000 to 50,000

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(1) Evaluate the potential effects of proposed channelization and channel modification on instream and riparian habitat in coastal areas;

(2) Plan and design channelization and channel modification to reduce undesirable impacts; and

(3) Develop an operation and maintenance program with specific timetables for existing modified channels that includes identification of opportunities to restore instream and riparian habitat in those channels.

1. Applicability

This management measure pertains to surface waters where channelization and channel modification have altered or have the potential to alter instream and riparian habitat such that historically present fish or wildlife are adversely affected. This management measure is intended to apply to any proposed channelization or channel modification project to determine changes in instream and riparian habitat and to existing modified channels to evaluate possible improvements to instream and riparian habitat. Under the Coastal Zone Act Reauthorization Amendments of 1990, States are subject to a number of requirements as they develop coastal NPS programs in conformity with management measures and will have some flexibility in doing so. The application of this management measure by States is described more fully in *Coastal Nonpoint Pollution Control Program: Program Development and Approval Guidance*, published jointly by the U.S. Environmental Protection Agency (EPA) and the National Oceanic and Atmospheric Administration (NOAA) of the U.S. Department of Commerce.

2. Description

The purpose of this management measure is to correct or prevent detrimental changes to instream and riparian habitat from the impacts of channelization and channel modification projects. Implementation of this management measure is intended to occur concurrently with the implementation of Management Measure A (Physical and Chemical Characteristics of Surface Waters) of this section.

Contact between floodwaters and overbank soil and vegetation can be increased by a combination of setback levees and use of compound-channel designs. Levees set back away from the streambank (setback levees) can be constructed to allow for overbank flooding, which provides surface water contact to important streamside areas (including wetlands and riparian areas). Additionally, setback levees still function to protect adjacent property from flood damage. Compound-channel designs consist of an incised, narrow channel to carry surface water during low (base)-flow periods, a staged overbank area into which the flow can expand during design flow events, and an extended overbank area, sometimes with meanders, for high-flow events. Planting of the extended overbank with suitable vegetation completes the design.

Preservation of ecosystem benefits can be achieved by site-specific design to obtain predefined optimum or existing ranges of physical environmental conditions. Mathematical models can be used to assist in site-specific design.

Instream and riparian habitat alterations caused by secondary effects can be evaluated by the use of models and other decision aids in the design process of a channelization and channel modification activity. After using models to evaluate secondary effects, restoration programs can be established.

3. Management Measure Selection

Selection of this management measure was based on the following factors:

(1) Published case studies that show that channelization projects cause instream and riparian habitat degradation. For example, wetland drainage due to hydraulic modifications was found to be significant by several researchers (Barclay, 1980; Erickson et al., 1979, Schoof, 1980; Wilcock and Essery, 1991).

(2) Published case studies that note instream habitat changes caused by channelization and channel modifications (Reiser et al., 1985; Sandheinrich and Atchison, 1986).

4. Practices

As explained more fully at the beginning of this chapter and in Chapter 1, the following practices are described for illustrative purposes only. State programs need not require implementation of practices. However, as a practical matter, EPA anticipates that the management measure set forth above generally will be implemented by applying one or more management practices appropriate to the source, location, and climate. The practices set forth below have been found by EPA to be representative of the types of practices that can be applied successfully to achieve the management measure described above.

■ a. ***Use models/methodologies to evaluate the effects of proposed channelization and channel modification projects on instream and riparian habitat and to determine the effects after such projects are implemented.***

Expert Judgment and Check Lists

Approaches using expert judgment and check lists developed based on experience acquired in previous projects and case studies may be very helpful in integrating environmental goals into project development. This concept of incorporating environmental goals into project design was used by the U.S. Army Corps of Engineers (Shields and Schaefer, 1990) in the development of a computer-based system for the environmental design of waterways (ENDOW). The system is composed of three modules: streambank protection module, flood control channel module, and streamside levee module. The three modules require the definition of the pertinent environmental goals to be considered in the identification of design features.

Depending on the environmental goals selected for each module, ENDOW will display a list of comments or cautions about anticipated impacts and other precautions to be taken into account in the design.

Biological Methods/Models

To assess the biological impacts of channelization, it is necessary to evaluate both physical and biological attributes of the stream system. Assessment studies should be performed before and after channel modification, with samples being collected upstream from, within, and downstream from the modified reach to allow characterization of baseline conditions. It is also desirable to identify and sample a reference site within the same ecoregion as part of the rapid bioassessment procedures discussed below.

Habitat Evaluation Procedures

Habitat Evaluation Procedures (HEPs) can be used to document the quality and quantity of available habitat, including aquatic habitat, for selected wildlife species. HEPs provide information for two general types of instream and riparian habitat comparisons:

(1) The relative value of different areas at the same point in time and
(2) The relative value of the same area at future points in time.

By combining the two types of comparisons, the impact of proposed or anticipated land and water use changes on instream and riparian habitat can be quantified (USDOI-FWS, 1980).

Rapid Bioassessment Protocols - Habitat Assessment

Rapid Bioassessment Protocols (RBPs) were developed as inexpensive screening tools for determining whether a stream is supporting a designated aquatic life use (Plafkin et al., 1989). One component of these protocols is an instream habitat assessment procedure that measures physical characteristics of the stream reach (Barbour and Stribling, 1991). An assessment of instream habitat quality based on 12 instream habitat parameters is performed in comparison to conditions at a "reference" site, which represents the "best attainable" instream habitat in nearby streams similar to the one being studied. The RBP habitat assessment procedure has been used in a number of locations across the United States. The procedure typically can be performed by a field crew of one person in approximately 20 minutes per sampling site.

Rapid Bioassessment Protocol III - Benthic Macroinvertebrates

Rapid Bioassessment Protocols (Plafkin et al., 1989) were designed to be scientifically valid and cost-effective and to offer rapid return of results and assessments. Protocol III (RBP III) focuses on quantitative sampling of benthic macroinvertebrates in riffle/run habitat or on other submerged, fixed structures (e.g., boulders, logs, bridge abutments, etc.) where such riffles may not be available. The data collected are used to calculate various metrics pertaining to benthic community structure, community balance, and functional feeding groups. The metrics are assigned scores and compared to biological conditions as described by either an ecoregional reference database or site-specific reference sites chosen to represent the "best attainable" biological community in similarly sized streams. In conjunction with the instream habitat quality assessment, an overall assessment of the biological and instream habitat quality at the site is derived. RBP III can be used to determine spatial and temporal differences in the modified stream reach. Application of RBP III requires a crew of two persons; field collections and lab processing require 4 to 7 hours per station and data analysis about 3 to 5 hours, totaling 7 to 12 hours per station. The RBP III has been extensively applied across the United States.

Rosgen Stream Classification System - Fish Habitat

Rosgen (1985) has developed a stream classification system that categorizes various stream types by morphological characteristics. Based on characteristics such as gradient, sinuosity, width/depth ratio, bed particle size, channel entrenchment/valley confinement, and landform features and watershed soil types, stream segments can be placed within major categories. Subcategories can be delineated using additional factors including organic debris, riparian vegetation, stream size, flow regimen, depositional features, and meander patterns. The method is designed to be applied using aerial photographs and topographic maps, with field validation necessary for gradients, particle size, and width/depth ratios. Rosgen and Fittante (1986) have prepared guidelines for fish habitat improvement structure suitability based on Rosgen's (1985) classification system. The methods have been used in the western States and have had some application in the eastern States.

Simon and Hupp Channel Response Model - Stream Habitat

A conceptual model of channel evolution in response to channelization has been developed by Simon and Hupp (1986, 1987), Hupp and Simon (1986, 1991), and Simon (1989a, 1989b). The model identifies six geomorphic stages of channel response and was developed and extensively applied to predict empirically stream channel changes following large-scale channelization projects in western Tennessee. Data required for model application include bed elevation and gradient, channel top-width, and channel length before, during, and after modification. Gauging station data can be used to evaluate changes through time of the stage-discharge relationship and bed-level trends. Riparian vegetation is dated to provide ages of various geomorphic surfaces and thereby to deduce the temporal stability of a reach.

Temperature Predictions

Stream temperature has been widely studied, and heat transfer is one of the better-understood processes in natural watershed systems. Most available approaches use energy balance formulations based on the physical processes of heat transfer to describe and predict changes in stream temperature. The six primary processes that transfer energy in the stream environment are (1) short-wave solar radiation, (2) long-wave solar radiation, (3) convection with the air, (4) evaporation, (5) conduction to the soil, and (6) advection from incoming water sources (e.g., ground-water seepage).

Several computer models that predict instream water temperature are currently available. These models vary in the complexity of detail with which site characteristics, including meteorology, hydrology, stream geometry, and riparian vegetation, are described. An instream surface water temperature model was developed by the U.S. Fish and Wildlife Service (Theurer et al., 1984) to predict mean daily temperature and diurnal fluctuations in surface water temperatures throughout a stream system. The model can be applied to any size watershed or river system. This predictive model uses either historical or synthetic hydrological, meteorological, and stream geometry characteristics to describe the ambient conditions. The purpose of the model is to predict the longitudinal temperature and its temporal variations. The instream surface water temperature model has been used satisfactorily to evaluate the impacts of riparian vegetation, reservoir releases, and stream withdrawal and returns on surface water temperature. In the Upper Colorado River Basin, the model was used to study the impact of temperature on endangered species (Theurer et al., 1982). It also has been used in smaller ungauged watersheds to study the impacts of riparian vegetation on salmonid habitat.

Index of Biological Integrity - Fish Habitat

Karr et al. (1986) describe an Index of Biological Integrity (IBI), which includes 12 matrices in three major categories of fish assemblage attributes: species composition, trophic composition, and fish abundance and condition. Data are collected at each site and compared to those collected at regional reference sites with relatively unimpacted biological conditions. A numerical rating is assigned to each metric based on its degree of agreement with expectations of biological condition provided by the reference sites. The sum of the metric ratings yields an overall score for the site. Application of the IBI requires a crew of two persons; field collections require 2 to 15 hours per station and data analysis about 1 to 2 hours, totaling 3 to 17 hours per station. The IBI, which was originally developed for Midwestern streams, can be readily adapted for use in other regions. It has been used in over two dozen States across the country to assess a wide range of impacts in streams and rivers.

Simon and Hupp Vegetative Recovery Model - Streamside Habitat

A component of Simon and Hupp's (1986, 1987) channel response model is the identification of specific groups of woody plants associated with each of the six geomorphic channel response stages. Their findings for western Tennessee streams suggest that the site preference or avoidance patterns of selected tree species allow their use as indicators of specific bank conditions. This method might require calibration for specific regions of the United States to account for differences in riparian zone plant communities, but it would allow simple vegetative reconnaissance of an area to be used for a preliminary estimate of stream recovery stage (Simon and Hupp, 1987).

b. Identify and evaluate appropriate BMPs for use in the design of proposed channelization or channel modification projects or in the operation and maintenance program of existing projects. Identify and evaluate positive and negative impacts of selected BMPs and include costs.

Operation and maintenance programs should include provisions to use one or more of the approaches described under Practice "b" of Management Measure A of this section. To prevent future impacts to instream or riparian habitat or to solve current problems caused by channelization or channel modification projects, include one or more of the following in an operation and maintenance program:

- Streambed protection;
- Levee protection;
- Channel stabilization and flow restrictors;
- Check dams;
- Vegetative cover;
- Instream sediment load control;
- Noneroding roadways; and
- Setback levees and flood walls.

Operation and maintenance programs should weigh the benefits of including practices such as these for mitigating any current or future impairments to instream or riparian habitat.

III. DAMS MANAGEMENT MEASURES

The second category of sources for which management measures and practices are presented in this chapter is dams. Dams are defined as constructed impoundments that are either (1) 25 feet or more in height *and* greater than 15 acre-feet in capacity, or (2) 6 feet or more in height *and* greater than 50 acre-feet in capacity.[1]

Based on this definition, there are 7,790 dams located in coastal counties of the United States, of which 6,928 dams are located in States with approved coastal zone programs (Quick and Richmond, 1992).

The siting and construction of a dam can be undertaken for many purposes, including flood control, power generation, irrigation, livestock watering, fish farming, navigation, and municipal water supply. Some reservoir impoundments are also used for recreation and water sports, for fish and wildlife propagation, and for augmentation of low flows. Dams can adversely impact the hydraulic regime, the quality of the surface waters, and habitat in the stream or river where they are located. A variety of impacts can result from the siting, construction, and operation of these facilities.

Dams are divided into the following classes: run-of-the-river, mainstem, transitional, and storage. A run-of-the-river dam is usually a low dam, with small hydraulic head, limited storage area, short detention time, and no positive control over lake storage. The amount of water released from these dams depends on the amount of water entering the impoundment from upstream sources. Mainstem dams, which include run-of-the-river dams, are characterized by a retention time of approximately 25 days and a reservoir depth of approximately 50 to 100 feet. In mainstem dams, the outflow temperature is approximately equal to the inflow temperature plus the solar input, thus causing a "warming" effect. Transitional dams are characterized by a retention time of about 25 to 200 days and a maximum reservoir depth of between 100 and 200 feet. In transitional dams, the outflow temperature is approximately equal to the inflow temperature so that during the warmer months coldwater fish cannot survive unless the inflows are cold. The storage dam is typically a high dam with large hydraulic head, long detention time, and positive control over the volume of water released from the impoundment. Dams constructed for either flood control or hydroelectric power generation are usually of the storage class. These dams typically have a retention time of over 200 days and a reservoir depth of over 100 feet. The outflow temperature is sufficient for coldwater fish, even with warm inflows.

The siting of dams can result in the inundation of wetlands, riparian areas, and fastland in upstream areas of the waterway. Dams either reduce or eliminate the downstream flooding needed by some wetlands and riparian areas. Dams can also impede or block migration routes of fish.

Construction activities from dams can cause increased turbidity and sedimentation in the waterway resulting from vegetation removal, soil disturbance, and soil rutting. Fuel and chemical spills and the cleaning of construction equipment (particularly concrete washout) have the potential for creating nonpoint source pollution. The proximity of dams to streambeds and floodplains increases the need for sensitivity to pollution prevention at the project site in planning and design, as well as during construction.

The operation of dams can also generate a variety of types of nonpoint source pollution in surface waters. Controlled releases from dams can change the timing and quantity of freshwater inputs into coastal waters. Dam operations may lead to reduced downstream flushing, which, in turn, may lead to increased loads of BOD, phosphorus, and nitrogen; changes in pH; and the potential for increased algal growth. Lower instream flows, and lower peak flows associated with controlled releases from dams, can result in sediment deposition in the channel several miles downstream of the dam. The tendency of dam releases to be clear water, or water without sediment, can result in erosion of the streambed and scouring of the channel below the dam, especially the smaller-sized sediments. One result is the siltation of gravel bars and riffle pool complexes, which are valuable spawning and nursery habitat for fish. Dams also limit downstream recruitment of suitably-sized substrate required for the anchoring and growth of aquatic plants.

[1] This definition is consistent with the Federal definition at 33 CFR 222.8(b)(1) (1991).

Finally, reservoir releases can alter the water temperature and lower the dissolved oxygen levels in downstream portions of the waterway.

The extent of changes in downstream temperature and dissolved oxygen from reservoir releases depends on the retention time of water in the reservoir and the withdrawal depth of releases from the reservoir. Releases from mainstem projects are typically higher in dissolved oxygen than are releases from storage projects. Storage reservoir releases are usually colder than inflows, while releases from mainstem reservoirs depend on retention time and depth of releases. Reservoirs with short hydraulic residence times have reduced impacts on tailwaters (Walburg et al., 1981).

It is important to note that the operation of dams can have positive, as well as negative, effects on water quality, aquatic habitat, and fisheries within the pool and downstream (USEPA, 1989). Potential positive effects include:

- Creation of above-the-dam summer pool refuge during low flows, an effect that has been documented for small dams built in the upper stream reaches of the Willamette River in the northwest United States (Li et al., 1983);
- Creation of reservoir sport fisheries (USDOI, 1983); and
- Less scouring and erosion of streambanks as a result of reduced velocities in downstream areas.

Once a river is dammed and a reservoir is created, processes such as stratification, seasonal overturn, chemical cycling, and sedimentation can intensify to create several NPS pollution problems. These processes occur primarily as a result of the presence of the dam, not the operation of the dam.

Stratification is the layering of a lake into an upper, well-lighted, productive, and warm layer, called the *epilimnion*; a mid-depth transitional layer, the *metalimnion*; and a lower, dark, cold, and unproductive layer, the *hypolimnion*. These layers are separated by a thermocline in the metalimnion, a sharp transition in water temperature between upper warm water and lower cold water (Figure 6-1). This stratification varies seasonally, being most pronounced in the summer and absent in the winter. Between these extremes are periods of less pronounced stratification and spring and fall overturns, when the entire waterbody mixes together. Poor mixing conditions, resulting in stratification, are estimated to occur in 40 percent of power impoundments and 37 percent of non-power impoundments (USEPA, 1989).

Dissolved oxygen levels are tied to the overturn, mixing, and stratification processes. Dissolved oxygen concentration in reservoir waters is the result of a delicate balance between both oxygen-producing and oxygen-consuming processes (Bohac and Ruane, 1990). Dissolved oxygen tends to become depleted in the hypolimnion due to decomposition of organic substances, algal respiration, and nitrification. The epilimnion, however, tends to be enriched with oxygen from the atmosphere and as a product of photosynthesis. The net difference between oxygen consumption and oxygen sources can create anoxic conditions in the lower layer (Figure 6-2).

Anoxic conditions in the hypolimnion may stimulate the formation of reduced species of iron, manganese, sulfur, and nitrogen. Chemical cycling of these elements occurs when they change from one state to another (e.g., from solid to dissolved). Many chemicals enter a reservoir attached to sediment particles or quickly become attached to sediment. As a solid, many chemicals typically are not toxic to many organisms, especially those in the water column. Some chemicals are easily reduced under anoxic conditions and become soluble. The reduced and soluble forms of many chemicals and compounds are toxic to most aquatic organisms at relatively low concentrations. For example, hydrogen sulfide is toxic to aquatic life and corrosive to construction materials at concentrations that are considerably lower than those detectable by commonly used procedures (Johnson et al., 1991). These reduced chemical compounds lead to taste and odor problems in drinking water supplies and toxicity problems for fish.

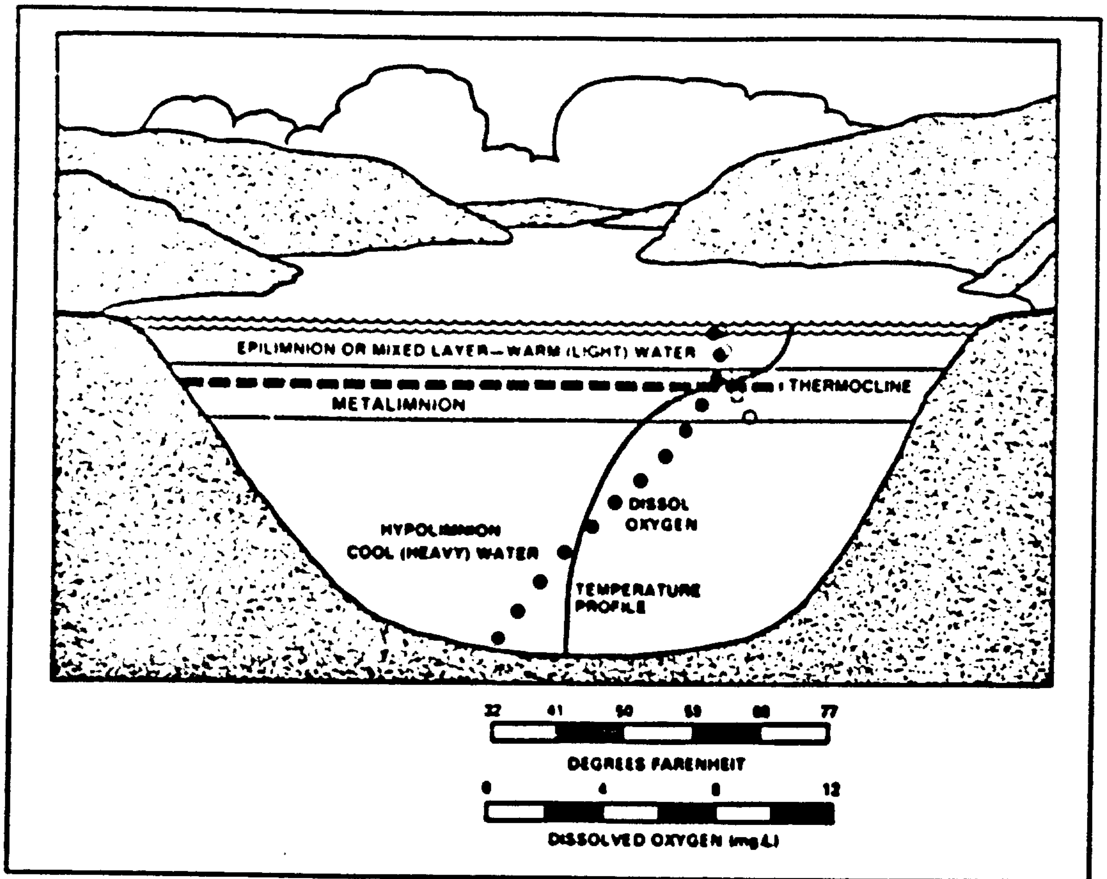

Figure 6-1. A cross-sectional view of a thermally stratified reservoir in mid-summer. The water temperature profile (curved solid line) illustrates how rapidly the water temperature decreases in the metalimnion compared to the nearly uniform temperatures in the epilimnion and hypolimnion. The solid circles represent the dissolved oxygen (DO) profile. The rate of organic matter decomposition is sufficient to deplete the DO content of the hypolimnion (USEPA, 1990).

Hydraulic residence time is defined as the average time required to completely renew a waterbody's water volume. For example, rivers have little or no hydraulic residence time, lakes with small volumes and high flow rates have short hydraulic residence times, and lakes with large volumes and low flow rates have long hydraulic residence times. Reservoirs differ from lakes in that, among other characteristics, their flow is regulated artificially. Hydraulic residence times of reservoirs are generally shorter than those of lakes, giving the water flowing into the reservoir less time to mix with the resident water.

The longer the hydraulic residence time, the greater the potential for incoming nutrients and sediment to settle in the reservoir. Conditions that lead to eutrophication in reservoirs promote increased algal growth, which in turn lead to a greater mass of dead plant cells. In reservoirs with long residence times, a major source of organic sediment settling to the bottom can be dead plant cells. Sediment will settle to the bottom; but, where reservoir releases are taken from the lower layer, they will release colder water downstream that is rich in nutrients, low in dissolved oxygen, and higher in some dissolved species such as iron, manganese, sulfur, and nitrogen.

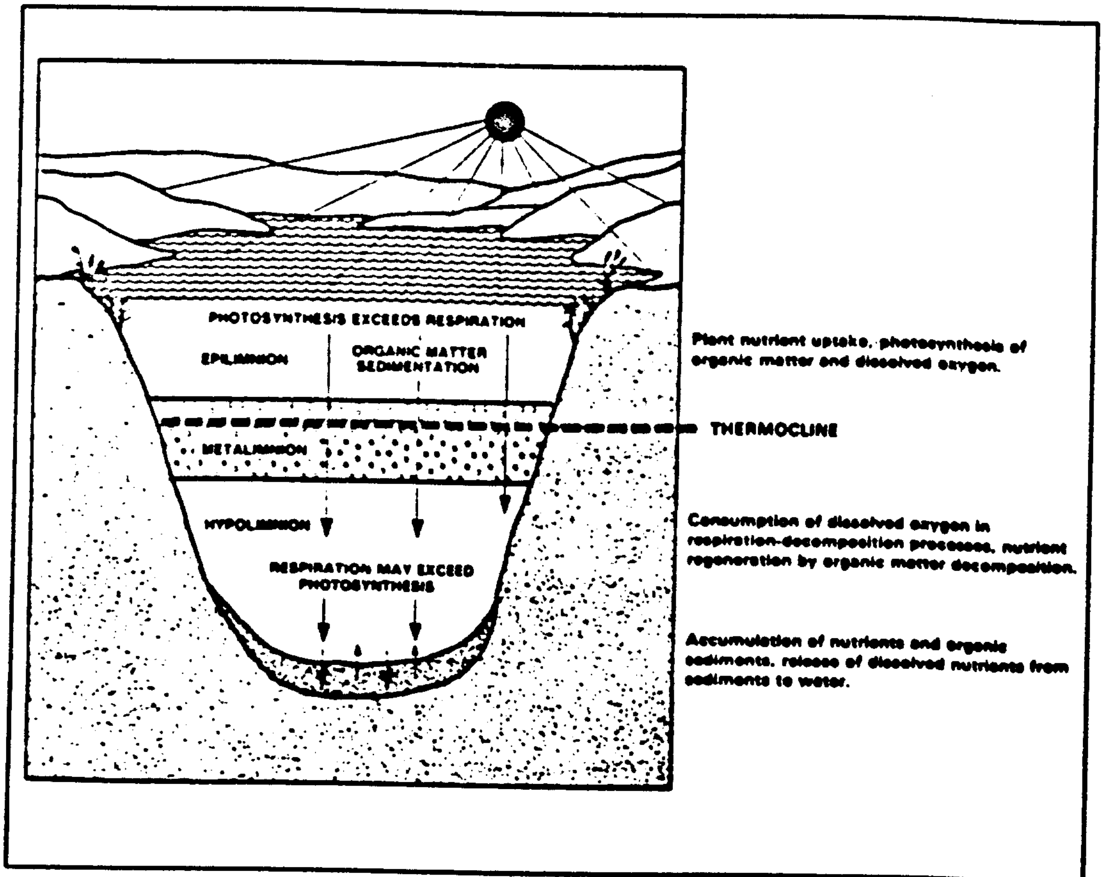

Figure 6-2. Influence of photosynthesis and respiration-decomposition processes and organic matter sedimentation on the distribution of nutrients and organic matter in a stratified reservoir (USEPA, 1990).

Management Measures A and B address two problems associated with the construction of dams:

(1) Increases in sediment delivery downstream resulting from construction and operation activities and
(2) Spillage of chemicals and other pollutants to the waterway during construction and operation.

The impacts of reservoir releases on the quality of surface waters and instream and riparian habitat in downstream areas is addressed in Management Measure III.C.

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(1) Reduce erosion and, to the extent practicable, retain sediment onsite during and after construction, and

(2) Prior to land disturbance, prepare and implement an approved erosion and sediment control plan or similar administrative document that contains erosion and sediment control provisions.

1. Applicability

This management measure is intended to be applied by States to the construction of new dams, as well as to construction activities associated with the maintenance of dams. Dams are defined[1] as constructed impoundments which are either:

(a) 25 feet or more in height *and* greater than 15 acre-feet in capacity, or
(b) six feet or more in height *and* greater than 50 acre-feet in capacity.

This measure also does not apply to projects that fall under NPDES jurisdiction. Under the Coastal Zone Act Reauthorization Amendments of 1990, States are subject to a number of requirements as they develop coastal NPS programs in conformity with this measure and will have some flexibility in doing so. The application of management measures by States is described more fully in *Coastal Nonpoint Pollution Control Program: Program Development and Approval Guidance*, published jointly by the U.S. Environmental Protection Agency (EPA) and the National Oceanic and Atmospheric Administration (NOAA) of the U.S. Department of Commerce.

2. Description

The purpose of this management measure is to prevent sediment from entering surface waters during the construction or maintenance of dams. Coastal States should incorporate this measure into existing State erosion and sediment control (ESC) programs or, if such programs are lacking, should develop them. States should incorporate this measure into ESC programs at the local level also. Erosion and sediment control is intended to be part of a comprehensive land use or watershed management program. (Refer to the Watershed and Site Development Management Measures in Chapter 4.)

Runoff from construction sites is the largest source of sediment in urban areas (Maine Department of Environmental Protection, Bureau of Water Quality, and York County Soil and Water Conservation District, 1990). Eroded sediment from construction sites creates many problems in coastal areas including adverse impacts to water quality, critical instream and riparian habitats, submerged aquatic vegetation (SAV) beds, recreational activities, and navigation.

[1] This definition is consistent with the Federal definition at 33 CFR 222.8(b)(1) (1991).

ESC plans are important for controlling the adverse impacts of dam construction. ESC plans ensure that provisions for control measures are incorporated into the site planning stage of development and provide for prevention of erosion and sediment problems and accountability if a problem occurs (Maine Department of Environmental Protection, 1990). Chapter 4 of this guidance presents a full description of construction-related erosion problems and the value of ESC plans. Readers should refer to Chapter 4 for further information.

3. Management Measure Selection

This management measure was selected because of the importance of minimizing sediment loss to surface waters during dam construction. It is essential that proper erosion and sediment control practices be used to protect surface water quality because of the high potential for sediment loss directly to surface waters.

Two broad performance goals constitute this management measure: minimizing erosion and maximizing the retention of sediment onsite. These performance goals give States and local governments flexibility in specifying practices appropriate for local conditions.

4. Practices

As discussed more fully at the beginning of this chapter and in Chapter 1, the following practices are described for illustrative purposes only. State programs need not require the implementation of these practices. However, as a practical matter, EPA anticipates that the management measure set forth above generally will be implemented by applying one or more management practices appropriate to the source, location, and climate. The practices set forth below have been found by EPA to be representative of the types of practices that can be applied successfully to achieve the management measure described above.

Practices for the control of erosion and sediment loss are discussed in Chapter 4 of this guidance and should be considered applicable to this management measure. Erosion controls are used to reduce the amount of sediment that is lost during dam construction and to prevent sediment from entering surface waters. Erosion control is based on two main concepts: (1) minimizing the area and time of land disturbance and (2) stabilizing disturbed soils to prevent erosion. The following practices have been found to be useful in these purposes and should be incorporated into ESC plans and used during dam construction as appropriate.

Additional discussions of the practices described below can be found in Chapter 4 of this guidance and should be referred to for more information.

■ ***a. Preserve trees and other vegetation that already exist near the dam construction site.***

This practice retains soil and limits runoff. The destruction of existing onsite vegetation can be minimized by initially surveying the site to plan access routes, locations of equipment storage areas, and the location and alignment of the dam. Construction workers should be encouraged to limit activities to designated areas. Reducing the disturbance of vegetation also reduces the need for revegetation after construction is completed, including the required fertilization, replanting, and grading that are associated with revegetation. Additionally, as much natural vegetation as possible should be left next to the waterbody where construction is occurring. This vegetation provides a buffer to reduce the NPS pollution effects of runoff originating from areas associated with the construction activities.

■ ***b. Control runoff from the construction site and construction-related areas.***

The largest surface water pollution problem during construction is turbidity resulting from aggregate processing, excavation, and concrete work. Preventing the entry of these materials into surface waters is always the preferable alternative because runoff due to these activities can adversely affect drinking water supplies, irrigation systems, and river ecology (Peters, 1978). If onsite treatment is necessary, methods are available to control the runoff of sediment and wastewater from the construction site. Sedimentation in settling ponds, sometimes with the addition of chemical precipitating agents, is one such method (Peters, 1978). Flocculation, the forced coagulation of fine-grained sediment through agitation to settle particles out of solution, is another method. Chemical precipitating agents can also be used in this flocculation process (Peters, 1978). Filtration with sand, anthracite, diatomaceous earth, or finely woven material, used singly or in combination, may be more useful than other methods for coarser grained materials (Peters, 1978).

c. *Control soil and surface water runoff during construction.*

To prevent the entry of sediment used during construction into surface waters, the following precautionary steps should be followed: identify areas with steep slopes, unstable soils, inadequate vegetation density, insufficient drainage, or other conditions that give rise to a high erosion potential; and identify measures to reduce runoff from such areas if disturbance of these areas cannot be avoided (Hynson et al., 1985). Refer to Chapter 4 for additional information.

Runoff control measures, mechanical sediment control measures, grassed filter strips, mulching, and/or sediment basins should be used to control runoff from the construction site. Scheduling construction during drier seasons, exposing areas for only the time needed for completion of specific activities, and avoiding stream fording also help to reduce the amount of runoff created during construction. Refer to Chapter 4 for additional information.

d. *Other practices*

Many other practices for the control of erosion and sediment loss are discussed in Chapter 4 of this guidance, which should be referred to for a complete discussion where noted. Below are brief descriptions of some of the other practices.

- **Revegetation.** Revegetation of construction sites during and after construction is the most effective way to permanently control erosion (Hynson et al., 1985). Many erosion control techniques are also intended to expedite revegetation.

- **Mulching.** Various mulching techniques are used in erosion control, such as use of straw, wood chip, or stone mulches; use of mulch nets or blankets; and hydromulching (Hynson et al., 1985). Mulching is used primarily to reduce the impact of rainfall on bare soil, to retain soil moisture, to reduce runoff, and often to protect seeded slopes (Hynson et al., 1985).

- **Soil Bioengineering.** Soil bioengineering techniques can be used to address the erosion resulting from dam operation. Grading or terracing a problem stream bank or eroding area and using interwoven vegetation mats, installed alone or in combination with structural measures, will facilitate infiltration stability. Refer to the section on shore protection in this chapter for additional information.

5. Effectiveness for All Practices

The effectiveness of erosion control practices can vary based on land slope, the size of the disturbed area, rainfall frequency and intensity, wind conditions, soil type, use of heavy machinery, length of time soils are exposed and unprotected, and other factors. In general, a system of erosion and sediment control practices can more effectively reduce offsite sediment transport than a single system. Numerous nonstructural measures such as protecting natural or newly planted vegetation, minimizing the disturbance of vegetation on steep slopes and other highly erodible areas, maximizing the distance eroded material must travel before reaching the drainage system, and locating roads away from sensitive areas may be used to reduce erosion. Chapter 4 has additional information for effectiveness of the practices listed above.

6. Costs for All Practices

Chapter 4 of this guidance contains the available cost data for most of the erosion controls listed above. Costs in Chapter 4 have been broken down into annual capital costs, annual maintenance costs, and total annual costs (including annualization of capital costs).

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(1) **Limit application, generation, and migration of toxic substances;**

(2) **Ensure the proper storage and disposal of toxic materials; and,**

(3) **Apply nutrients at rates necessary to establish and maintain vegetation without causing significant nutrient runoff to surface waters.**

1. Applicability

This management measure is intended to be applied by States to the construction of new dams, as well as to construction activities associated with the maintenance of dams. Dams are defined[3] as constructed impoundments which are either:

(a) 25 feet or more in height *and* greater than 15 acre-feet in capacity, or
(b) 6 feet or more in height *and* greater than 50 acre-feet in capacity.

This management measure addresses fuel and chemical spills associated with dam construction, as well as concrete washout and related construction activities. Under the Coastal Zone Act Reauthorization Amendments of 1990, States are subject to a number of requirements as they develop coastal NPS programs in conformity with this measure and will have some flexibility in doing so. The application of management measures by States is described more fully in *Coastal Nonpoint Pollution Control Program: Program Development and Approval Guidance*, published jointly by the U.S. Environmental Protection Agency (EPA) and the National Oceanic and Atmospheric Administration (NOAA) of the U.S. Department of Commerce.

2. Description

The purpose of this management measure is to prevent downstream contamination from pollutants associated with dam construction activities.

Although suspended sediment is the major pollutant generated at a construction site (USEPA, 1973), other pollutants include:

- Pesticides - insecticides, fungicides, herbicides, rodenticides;
- Petrochemicals - oil, gasoline, lubricants, asphalt;
- Solid wastes - paper, wood, metal, rubber, plastic, roofing materials;

[3] This definition is consistent with the Federal definition at 33 CFR 222.8(b)(1) (1991).

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- Construction chemicals - acids, soil additives, concrete-curing compounds;
- Wastewater - aggregate wash water, herbicide wash water, concrete-curing water, core-drilling wastewater, or clean-up water from concrete mixers;
- Garbage;
- Cement;
- Lime;
- Sanitary wastes; and
- Fertilizers.

A complete discussion of these pollutants can be found in Chapter 4 of this guidance.

3. Management Measure Selection

This management measure was selected because most erosion and sediment control practices are ineffective at retaining soluble NPS pollutants on a construction site. Many of the NPS pollutants, other than suspended sediment, generated at a construction site are carried offsite in solution or attached to clay particles in runoff (USEPA, 1973). Some metals (e.g., manganese, iron, and nickel) attach to sediment and usually can be retained onsite. Other metals (e.g., copper, cobalt, and chromium) attach to fine clay particles and have greater potential to be carried offsite. Insoluble pollutants (e.g., oils, petrochemicals, and asphalt) form a surface film on runoff water and can be easily washed away (USEPA, 1973).

A number of factors that influence the pollution potential of construction chemicals have been identified (USEPA, 1973). These include:

- The nature of the construction activity;
- The physical characteristics of the construction site; and
- The characteristics of the receiving water.

Dam construction sites are particularly sensitive areas and have the potential to severely impact surface waters with runoff containing construction chemical pollutants. Because dams are located on rivers or streams, pollutants generated at these construction sites have a much shorter distance to travel before entering surface waters. Therefore, chemicals and other NPS pollutants generated at a dam construction site should be controlled.

4. Practices

As explained more fully at the beginning of this chapter and in Chapter 1, the following practices are described for illustrative purposes only. State programs need not require the implementation of these practices. However, as a practical matter, EPA anticipates that the management measure set forth above generally will be implemented by applying one or more management practices appropriate to the source, location, and climate. The practices set forth below have been found by EPA to be representative of the types of practices that can be applied successfully to achieve the management measure described above.

Practices for the control of erosion and sediment loss are discussed in Chapter 4 of this guidance and should be considered applicable to this management measure.

a. Develop and implement a spill prevention and control plan. Agencies, contractors, and other commercial entities associated with the dam construction project that store, handle, or transport fuel, oil, or hazardous materials should have a spill response plan, especially if large quantities of oil or other polluting liquid materials are used.

Spill procedure information should be posted, and persons trained in spill handling should be onsite or on call at all times. Materials for cleaning up spills should be kept onsite and easily available. Spills should be cleaned up immediately and the contaminated material properly disposed of. Spill control plan components should include (Peters, 1978):

- Stopping the source of the spill;
- Containing any liquid;
- Covering the spill with absorbent material such as kitty litter or sawdust, but do not use straw; and
- Disposing of the used absorbent properly.

b. Maintain and wash equipment and machinery in confined areas specifically designed to control runoff.

Thinners or solvents should not be discharged into sanitary or storm sewer systems, or surface water systems, when cleaning machinery. Use alternative methods for cleaning larger equipment parts, such as high-pressure, high-temperature water washes or steam cleaning. Equipment-washing detergents can be used and wash water discharged into sanitary sewers if solids are removed from the solution first. Small parts should be cleaned with degreasing solvents that can then be reused or recycled. Do not discharge or otherwise dispose of any solvents into sewers, or into surface waters.

Washout from concrete trucks should be disposed of into:

- A designated area that will later be backfilled;
- An area where the concrete wash can harden, can be broken up, and can then be placed in a dumpster; or
- A location not subject to surface water runoff and more than 50 feet away from a receiving water.

Never dump washout directly into surface waters or into a drainage leading to surface waters.

c. Establish fuel and vehicle maintenance staging areas located away from surface waters and all drainages leading to surface waters, and design these areas to control runoff.

d. Store, cover, and isolate construction materials, refuse, garbage, sewage, debris, oil and other petroleum products, mineral salts, industrial chemicals, and topsoil to prevent runoff of pollutants and contamination of ground water.

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Develop and implement a program to manage the operation of dams in coastal areas that includes an assessment of:

(1) Surface water quality and instream and riparian habitat and potential for improvement and

(2) Significant nonpoint source pollution problems that result from excessive surface water withdrawals.

1. Applicability

This management measure is intended to be applied by States to dam operations that result in the loss of desirable surface water quality, and of desirable instream and riparian habitat. Dams are defined[4] as constructed impoundments which are either:

(a) 25 feet or more in height *and* greater than 15 acre-feet in capacity, or
(b) 6 feet or more in height *and* greater than 50 acre-feet in capacity.

This measure does not apply to projects that fall under NPDES jurisdiction. This measure also does not apply to the extent that its implementation under State law is precluded under *California* v. *Federal Energy Regulatory Commission*, 110 S. Ct. 2024 (1990) (addressing the supersedence of State instream flow requirements by Federal flow requirements set forth in FERC licenses for hydroelectric power plants under the Federal Power Act).

Under the Coastal Zone Act Reauthorization Amendments of 1990, States are subject to a number of requirements as they develop coastal NPS programs in conformity with this measure and will have some flexibility in doing so. The application of management measures by States is described more fully in *Coastal Nonpoint Pollution Control Program: Program Development and Approval Guidance*, published jointly by the U.S. Environmental Protection Agency (EPA) and the National Oceanic and Atmospheric Administration (NOAA) of the U.S. Department of Commerce.

2. Description

The purpose of this management measure is to protect the quality of surface waters and aquatic habitat in reservoirs and in the downstream portions of rivers and streams that are influenced by the quality of water contained in the releases (tailwaters) from reservoir impoundments. Impacts from the operation of dams to surface water quality and aquatic and riparian habitat should be assessed and the potential for improvement evaluated. Additionally, new upstream and downstream impacts to surface water quality and aquatic and riparian habitat caused by the implementation of practices should also be considered in the assessment. The overall program approach is to

[4] This definition is consistent with the Federal definition at 33 CFR 222.8(h)(1) (1991).

evaluate a set of practices that can be applied individually or in combination to protect and improve surface water quality and aquatic habitat in reservoirs, as well as in areas downstream of dams. Then, the program should implement the most cost-effective operations to protect surface water quality and aquatic and riparian habitat and to improve the water quality and aquatic and riparian habitat where economically feasible.

A variety of approaches have been developed and tested for their effectiveness at improving or maintaining acceptable levels of dissolved oxygen, temperature, phosphorus, and other constituents in reservoirs and tailwaters.

One general method uses pumps, air diffusers, or air lifts to induce circulation and mixing of the oxygen-poor, but cold hypolimnion with the oxygen-rich, but warm epilimnion. The desired result is a more thermally uniform reservoir with increased dissolved oxygen (DO) in the hypolimnion. Reservoir mixing improves water quality both in the reservoir and in tailwaters and helps to maintain the temperatures required by warm-water fisheries.

Another approach to improving water quality in tailwaters is appropriate if trout fisheries are desired downstream. In this approach, air or oxygen is mixed with water passing through the turbines of hydropower dams to increase the concentration of DO. Air or oxygen can be selectively added to impoundment waters entering turbine intakes. Reservoir waters can also be aerated by venting turbines to the atmosphere or by injecting compressed air into the turbine chamber.

A third group of approaches include engineering modifications to the intakes, the spillway, or the tailrace, or the installation of various types of weirs downstream of the dam to improve temperature or DO levels in tailwaters. These practices rely on agitation and turbulence to mix the reservoir releases with atmospheric air in order to increase the concentrations of dissolved oxygen. Selective withdrawal of water from different depths allows dam operators to maintain desired temperatures for fish and other aquatic species in downstream surface waters.

The quality of reservoir releases can also be improved through adjustments in the operational procedures at dams. These include scheduling releases or the duration of shutoff periods, instituting procedures for the maintenance of minimum flows, and making seasonal adjustments in the pool levels and in the timing and variation of the rate of drawdown.

Dam operators such as the Tennessee Valley Authority (TVA) further recognize the need for watershed management as a valuable tool to reduce water quality problems in reservoirs and dam releases. Reducing NPS pollutants coming from watersheds surrounding reservoirs can have a beneficial effect on concentrations of DO and pollutants within a reservoir and its tailwaters.

There is also a need for riparian habitat maintenance and restoration in the areas around the impounded reservoir and downstream from a dam. Reservoir shorelines are important riparian areas, and they need to be managed or restored to realize their many riparian habitat and water quality benefits. Examples of downstream aquatic habitat improvements include maintaining minimum instream flows, provid , scouring flows when and where needed, providing alternative spawning areas or fish passage, protecting streambanks from erosion, and maintaining wetlands and riparian areas.

The individual application of any particular technique, such as aeration, change in operational procedure, restoration of an aquatic or riparian habitat, or implementation of a watershed protection best management practice (BMP), will, by itself, probably not improve water quality to an acceptable level within the reservoir impoundment or in tailwaters flowing through downstream areas. The individual practices discussed in this portion of the guidance will usually have to be implemented in some combination in order to raise water quality in the impoundment or in tailwaters to acceptable levels.

One such combination of practices has addressed low DO levels at the Canyon Dam (Guadalupe River, Texas). A combination of turbine venting and a downstream weir was used to increase DO levels to acceptable levels. The concentration of dissolved oxygen in water entering the dam was measured at 0.5 mg/L. After passing through the turbine (but still upstream of the aeration weir), the DO concentration was raised to 3.3 mg/L. The concentration of the same water after passing through the aeration weir was 6.7 mg/L (EPRI, 1990).

Another combination of practices, consisting of a vacuum breaker turbine venting system and a stream flow reregulation weir, has been implemented at Norris Dam (Clinch River, Tennessee). The vacuum breaker aeration system uses hub baffles and appears to be the most successful design (EPRI, 1990). The baffles induce enough air to add from 2 mg/L to 4 mg/L to the discharge, while reducing turbine efficiency less than 0.5 percent. The downstream weir retains part of the discharge from the turbines when they are not in operation to sustain a stream flow of about 200 cubic feet per second (cfs). Prior to these improvements, the tailwaters of the Norris Dam had DO levels below 6 mg/L an average of 131 days per year and DO levels below 3 mg/L an average of 55 days per year. After installation of the turbine venting system and reregulation weir, DO levels were below 6 mg/L only 55 days per year and were above 3 mg/L at all times (TVA, 1988).

Combinations of increased flow, stream aeration, and wasteload reduction (from municipal and industrial sources) were found to be necessary to treat releases from the Fort Patrick Henry Dam (Holston River, Tennessee). An unsteady state flow and water quality model was used to simulate concentrations of dissolved oxygen in the 20-mile downstream reach from Fort Patrick Henry Dam and to explore water quality management alternatives. Several pollution abatement options were considered to identify the most cost-effective alternative. These options included changing wasteloads of the various dischargers, varying the flows from the reservoir, and improving aeration levels in water leaving the reservoir and in areas downstream. The modeling study identified flow regime modifications as more effective in improving DO than wasteload modifications. However, a decision to increase flow from the dam when stream levels are low might result in unacceptable reservoir drawdown in dry years. Although at some projects the increased DO will persist for many miles, improvements that were predicted by aeration of dam releases diminished rapidly at this particular site because they decreased the DO deficit and reduced natural reaeration rates. No wasteload treatments short of total recycle would achieve the 5-mg/L standard under base conditions (Hauser and Ruane, 1985).

3. Management Measure Selection

Selection of this management measure was based on:

(1) The availability and demonstrated effectiveness of practices to improve water quality in impoundments and in tailwaters of dams and

(2) The level of improvement in water quality of impoundments and tailwaters that can be measured from implementation of engineering practices, operational procedures, watershed protection approaches, or aquatic or riparian habitat improvements.

Successful implementation of the management measure will generally involve the following categories of practices undertaken individually or in combination to improve water quality and aquatic and riparian habitat in reservoir impoundments and in tailwaters:

- Artificial destratification and hypolimnetic aeration of reservoirs with deep withdrawal points that do not have multilevel outlets to improve dissolved oxygen levels in the impoundment and to decrease levels of other types of nonpoint source pollutants, such as manganese, iron, hydrogen sulfide, methane, ammonia, and phosphorus in reservoir releases (Cooke and Kennedy, 1989; Henderson and Shields, 1984);

- Aeration of reservoir releases, through turbine venting, injection of air into turbine releases, installation of reregulation weirs, use of selective withdrawal structures, or modification of other turbine start-up or pulsing procedures (Hauser and Ruane, 1985; Henderson and Shields, 1984);

- Providing both minimum flows to enhance the establishment of desirable instream habitat and scouring flows as necessary to maintain instream habitat (Kondolf et al., 1987; Walburg et al., 1981);

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- Establishing adequate fish passage or alternative spawning ground and instream habitat for fish species (Andrews, 1988); and

- Improving watershed protection by installing and maintaining BMPs in the drainage area above the dam to remove phosphorus, suspended sediment, and organic matter and otherwise improve the quality of surface waters flowing into the impoundment (Kortmann, 1989).

4. Introduction to Practices

As discussed more fully at the beginning of this chapter and in Chapter 1, the following practices are described for illustrative purposes only. State programs need not require the implementation of these practices. However, as a practical matter, EPA anticipates that the management measure set forth above generally will be implemented by applying one or more management practices appropriate to the source, location, and climate. The practices set forth below have been found by EPA to be representative of the types of practices that can be applied successfully to achieve the management measure described above.

5. Practices for Aeration of Reservoir Waters and Releases

The systems that have been developed and tested for reservoir aeration rely on atmospheric air, compressed air, or liquid oxygen to increase concentrations of dissolved oxygen in reservoir waters before they pass through the dam. Depending on the method selected, aeration can accomplish thorough mixing throughout the impoundment. However, this practice has not been used at large hydropower reservoirs because of the cost associated with aerating these large-flow reservoirs. Aeration will elevate levels of DO, but also will usually redistribute higher concentrations of algae found in the shallower depths and nutrients that are normally restricted to the deeper waters. It is not always desirable to have waters containing higher levels of algae and nutrients released into portions of the waterway below the dam (Kortmann, 1989). If the principal objective is to improve DO levels only in the reservoir releases and not throughout the entire impoundment, then aeration can be applied selectively to discrete layers of water immediately surrounding the intakes or as water passes through release structures such as hydroelectric turbines.

a. *Pumping and Injection Practices*

One method for deployment of circulation pumps is the U-tube design, in which water from deep in the impoundment is pumped to the surface layer. The inducement of artificial circulation through aeration of the impoundment may also provide the opportunity for a "two-story" fishery, reduce internal phosphorus loading, and eliminate problems with iron and manganese in drinking water (Cooke and Kennedy, 1989).

Air injection systems operate in a manner similar to that of pumping systems to mix water from different strata in the impoundment, except that air or pure oxygen is injected into the pumping system (Henderson and Shields, 1984). These kinds of systems are divided into two categories: partial air lift systems and full air lift systems. In the partial air lift system, compressed air is injected at the bottom of the unit; then, the air and water are separated at depth and the air is vented to the surface. In the full air lift system, compressed air is injected at the bottom of the unit (as in the partial air lift system), but the air-water mixture rises to the surface (Figure 6-3). The full air lift design has a higher efficiency than the partial-air lift and has a lesser tendency to elevate dissolved nitrogen levels (Cooke and Kennedy, 1989).

Diffused air systems provide effective transfer of oxygen to water by forcing compressed air through small pores in systems of diffusers to form bubbles (Figure 6-4). One test of a diffuser system in the Delaware River near Philadelphia, Pennsylvania, in 1969-1970 demonstrated the efficiency of this practice. Coarse-bubble diffusers were deployed at depths ranging from 13 to 38 feet. Depending on the depth of deployment, the oxygen transfer efficiency varied from 1 to 12 percent. When compared with other systems discussed below, this efficiency

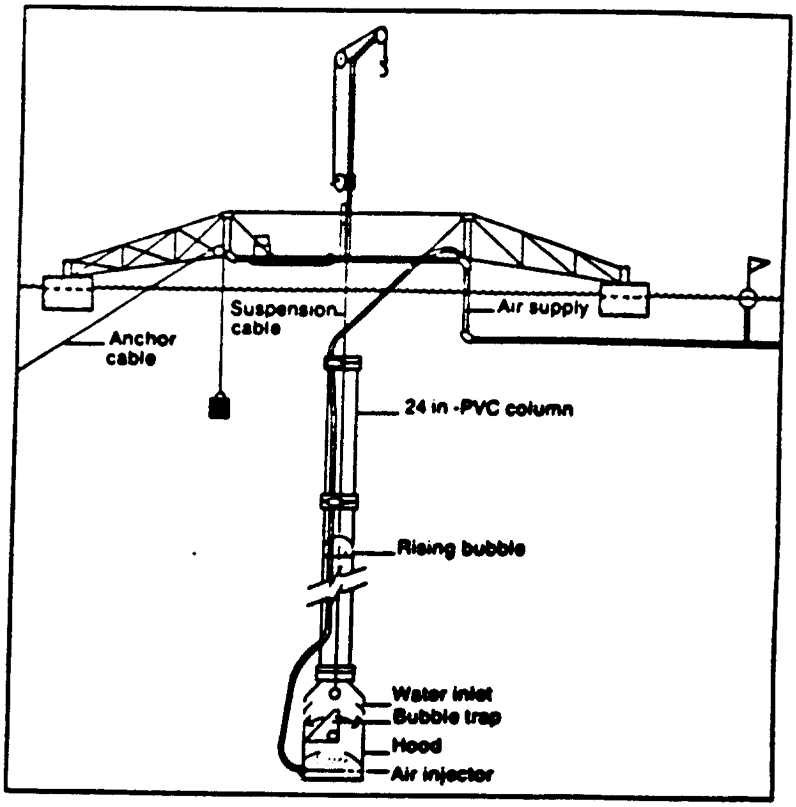

Figure 6-3. Air injection system for reservoir aeration-destratification (Nelson et al., 1978).

rate is rather low. But the results of this particular test determined that river aeration was more economical than advanced wastewater treatment as a strategy for improving the levels of DO in the river (EPRI, 1990).

Mechanical agitation systems operate by pumping water from the reservoir into a splash basin on shore, where it is aerated and then returned to the hypolimnion. Although these types of systems are comparatively inefficient, they have been used successfully (Wilhelms and Smith, 1981).

Localized mixing is a practice to improve releases of thermally stratified reservoirs by destratifying the reservoir in the immediate vicinity of the outlet structure. This practice differs from the practice of artificial destratification, where mixing is designed to destratify all or most of the reservoir volume (Holland, 1984). Localized mixing is provided by forcing a jet of high-quality surface water downward into the hypolimnion. Pumps used to create the jet generally fall into two categories, axial flow propellers and direct drive mixers (Price, 1989). Axial flow pumps usually have a large-diameter propeller (6 to 15 feet) that produces a high-discharge, low-velocity jet. Direct drive mixers have small propellers (1 to 2 feet) that rotate at high speeds and produce a high-velocity jet. The axial flow pumps are suitable for shallow reservoirs because they can force large quantities of water down to shallow depths. The high-momentum jets produced by direct drive mixers are necessary to penetrate deeper reservoirs (Price, 1989).

Water pumps have been used to move surface water containing higher concentrations of DO downward to mix with deeper waters as the two strata are entering the turbine. Aspirating surface aerators deployed in Lake Texoma

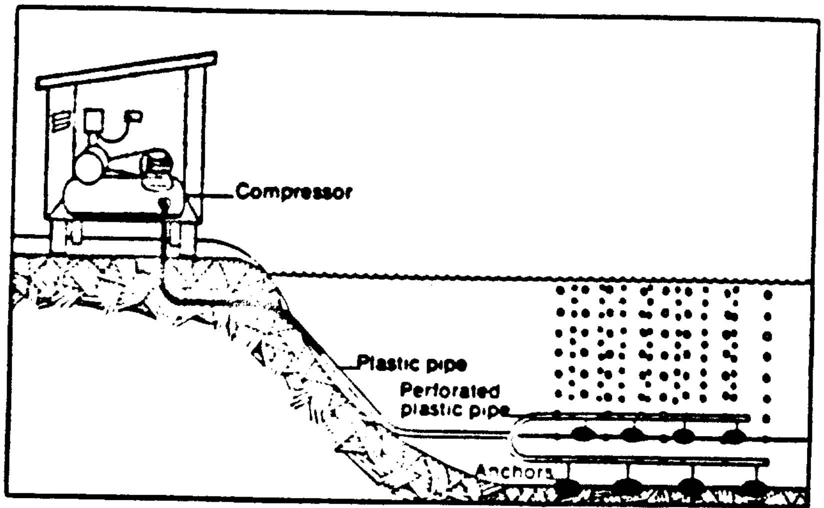

Figure 6-4. Compressed air diffusion system for reservoir aeration-destratification (Nelson et al., 1978).

(Texas/Oklahoma border) raised the levels of DO in the tailwaters from concentrations of 1.8 mg/L (without aerators) to 2.0 mg/L (with one 5-hp aeration unit in operation) and to 2.6 mg/L (with three 5-hp units operating).

A test of large-diameter axial-flow surface water pumps at Bagnell Dam (Lake of the Ozarks, Missouri) increased DO levels in the reservoir releases from 1.3 mg/L to 3.6 mg/L, before maintenance problems caused a discontinuance of use of the pumps (EPRI, 1990).

Small-diameter surface pumps, operated at the J. Percy Priest Dam (Tennessee), increased the DO levels in the tailwaters to 4.0 mg/L from a background level of 2.7 mg/L (EPRI, 1990).

Oxygen injection systems use pure oxygen to increase levels of dissolved oxygen in reservoirs. One type of design, termed side stream pumping, carries water from the impoundment onto the shore and through a piping system into which pure oxygen is injected. After passing through this system, the water is returned to the impoundment. Another type of system, which pumps gaseous oxygen into the hypolimnion through diffusers, has effectively improved DO levels in the reservoir behind the Richard B. Russell Dam (Savannah River, on the Georgia-South Carolina border). The system is operated 1 mile upstream of the dam, with occasional supplemental injection of oxygen at the dam face when DO levels are especially low. The system has successfully maintained DO levels above 6 mg/L in the releases, with an average oxygen transfer efficiency of 75 percent (EPRI, 1990; Gallagher and Mauldin, 1987).

The TVA has been testing the use of pure oxygen at the Douglas Dam (French Broad River, Tennessee) since 1988 (TVA, 1988). The absorption efficiencies measured in the downstream tailwaters range from 30 to 50 percent when the diffusers are arranged in a loose arc around the intakes. When the diffusers are placed tightly around the intakes, the efficiency range improves to 72 to 76 percent.

In another test at facilities operated by the Tennessee Valley Authority, diffusers were deployed to inject high-purity oxygen near the bottom of the 70-foot-deep reservoir at Fort Patrick Henry Dam (Holston River, Tennessee) near one of the turbine intakes. Levels of DO in the tailwaters increased from near 0 mg/L to 4 mg/L as a result of operation of this aeration system. Unfortunately, the operation costs of this kind of system were determined to be

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relatively high (Harshbarger, 1987). However, these results were very site-specific and every site needs to be evaluated for the best mix of solutions.

b. Turbine Venting

Turbine venting is the practice of injecting air into water as it passes through a turbine. If vents are provided inside the turbine chamber, the turbine will aspirate air from the atmosphere and mix it with water passing through the turbine as part of its normal operation. In early designs, the turbine was vented through existing openings, such as the draft tube opening or the vacuum breaker valve in the turbine assembly. Air forced by compressors into the draft tube opening enriched reservoir waters with little detectable DO to concentrations of 3 to 4 mg/L. Overriding the automatic closure of the vacuum breaker valve (at high turbine discharges) increased DO by only 2 mg/L (Harshbarger, 1987).

Turbine venting makes use of the low-pressure region just below the turbine wheel to aspirate air into the discharges (Wilhelms, 1984). Autoventing turbines are constructed with hub baffles, or deflector plates placed on the turbine hub upstream of the vent holes to enhance the low-pressure zone in the vicinity of the vent and thereby increase the amount of air aspirated through the venting system (Figure 6-5). Turbine efficiency relates to the amount of energy output from a turbine per unit of water passing through the turbine. Efficiency decreases as less power is produced for the same volume of water. In systems where the water is aerated before passing through the turbine, part of the water volume is displaced by the air, thus leading to decreased efficiency. Hub baffles have also been added to autoventing turbines at the Norris Dam to further improve the DO levels in the turbine releases (Jones and March, 1991).

Recent developments in autoventing turbine technology show that it may be possible to aspirate air with no resulting decrease in turbine efficiency. In one test of an autoventing turbine at the Norris Dam (Clinch River, Tennessee), the turbine efficiency increased by 1.8 percent (March et al., 1991; Waldrop, 1992). Technologies like autoventing turbines are very site-specific and outcomes will vary considerably. Achievement of desired DO levels at specific projects may require evaluation of several different technologies.

6. Practices to Improve Oxygen Levels in Tailwaters

In addition to the pumping and injection systems for reservoir aeration discussed in the preceding section, another set of systems can accomplish the aeration of water as it passes through the dam or through the portion of the waterway immediately downstream from the dam. The systems in this category rely on agitation and turbulence to mix the reservoir releases with atmospheric air in order to increase the concentrations of dissolved oxygen. Another approach involves the increased use of spillways, which release surface water to prevent it from overtopping the dam. The third approach is to install barriers called weirs in the downstream areas. Weirs designed to allow water to overtop them can increase DO through surface agitation and increased surface area contact. Some systems create supersaturation of dissolved gases and may require additional modifications to prevent supersaturation.

Two factors should be considered when evaluating the suitability of hydraulic structures such as spillways and weirs for their application in raising the DO concentration in waterways:

- Most of the measurements of DO increases associated with hydraulic structures have been collected at low-head facilities. The effectiveness of these devices may be limited as the level of discharge increases (Wilhelms, 1988).

- The hydraulic functioning of these types of structures should be carefully considered since undesirable flow conditions may occur in some instances (Wilhelms, 1988).

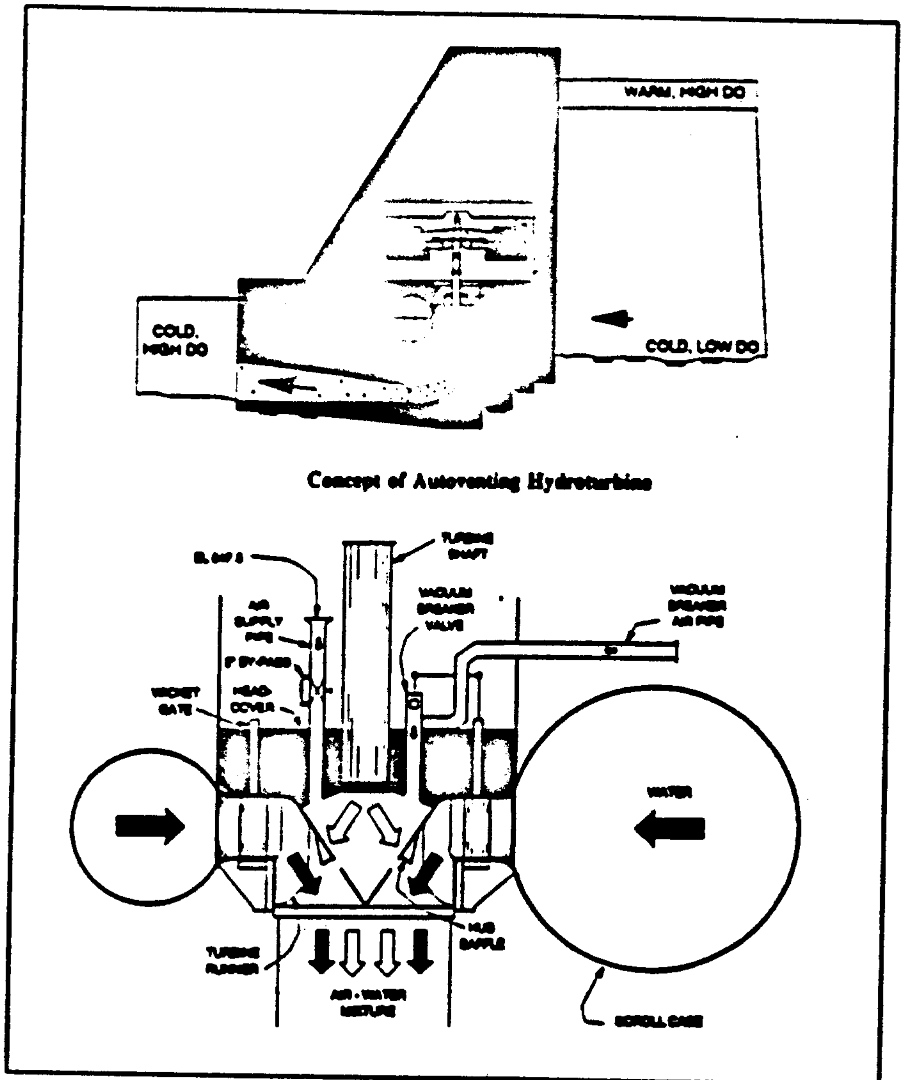

Figure 6-5. Top: Schematic drawing of an autoventing turbine. Bottom: Sketch of the hub baffle system used in the autoventing turbines at Norris Dam (French Broad River), Tennessee.(TVA-Engineering Laboratory, 1991.)

a. *Gated Conduits*

Gated conduits are hydraulic structures that divert the flow of water under the dam. They are designed to create turbulent mixing to enhance the rest of the oxygen transfer. Gates are used to control the cross-sectional area of flow. Gated conduits have been extensively analyzed for their performance and effectiveness (Wilhelms and Smith, 1981), although the available data are mostly from high-head projects (Wilhelms, 1988). In modeling studies, gated conduit structures have been found to achieve 90 percent aeration and a minimum DO standard of 5 mg/L (Wilhelms and Smith, 1981).

b. Spillways

The U.S. Army Corps of Engineers has studied the performance of spillways and overflow weirs at its facilities to determine the importance of these structures in improving DO levels. Increases in DO concentration of about 2.5 mg/L have been measured at the overflow weir of the Jonesville Lock and Dam (Ouachita River, Louisiana) (Wilhelms, 1988). Increases in DO concentrations of 3 mg/L have been measured at the overflow weir of the Columbia Lock and Dam (Ouachita River, Louisiana). Passage of water through the combinations of spillways and overflow weirs at these two facilities resulted in DO saturation levels of 85 to 95 percent in downstream waters (Wilhelms, 1988).

c. Spillway Modifications

At the Tellico Dam (Little Tennessee River, Tennessee), a siphon/underwater barrier dam was installed to improve DO and temperature conditions in the releases. The installed siphon draws about 8 cfs of cool water from the reservoir over the spillway into the Little Tennessee River. During the summer, the water forms a pool behind a 6-ft high underwater barrier dam and creates the temperature and oxygen concentrations needed by striped bass. The fish attracted to the pool provide a desirable sport fishery for the community (TVA, 1988).

The operation of some types of hydraulic structures has been tied to problems stemming from the supersaturation of some types of gases. An unexpected fish kill occurred in spring 1978 due to supersaturation of nitrogen gas in the Lake of the Ozarks (Missouri) within 5 miles of Truman Dam, caused by water plunging over the spillway and entraining air. The vertical drop between the spillway crest and the tailwaters was only 5 feet. The maximum saturation was 143 percent. In this case, the spillway was modified by cutting a notch to prevent water from plunging directly into the stilling basin (ASCE, 1986). At dams along the Columbia and Snake Rivers of the western United States, spillway deflectors have been found to be the most effective means for reducing nitrogen supersaturation (Bonneville Power Administration, 1991). The deflectors are designed to direct flows horizontally into the stilling basin to prevent deep plunging and air entrainment (ASCE, 1986).

Spill at hydroelectric dams is routinely required during periods of high runoff when the river discharge exceeds what can be passed through the powerhouse turbines. The Columbia River of Washington State has a series of 11 dams beginning with the Grand Coulee and ending with Bonneville. The Snake River also has four dams. If all of these dams were spilling simultaneously, the entire river would become and remain highly saturated with nitrogen gas since the water would pick up gas at each successive spilling project. The Corps of Engineers has proposed several practices for solving the gas supersaturation problem. These include (1) passing more headwater storage through turbines, installing new fish bypass structures, and installing additional power units to reduce the need for spill; (2) incorporating "flip-lip" deflectors in spillway-stilling basins (Figure 6-6), transferring power generation to high-dissolved-gas-producing dams, and altering spill patterns at individual dams to minimize nitrogen mass entrainment; and (3) collecting and transporting juvenile salmonids around affected river reaches. Only a few of these practices have been implemented (Tanovan, 1987).

d. Reregulation Weir

Reregulation weirs have been constructed from stone, wood, and aggregate. In addition to increasing the levels of DO in the tailwaters, reregulation weirs result in a more constant rate of flow farther downstream during periods when turbines are not in operation. A reregulation weir constructed downstream of the Canyon Dam (Guadalupe River, Texas) increased DO levels in waters leaving the turbine from 3.3 mg/L to 6.7 mg/L (EPRI, 1990).

The U.S. Army Corps of Engineers Waterways Experiment Station (Wilhelms, 1988) has compared the effectiveness with which various hydraulic structures accomplished the reaeration of reservoir releases. The study concluded that, whenever operationally feasible, more discharge should be passed over weirs to improve DO concentrations in releases. Although additional field tests are planned, current results indicate that overflow weirs aerate releases more effectively than low-sill spillways (Wilhelms, 1988).

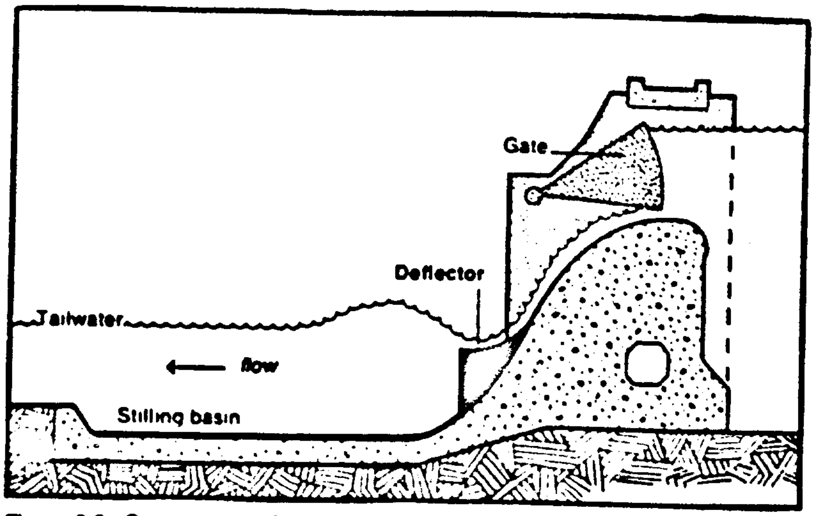

Figure 6-6. Cross section of a spillway with a "flip-lip" deflector (Nelson et al., 1978).

e. *Labyrinth Weir*

Labyrinth weirs have extended crest length and are usually W-shaped. These weirs spread the flow out to prevent dangerous undertows in the plunge pool. A labyrinth weir at South Holston Dam (Figure 6-7) was constructed for the dual purpose of providing minimum flows and improving DO in reservoir releases. The weir aerates to up to 60 percent of the oxygen deficit. For instance, projected performance at the end of the summer is an increase in the DO from 3 mg/L to 7 mg/L (or an increase of 4 mg/L) (Gary Hauser, TVA, personal communication, 1992). Actual increases in the DO will depend on the temperature and the level of DO in the incoming water.

7. Practices for Adjustments in the Operational Procedures of Dams for Improvement of Water Quality

The quality of reservoir releases can be improved through adjustments in the operational procedures at dams. These include scheduling of releases or of the duration of shutoff periods, instituting procedures for the maintenance of minimum flows, making seasonal adjustments in the pool levels or in the timing and variation of the rate of drawdown, selecting the turbine unit that most increases DO (often increasing the DO levels by 1 mg/L), and operating more units simultaneously (often increasing DO levels by about 2 mg/L). The magnitude and duration of reservoir releases also should be timed and scheduled so that the salinity regime in coastal waters is not substantially altered from historical patterns.

a. *Selective Withdrawal*

Temperature control in reservoir releases depends on the volume of water storage in the reservoir, the timing of the release relative to storage time, and the level from which the water is withdrawn. Dams capable of selectively releasing waters of different temperatures can provide cooler or warmer water temperature downstream at times that are critical for other instream resources, such as during periods of fish spawning and development of fry (Fontane et al., 1981; Hansen and Crumrine, 1991). Stratified reservoirs are operated to meet downstream temperature objectives such as to enhance a cold-water or warm-water fishery or to maintain preproject stream temperature conditions. Release temperature may also be important for irrigation (Fontane et al., 1981).

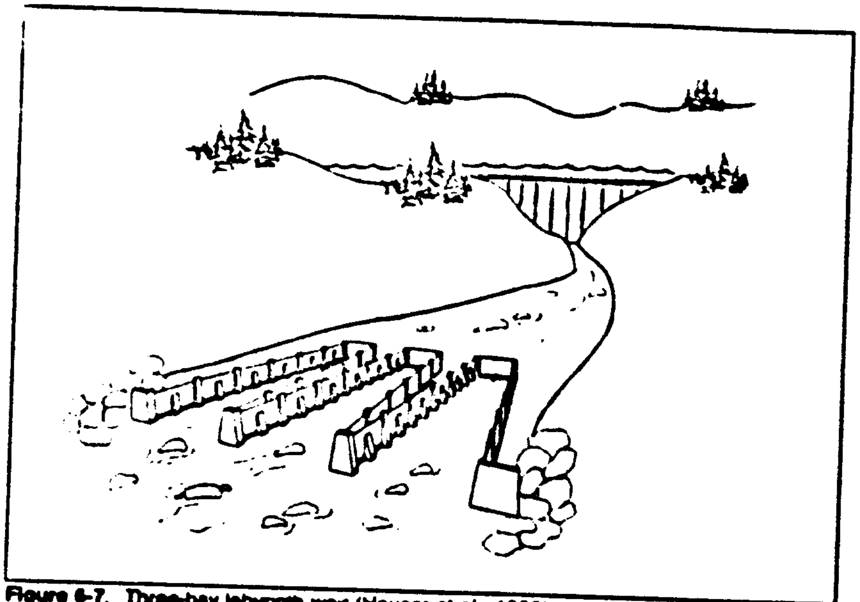

Figure 6-7. Three-bay labyrinth weir (Hauser et al., 1990).

Multilevel intake devices in storage reservoirs allow selective withdrawal of water based on temperature and DO levels. These devices minimize the withdrawal of surface water high in blue-green algae, or of deep water enriched in iron and manganese. Care should be taken in the design of these systems not to position the multilevel intakes too far apart because this will increase the difficulty with which withdrawals can be controlled, making the discharge of poor-quality hypolimnetic water more likely (Howington, 1990; Johnson and LaBounty, 1988; Smith et al., 1987).

b. Turbine Operation

Implementation of changes in the turbine start-up procedures can also enlarge the zone of withdrawal to include more of the epilimnetic waters in the downstream releases. Monitoring of the releases at the Walter F. George lock and dam (Chattahoochee River, Georgia), showed levels of DO declined sharply at the start-up of hydropower production. The severity and duration of the DO drop could be reduced by starting up all the generator units within a minute of each other (Findley and Day, 1987).

A useful tool for evaluating the effects of operational procedures on the quality of tailwaters is computer modeling. For instance, computer models can describe the vertical withdrawal zone that would be expected under different scenarios of turbine operation (Smith et al., 1987). Zimmerman and Dortch (1989) modeled release operations for a series of dams on a Georgia River and found that procedures that were maintaining cool temperatures in summer were causing undesirable decreases in DO and increases in dissolved iron in autumn. The suggested solution was a seasonal release plan that is flexible, depending on variations in the in-pool water quality and predicted local weather conditions. Care should be taken with this sort of approach to accommodate the needs of both the fishery resource and reservoir recreationalists, particularly in late summer.

Modeling has also been undertaken for a variety of TVA and Corps of Engineers facilities to evaluate the downstream impacts on DO and temperature that would result from changes in several operational procedures, including (Hauser et al., 1990a, 1990b; Higgins and Kim, 1982; Nestler et al., 1986b):

- Maintenance of minimum flows;
- Timing and duration of shutoff periods;

- Seasonal adjustments to the pool levels; and
- Timing and variation of the rate of drawdown.

8. Watershed Protection Practices

Most nonpoint source pollution problems in reservoirs and dam tailwaters frequently result from sources in the contributing watershed (e.g., sediment, nutrients, metals, and toxics). Management of pollution sources from a watershed has been found to be a cost-effective solution for improving reservoir and dam tailwater water quality (TVA, 1988). Practices for watershed management include land use planning, erosion control, ground-water protection, mine reclamation, NPS screening and identification, animal waste control, and failing septic tank control (TVA, 1988).

Another general watershed management practice involves the evaluation of the total watershed and the use of point/nonpoint source trading. Simply put, this practice involves the evaluation of the sources of pollution in a watershed and determination of the most cost-effective combination of practices to reduce pollution among the various point and nonpoint sources. Podar and others (1985) present an excellent example of point/nonpoint source trading as applied to the Holston River near Kingsport, Tennessee. Bender and others (1991) used modeling to evaluate the cost-effectiveness of various point/nonpoint source trading strategies for the Boone Reservoir in the upper Tennessee River Valley.

a. Land Use Planning

Land use plans that establish guidelines for permissible uses of land within a watershed serve as a guide for reservoir management programs addressing NPS pollution (TVA, 1988). Watershed land use plans identify suitable uses for land surrounding a reservoir, establish sites for economic development and natural resource management activities, and facilitate improved land management (TVA, 1988). Land use plans must be flexible documents that account for the needs of the landowners, State and local land use goals, the characteristics of the land and its ability to support various uses, and the control of NPS pollution (TVA, 1988). The watershed planning section of Chapter 4 contains additional information on land use planning.

b. Nonpoint Source Screening and Identification

The analysis and interpretation of stereoscopic color infrared aerial photographs can be used to find and map specific areas of concern where a high probability of NPS pollution exists from septic tank systems, animal wastes, soil erosion, and other similar types of NPS pollution (TVA, 1988). TVA has used this technique to survey about 25 percent of the Tennessee Valley to identify sources of nonpoint pollution in a period of less than 5 years at a cost of a few cents per acre (TVA, 1988).

c. Soil Erosion Control

Soil erosion has been determined to be the major source of suspended solids, nutrients, organic wastes, pesticides, and sediment that combined form the most problematic form of NPS pollution (TVA, 1988). Chapter 4 in this guidance contains an extensive selection of practices aimed at preventing soil erosion and controlling sediment from reaching surface waters in runoff.

d. Ground-Water Protection

Proper protection and management of ground-water resources primarily depends on the effective control of NPS pollution, particularly in ground-water recharge areas. Polluted ground water has the potential to contribute to surface-water pollution problems in reservoirs. Ground-water protection can be achieved only through public awareness of the problems associated with ground-water pollution and the potential of various activities to contaminate ground water. Identifying the ground-water resources in a watershed and developing a plan for protection of these resources are critical in establishing a good ground-water protection program. TVA (1988) has found that an extensive public outreach program is instrumental in the development of an effective ground-water protection program and in eventual protection of the resource.

e. Mine Reclamation

Abandoned mines have the potential to contribute significant sediment, metals, acidified water, and other pollutants to reservoirs (TVA, 1988). Old mines need to be located and reclaimed to reduce the NPS pollutants emanating from them. Revegetation is a cost-effective method of reclaiming denuded strip-mined lands, and agencies such as the Soil Conservation Service can provide technical insight for revegetation practices.

f. Animal Waste Control

A major contributor to reservoir pollution in some watersheds is wastes from animal confinement facilities. TVA (1988) estimated that in the Tennessee Valley, farms produced about six times the organic wastes of the population of the valley. A cooperative program was established to address the animal waste problem in the Tennessee Valley. The results of demonstration facilities in the Tennessee Valley reduced NPS pollution from animal wastes by 25,000 tons in the Duck River basin. The program also had the benefit of reducing the additional input of 1,400 tons of nitrogen and 200 tons of phosphorus to farm fields (TVA, 1988). Refer to Chapter 2 of this guidance for additional information on animal waste control practices.

g. Failing Septic Systems

Failing septic tank or onsite sewage disposal systems (OSDS) are another source of NPS pollution in reservoirs. TVA has found septic tank failures to be a problem in some of its reservoirs and has identified them through an aerial survey (TVA, 1988). Additional information on OSDS practices can be found in Chapter 4.

9. Practices to Restore or Maintain Aquatic and Riparian Habitat

Studies like the one undertaken by the U.S. Department of the Interior (USDOI, 1988) on the Glen Canyon Dam (Colorado River, Colorado) illustrate the potential for disruption to downstream aquatic and riparian habitat resulting from the operation of dams.

Several options are available for the restoration or maintenance of aquatic and riparian habitat in the area of a reservoir impoundment or in portions of the waterway downstream from a dam. One set of practices is designed to augment existing flows that result from normal operation of the dam. These include operation of the facility to produce flushing flows, minimum flows, or turbine pulsing. Another approach to producing minimum flows is to install small turbines that operate continuously. Installation of reregulation weirs in the waterway downstream from the dam can also achieve minimum flows. Finally, riparian improvements are discussed for their importance and effectiveness in restoring or maintaining aquatic and riparian habitat in portions of the waterway affected by the location and operation of a dam.

a. Flow Augmentation

Operational procedures such as flow regulation, flood releases, or fluctuating flow releases all have a detrimental impact on downstream aquatic and riparian habitat. Confounding the problem of aquatic and riparian habitat restoration is necessary for a balance of operational procedures to address the needs of downstream aquatic and riparian habitat with the requirements of dam operation. There are often legal and jurisdictional requirements for an operational procedure at a particular dam that should be considered (USDOI, 1988).

A flushing flow is a high-magnitude, short-duration release for the purpose of maintaining channel capacity and the quality of instream habitat by scouring the accumulation of fine-grained sediments from the streambed. For example,

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at Owens River in the Eastern Sierra Nevadas, California, a study found that wild salmonids prefer to deposit their eggs in streambed gravel free of fine sediments (Kondolf et al., 1987). Availability of suitable instream habitat is a key factor limiting spawning success. Flushing flows wash away the sediments without removing the gravel. Flushing flows also prevent the encroachment of riparian vegetation. According to a study of the Trinity River Drainage Basin in northwestern California (Nelson et al., 1987), remedial and maintenance flushing flows suppress riparian vegetation and maintain the stream channel dimensions necessary to provide instream habitat in addition to preventing large accumulations of sediment in river deltas. Recommendations for the use of flushing flows as part of an overall instream management program are becoming more common in areas downstream of water development projects in the western United States. For instance, Wesche and others (1987) used a sediment transport input-output model to determine the required flushing regimen for removing fine-grained sediments from portions of the Little Snake River that served as instream habitat for Colorado cutthroat trout. The flushing flows reduced the overall mass of sediment covering the channel bottom and removed the finer grained material, thereby increasing the size of the residual sediment forming the bottom streambed deposits.

However, it is important to keep in mind that flushing flows are not recommended in all cases. Flushing flows of a large magnitude may cause flooding in the old floodplain or depletion of gravel below the dam. Flushing flows are more efficient and predictable for small, shallow, high-velocity mountain streams unaltered by dams, diversions, or intensive land use. Routine maintenance generally requires a combination of practices including high flows coupled with sediment dams or channel dredging, rather than simply relying on flushing or scouring flows (Nelson et al., 1988).

Minimum flows are needed to keep streambeds wetted to an acceptable depth to support desired fish and wildlife. Since wetlands and riparian areas are linked hydrologically to adjoining streams, instream flows should be sufficient to maintain wetland or riparian habitat and function. Flushing and scouring flows may also be necessary to clean some streambeds and to provide the proper substrate for aquatic species.

In the design, construction, and operation of dams, the minimum flow requirements to support aquatic organisms and other water-dependent wildlife in downstream areas should be addressed. Minimum flow requirements are typically determined to protect or enhance one or a few harvestable species of fish (USDOI-FWS, 1976). Other fish, aquatic organisms, and riparian wildlife are usually assumed to be protected by these flows. For instance, when minimum flows at the Conowingo Dam (Susquehanna River, Maryland-Pennsylvania border) were increased from essentially zero to 5,000 cfs, up to a 100-fold increase was noted in the abundance of macroinvertebrates (USDOE, 1991). When minimum flows were increased from 1.0 cfs to 5.5 cfs at the Rob Roy Dam (Douglas Creek, Wyoming), there was a four- to six-fold increase in the number of brown trout (USDOE, 1991).

Flows at Rush Creek on the Eastern slope of the Sierra Nevadas in California have averaged about 50 percent of their prediversion levels (Stromberg and Patten, 1990). Since the construction of the Grant Lake Reservoir, the influence of flow rates and volumes on the growth of riparian trees has been studied. Stromberg and Patten (1990) found that a strong relationship exists between growth rates of riparian tree species and annual and prior-year flow volumes. If the level of growth needed to maintain populations is known, the relationship between growth and flow can be used to determine the instream flow needs of riparian vegetation. Instream models for Rush Creek suggest that requirements of riparian vegetation may be greater than requirements for fisheries.

Seasonal discharge limits can be established to prevent excessive, damaging rates of flow release. Limits can also be placed on the rate of change of flow and on the stage of the river (as measured at a point downstream of the dam facility) to further protect against damage to instream and riparian habitat.

Several options exist for establishing minimum flows in the tailwaters below dams. As indicated in the case studies described below, the selection of any particular technique as the most cost-effective depends on several factors including adequate performance to achieve the desired instream and riparian habitat characteristic, compatibility with other requirements for operation of the hydropower facility, availability of materials, and cost.

Sluicing is the practice of releasing water through the sluice gate rather than through the turbines. For portions of the waterway immediately below the dam, the steady release of water by sluicing provides minimum flows with the least amount of water expenditure. At some facilities, this practice may dictate that modifications be made to the existing sluice outlets to maintain continuous low releases.

Continuous low-level sluice releases at Eufala Lake and Fort Gibson Lake (Oklahoma) improved DO levels in tailwaters downstream of these two dams such that fish mortalities, which had been experienced in the tailwaters below these two dams prior to initiating this practice, no longer occurred (USDOE, 1991).

Turbine pulsing is a practice involving the release of water through the turbines at regular intervals to improve minimum flows. In the absence of turbine pulsing, water is released from large hydropower dams only when the turbines are operating, which is typically when the demand for power is high.

A study undertaken at the Douglas Dam (French Broad River, Tennessee) suggests some of the site-specific factors that should be considered when evaluating the advantages of practices such as turbine pulsing, sluicing, or other alternatives for providing minimum flows and improving DO levels in reservoir releases. Three options (turbine pulsing, sluicing, and operation of surface water pumps and diffusers) were evaluated for their effectiveness, advantages, and disadvantages in providing minimum flows and aeration of reservoir releases. Computer modeling indicated that either turbine pulsing or sluicing could improve DO concentrations in releases by levels ranging from 0.7 to 1.5 mg/L. (Based on studies cited in a previous section of this chapter, this is slightly below the level of improvement that might be expected from operation of a diffuser system for aeration.) A trade-off can also be expected at this facility between water saved by frequent short-release pulses and the higher maintenance costs due to setting turbines on and off frequently (Hauser et al., 1989). Hauser (1989) found that schemes of turbine pulsing ranging from 15-minute intervals to 60-minute intervals every 2 to 6 hours were found to provide fairly stable flow regimes after the first 3 to 8 miles downstream at several TVA projects. However, at points farther downstream, less overall flow would be produced by sluicing than by pulsing. Turbine pulsing may also cause waters to rise rapidly, which could endanger people wading or swimming in the tailwaters downstream of the dam (TVA, 1990).

A reregulation weir is one alternative that has been used to establish minimum flows for preservation of instream habitat. This device is installed in the streambed a short distance below a dam and captures hydropower releases. Flows through the weir can be regulated to produce the desired conditions of water level and flow velocities that are best for instream habitat. As discussed previously in this chapter, reregulation weirs can also be used in some circumstances to improve levels of dissolved oxygen in reservoir releases.

The installation of such an instream structure requires some degree of planning and design since the performance of the weir will affect both the downstream water surface elevation and the velocity of the discharge. These relationships have been investigated for the Buford Dam (Chattahoochee River, Georgia), where computer simulations of a proposed reregulation weir indicated that a discharge of 500 cfs created the best instream habitat conditions for juvenile brown trout. Instream habitat for adult brook trout, adult brown trout, and adult rainbow trout was most desirable at discharges in the vicinity of 1,000 to 2,000 cfs (Nestler et al., 1986a).

A reregulation weir was also found to be the most cost-effective alternative for providing a 90-cfs minimum flow below the Holston Dam (South Fork Holston River, Tennessee) for maintenance of instream trout habitat (Adams and Hauser, 1990). The weir was investigated as one alternative for establishing minimum flows, along with turbine pulsing and installation of a small generating unit in the existing tailrace that would operate at all times when the existing unit was not operating. The three alternatives were assessed for their effects on river hydraulics and on operation of the hydropower facility.

Small turbines are another alternative that has been evaluated for establishing minimum flows. Small turbines are capable of providing continuous generation of power using small flows, as opposed to operating large turbine units with the resultant high flows. In a study of alternatives for providing minimum flows at the Tims Ford Dam (Elk River, Tennessee), small turbines were found to represent the most attractive alternative from a cost-benefit perspective. The other alternatives evaluated included continuous operation of a sluice gate at the dam, pulsing of the existing turbines, and construction of an instream rock gabion regulating weir downstream of the dam (TVA, 1985).

b. Riparian Improvements

Riparian improvements are another strategy that can be used to restore or maintain aquatic and riparian habitat around reservoir impoundments or along the waterways downstream from dams. In fact, Johnson and LaBounty (1988) found that riparian improvements were more effective than flow augmentation for protection of instream habitat. In the Salmon River (Idaho), a variety of instream and riparian habitat improvements have been recommended to improve the indigenous stocks of chinook salmon. These include reducing sediment loading in the watershed, improving riparian vegetation, eliminating barriers to fish migration (see sections discussing this practice below), and providing greater instream and riparian habitat diversity (Andrews, 1988).

c. Aquatic Plant Management

One study of the Cherokee Reservoir (Holston River, Tennessee) reveals the potential importance of watershed protection practices for the improvement of water quality in the reservoir (Hauser et al., 1987). An improved two-dimensional model of reservoir water quality was used to investigate the advantages and disadvantages of several practices for improving temperature and DO levels in the reservoir.

10. Practices to Maintain Fish Passage

Migrating fish populations may suffer losses when passing through the turbines of hydroelectric dams unless these facilities have been equipped with special design features to accommodate fish passage. The effect of dams and other hydraulic structures on migrating fish has been studied since the early 1950s in an effort to develop systems or identify operating conditions that would minimize mortality rates. Despite extensive research, no single device or system has received regulatory agency approval for general use (Stone and Webster, 1986).

The safe passage of fish either upstream or downstream through a dam requires a balance between operation of the facility for its intended uses and implementation of practices that will ensure safe passage of fish. Rochester and others (1984) provide an excellent discussion of some of the economic and engineering considerations necessary to address the problems associated with the safe passage of fish.

Available fish-protection systems for hydropower facilities fall into one of four categories based on their mode of action (Stone and Webster, 1986): behavioral barriers, physical barriers, collection systems, and diversion systems. These are discussed in separate sections below, along with four additional practices that have been successfully used to maintain fish passage: spill and water budgets, fish ladders, transference of fish runs, and constructed spawning beds.

a. Behavioral Barriers

Behavioral barriers use fish responses to external stimuli to keep fish away from the intakes or to attract them to a bypass. Since fish behavior is notably variable both within and between species, behavioral barriers cannot be expected to prevent all fish from entering hydropower intakes. Environmental conditions such as high turbidity levels can obscure some behavioral barriers such as lighting systems and curtains. Competing behaviors such as feeding or predator avoidance can also be a factor influencing the effectiveness of behavioral barriers at a particular time.

Electric screens, bubble and chain curtains, light, sound, and water jets have been evaluated in laboratory or field studies, with mixed results. The results with system tests of strobe lights, poppers, and hybrid systems are the most promising, but these systems are still in need of further testing (Mattice, 1990). Experiences with some kinds of behavioral barrier systems are described more fully in the following paragraphs.

Electrical screens are intended to produce an avoidance response in fish. This type of fish-protection system is designed to keep fish away from structures or to guide them into bypass areas for removal. Fish seem to respond to the electrical stimulus best when water velocities are low. Tests of an electrical guidance system at the Chandler Canal diversion (Yakima River, Washington) showed the efficiency ranged from 70 to 84 percent for velocities of less than 1 ft/sec. Efficiencies decreased to less than 50 percent when water velocities were higher than 2 ft/sec (Pugh et al., 1971). The success of this type of system may also be species-specific and size-specific. An electrical field strength suitable to deter small fish may result in injury or death to large fish, since total fish body voltage is directly proportional to fish body length (Stone and Webster, 1986). This type of system requires constant maintenance of the electrodes and the associated underwater hardware in order to maintain effectiveness. Surface water quality, in particular, can affect the life and performance of the electrodes.

Air bubble curtains are created by pumping air through a diffuser to create a continuous, dense curtain of bubbles, which can cause an avoidance response in fish. Many factors affect the response of fish to air bubble curtains, including temperature, turbidity, light intensity, water velocity, and orientation in the channel. Bubbler systems should be constructed from materials that are resistant to corrosion and rusting. Installation of bubbler systems needs to consider adequate positioning of the diffuser away from areas where siltation could clog the air ducts.

Hanging chains are used to provide a physical, visible obstacle that fish will avoid. Hanging chains are both species-specific and lifestage-specific. Their efficiency is affected by such variables as instream flow velocity, turbidity, and illumination levels. Debris can limit the performance of hanging chains; in particular, buildup of debris can deflect the chains into a nonuniform pattern and disrupt hydraulic flow patterns.

Strobe lights repel fish by producing an avoidance response. A strobe light system at Saunders Generating Station in Ontario was rated 65 to 95 percent effective at repelling or diverting eels (Stone and Webster, 1986). Turbidity levels in the water can affect strobe light efficiency. The intensity and duration of the flash can also affect the response of the fish; for instance, an increase in flash duration has been associated with less avoidance. Strobe lights also have the potential for far-field fish attraction, since they can appear to fish as a constant light source due to light attenuation over a long distance (Stone and Webster, 1986).

Mercury lights are used to attract the fish as opposed to repelling them. Studies of mercury lights suggest their effectiveness is species-specific; alewives were attracted to a zone of filtered mercury light, whereas coho salmon and rainbow trout displayed no attraction to mercury light (Stone and Webster, 1986). Insufficient data are available to determine whether mercury lights are lifestage-specific. The device shows promise, but more research is being conducted to determine factors that affect performance and efficiency.

Underwater sound broadcast at different frequencies and amplitudes has been shown to be effective in attracting or repelling fish, although the results of field tests are not consistent. Fish have been attracted, repelled, or guided by the sound, and no conclusive response to sound has been observed. Not all fish possess the ability to perceive sound or localized acoustical sources (Harris and Van Bergeijk, 1962). Fish also frequently seem to become habituated to the sound source.

Poppers are pneumatic sound generators that create a high-energy acoustic output to repel fish. Poppers have been shown to be effective in repelling warm-water fish from water intakes. Laboratory and field studies conducted in California indicate good avoidance for several freshwater species such as alewives, perch, and smelt (Stone and Webster, 1986), but salmonids do not seem to be effectively repelled by this device (Stone and Webster, 1986). One important maintenance consideration is that internal "O" rings positioned between the air chambers have been found to wear out quickly. Other considerations are air entrainment in water inlets and vibration of structures associated with the inlets.

Water jet curtains can be used to create hydraulic conditions that will repel fish. Effectiveness is influenced by the angle at which the water is jetted. Although effectiveness averages 75 percent in repelling fish (Stone and Webster, 1986), not enough is known to determine what variables affect the performance of water jet curtains. Important concerns would be clogging of the jet nozzles by debris or rust and the acceptable range of flow conditions.

Hybrid barriers, or combinations of different barriers, can enhance the effectiveness of individual behavioral barriers. A chain net barrier combined with strobe lights has been shown in laboratory studies to be 90 percent effective at repelling fish. Combinations of rope-net and chain-rope barriers have also been tested with good results. Barriers with horizontal components as well as vertical components are more effective than those with vertical components alone. Barriers having elements with a large diameter are more effective than those with a small diameter, and thicker barriers are more effective than thinner barriers. Therefore, diameter and spacing of the barriers are factors influencing performance (Stone and Webster, 1986). With hanging chains, illumination appears to be a necessary factor to ensure effectiveness. Their effectiveness was increased with the use of strobe lights (Stone and Webster, 1986). Effectiveness also increased when strobe lights were added to air bubble curtains and poppers (Stone and Webster, 1986).

b. Physical Barriers

Physical barriers such as barrier nets and stationary screens can prevent the entry of fish and other aquatic organisms into the intakes at a generating facility. However, they should not be regarded as having much potential for application to promote fish bypass at hydroelectric dams for two reasons. First, the size of the mesh and the labor-intensive maintenance required to remove water-borne trash lower the feasibility of their use. Second, these barriers do little to assist fish in bypassing dams during migration (Mattice, 1990).

c. Fish Collection Systems

Collection systems involve capture of fish by screening and/or netting followed by transport by truck or barge to a downstream location (Figure 6-8). Since the late 1970s, the Corps of Engineers has successfully implemented a program that takes juvenile salmon from the uppermost dams in the Columbia River system (Pacific Northwest) and transports them by barge or truck to below the last dam. The program improves the travel time of fish through the river system, reduces most of the exposure to reservoir predators, and eliminates the mortality associated with passing through a series of turbines (van der Borg and Ferguson, 1989). Survivability rates for the collected fish are in excess of 95 percent, as opposed to survival rates of about 60 percent had the fish remained in the river system and passed through the dams (Dodge, 1989). However, the collection efficiency can range from 70 percent to as low as 30 percent. At the McNary Dam on the Columbia River, spill budgets are implemented (see below) when the collection rate achieves less than 70 percent efficiency (Dodge, 1989).

d. Fish Diversion Systems

Diversion systems lead or force fish to bypasses that transport them to the natural waterbody below the dam (USEPA, 1979). Physical diversion structures deployed at dams include traveling screens, louvers, angled screens, drum screens, and inclined plane screens. Most of these systems have been effectively deployed at specific hydropower facilities. However, a sufficient range of performance data is not yet available for categorizing the efficiency of specific designs in a particular set of site conditions and fish population assemblages (Mattice, 1990).

Angled screens are used to guide fish to a bypass by guiding them through the channel at some angle to the flow. Coarse-mesh angled screens have been shown to be highly effective with numerous warm- and cold-water species and adult stages. Fine-mesh angled screens have been shown in laboratory studies to be highly effective in diverting larval and juvenile fish to a bypass with resultant high survival. Performance of this device can vary by species, approach velocity, fish length, screen mesh size,screen type, and temperature (Stone and Webster, 1986).

Angled rotary drum screens oriented perpendicular to the flow direction have been used extensively to lead fish to a bypass. They have not experienced major operational and maintenance problems. Maintenance typically consists of routine inspection, cleaning, lubrication, and periodic replacement of the screen mesh (Stone and Webster, 1986).

An inclined plane screen is used to divert fish upward in the water column into a bypass. Once concentrated, the fish are transported to a release point below the dam. An inclined plane pressure screen at the T.W. Sullivan

Hydroelectric Project (Willamette Falls, Oregon) is located in the penstock of one unit. The design is effective in diverting fish, with a high survival rate. However, this device has been linked to injuries in migrating fish, and it has not been accepted for routine use (Stone and Webster, 1986).

Louvers consist of an array of evenly spaced, vertical slats aligned across a channel at an angle leading to a bypass. They operate by creating turbulence that fish are able to detect and avoid (Stone and Webster, 1986).

Submerged traveling screens are used to divert downstream migrating fish out of turbine intakes to adjoining gatewell structures, where they are concentrated for release downstream (Figure 6-9). This device has been tested extensively at hydropower facilities on the Snake and Columbia Rivers. Because of their complexity, submerged traveling screens must be continually maintained. The screens must be serviced seasonally, depending on the debris load, and trash racks and bypass orifices must be kept free of debris (Stone and Webster, 1986).

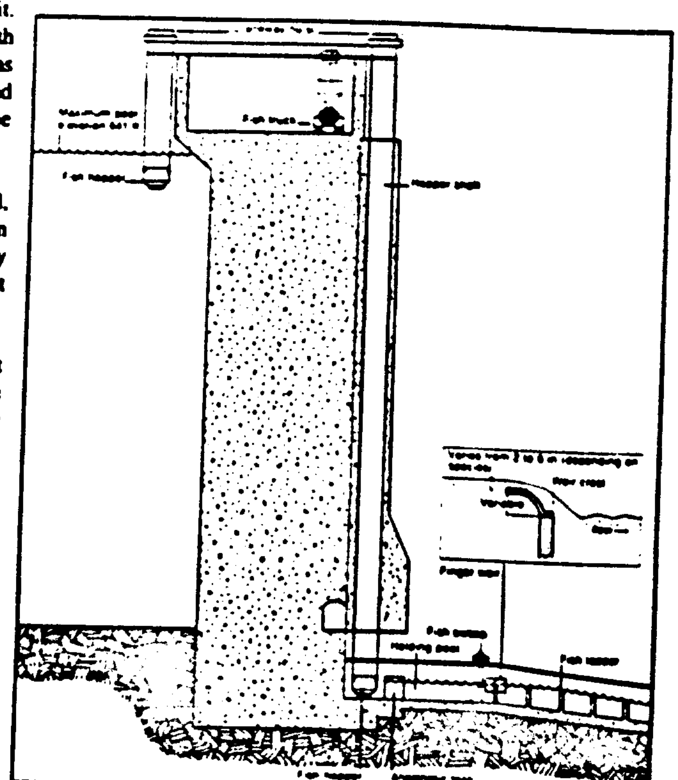

Figure 6-8. Trap and haul system for fish bypass of the Foster Dam, Oregon (Nelson et al., 1978).

e. Spill and Water Budgets

Although used together, spill and water budgets are independent methods of facilitating downstream fish migration.

The water budget is the mechanism for increasing flows through dams during the out-migration of anadromous fish species. It is employed to speed smolt migration through reservoirs and dams. Water that would normally be released from the impoundment during the winter period to generate power is instead released in the May-June period when it can be sold only as secondary energy. This concept has been put into practice in some regions of the United States, although quantification of the benefits is lacking (Dodge, 1989).

Spill budgets provide alternative methods for fish passage that are less dangerous than passage through turbines. Spillways are used to allow fish to leave the reservoir by passing over the dam rather than through the turbines. The spillways must be designed to ensure that hydraulic conditions do not induce injury to the passing fish from scraping and abrasion, turbulence, rapid pressure changes, or supersaturation of dissolved gases in water passing through plunge pools (Stone and Webster, 1986).

In the Columbia River basin (Pacific Northwest), the Corps of Engineers provides spill on a limited basis to pass fish around specific dams to improve survival rates. At key dams, spill is used in special operations to protect hatchery releases or provide better passage conditions until bypass systems are fully developed or, in some cases, improved (van der Borg and Ferguson, 1989). The cost of this alternative depends on the volume of water that is lost for power production (Mattice, 1990). Analyses of this practice, using a Corps of Engineers model called FISHPASS, show that the application of spill budgets in the Columbia River basin is consistently the most costly and least efficient method of improving overall downstream migration efficiency (Dodge, 1989).

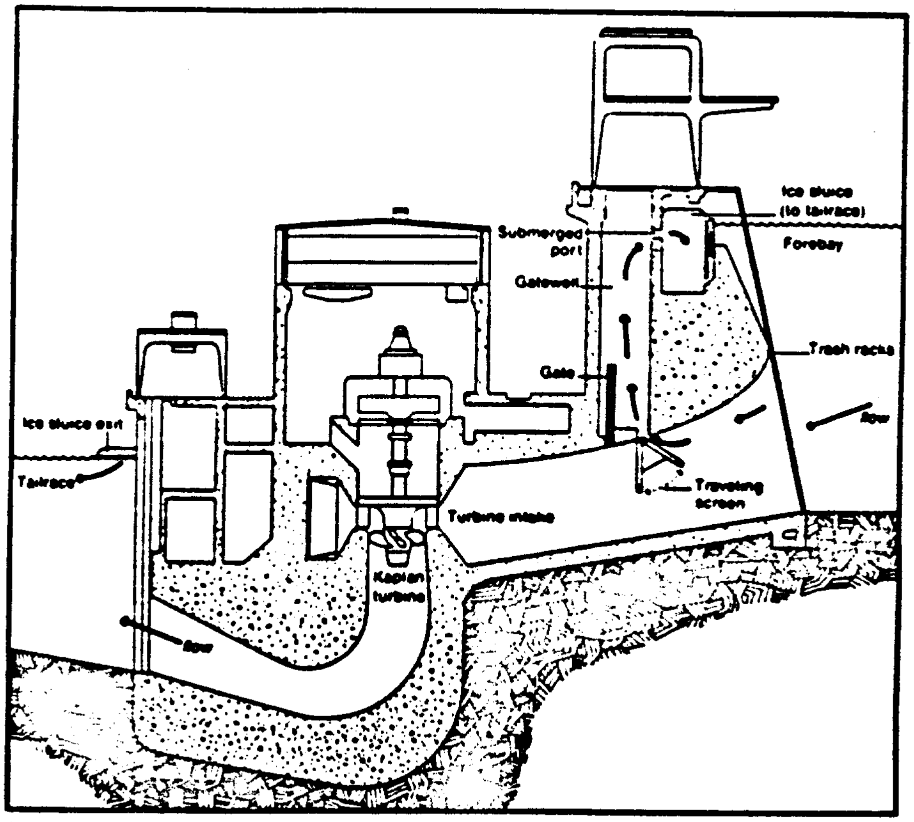

Figure 6-9. Cross section of a turbine bypass system used at Lower Granite and Little Goose Dams, Washington (Nelson et al., 1978).

The volume of a typical water budget is generally not adequate to sustain minimum desirable flows for fish passage during the entire migration period. The Columbia Basin Fish and Wildlife Authority has proposed replacement of the water budget on the Columbia River system with a minimum flow requirement to prevent problems of inadequate water volume in discharge during low-flow years (Muckleston, 1990).

f. Fish Ladders

Fish ladders are one type of structure that can be provided to enable the safe upstream and downstream passage of mature fish. One such installation in Maine consists of a vertical slot fishway, constructed parallel to the tailrace, which allows fish to pass from below the dam to the headwaters (ASCE, 1986). The fishway consists of a series of pools, each 8.5 feet by 10 feet in size, which ascend in 1-foot increments through the 40-foot rise from the tailwater area to the headwater area. When there is no flow in the spillway, fish can pass downstream through an 18-inch pipe. Flow is provided in the tailrace during fish migration season. Fish prefer to travel in these fishways at night under low illumination (Larinier and Boyer-Bernard, 1991).

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Information on the effectiveness of these types of structures is scarce and inconclusive, according to a study by the General Accounting Office (GAO, 1990). GAO noted that many studies of bypass facilities have emphasized data collection to document the number of juvenile fish entering the bypass structures and the condition of the individuals after passage is completed. Only two studies were identified in which bypass methods were compared with alternative methods to identify the most successful approaches. The observations collected at Lower Granite Dam and at Bonneville Dam (Columbia River) indicate a higher survival rate for young fish passing through turbines than for those passing through a bypass structure.

g. Transference of Fish Runs

Transference of fish runs involves inducing anadromous fish species to use different spawning grounds in the vicinity of the impoundment. To implement this practice, the nature and extent of the spawning grounds that were lost due to the blockage in the river need to be assessed, and suitable alternative spawning grounds need to be identified. The feasibility of successfully collecting the fish and transporting them to alternative tributaries also needs to be carefully determined.

One strategy for mitigating the impacts of diversions on fisheries is the use of ephemeral streams as conveyance channels for all or a portion of the diverted water. If flow releases are controlled and uninterrupted, a perennial stream is created, along with new instream and riparian habitat. However, the biota that had been adapted to preexisting conditions in the ephemeral stream will probably be eliminated. One case where an ephemeral stream was used to convey water and create alternative instream habitat for fish is along South Fort Crow Creek, in Medicine Bow National Forest, Wyoming. After 2 years of diversion, the amount of stream channel on an 88-km reach had increased 32 percent. Some measure of the success with which alternative instream habitat has replaced the original conditions can be seen in the total area of beaver ponds, which doubled within 2 years of completion of the project (Wolff et al., 1989).

h. Constructed Spawning Beds

When the adverse effects of a dam on the aquatic habitat of an anadromous fish species are severe, one option may be to construct suitable replacement spawning beds (Virginia State Water Control Board, 1979). Additional facilities such as electric barriers, fish ladders, or bypass channels will have to be furnished to channel the fish to these spawning beds.

11. Costs for All Practices

a. Costs for Minimum Flow Alternatives

In a comparisons of costs of minimum flows alternatives at South Fork Holston River, Adams and Hauser (1990) describe costs for a variety of practices, including an estimated total direct cost of $539,000 for a reregulating weir and $1,258,000 for a small hydro unit.

b. Costs for Hypolimnetic Aeration

The diffused air system is generally the most cost-effective method to raise low DO levels (Henderson and Shields, 1984; Cooke and Kennedy, 1989). However, the costs of air diffuser operation may be high for deep reservoirs because of hydraulic pressures that must be overcome. Any destratification that results from deployment of an air diffuser system will also mix nutrient-rich waters located deep in the impoundment into layers located closer to the surface, increasing the potential for stimulation of algal populations. The mixing must be complete to avoid problems with algal blooms (Cooke and Kennedy, 1989).

Fast and others (1976) and Lorenzen and Fast (1977) discuss costs of hypolimnetic aeration. The following are capital cost items for aeration systems: air lift devices, the compressor, the air supply lines, and the diffusers. The costs for these items are dependent on aerator size, which in turn is dependent on the need for oxygen in the reservoir impoundment (McQueen and Lean, 1986). Cooke and Kennedy (1989) reported side stream pumping costs (adjusted to 1990 dollars) were $347,023 (capital costs) and $167,240 (yearly operation and maintenance costs). Partial air lift system costs (adjusted to 1990 dollars) were reported by Cooke and Kennedy (1989) as $627,150 (capital costs) and $105,257 (operation and maintenance costs). Capital costs for full air lift systems ranged (in 1990 dollars) from $250,860 to $585,340, and operation and maintenance costs (in 1990 dollars) were reported as $44,862 (Cooke and Kennedy, 1989). In the opinion of Cooke and Kennedy (1989), the full air lift system is the least costly to operate and the most efficient. Furthermore, there is the potential for surface water quality problems caused by the supersaturation of nitrogen gas with the use of the partial air lift system (Fast et al., 1976). Accordingly, the full air lift system seems to be the overall best choice for aeration, based on cost, efficiency, and environmental impacts.

c. Costs for Diffusers

A cost-effective means of achieving better water quality for reservoir releases is to aerate discrete layers near the intakes to avoid any unnecessary release of algae and nutrients into tailwaters below the dam. In another test at facilities operated by the Tennessee Valley Authority (TVA), diffusers were deployed at the 70-foot depth of Fort Patrick Henry Dam near one of the turbine intakes. Levels of DO in the tailwaters increased from near zero to 4 mg/L as a result of operation of this aeration system. Unfortunately, the operation costs of this kind of system were determined to be relatively high. An operation system to increase the DO in the discharge from both hydroturbines at Fort Patrick Henry Dam to 5 mg/L would have an initial capital cost of $400,000 and an annual operating cost of $110,000 (Harshbarger, 1987).

The TVA has determined that approximately $44 million would be required to purchase and install aeration equipment at 16 TVA facilities (TVA, 1990). The aeration of reservoir waters, combined with other practices such as turbine pulsing, would result in the recovery of over 180 miles of instream habitat in areas below TVA dams. An additional $4 million per year in annual operating costs would also be required.

d. Costs for Aeration Weirs

The estimated costs for an aeration weir constructed downstream of the Canyon Dam (Guadalupe River, Texas) were $60,000. However, the construction of this device occurred at the same time as other construction at the facility, resulting in a reduction in overall project costs (EPRI, 1990).

e. Costs for Fish Bypass System

The Philadelphia Electric Company installed a fish lift system on the Conowingo Dam, located on the Susquehanna River at the head of the Chesapeake Bay. The fish lift system has the capacity of lifting 750,000 shad and 5 million river herring per year. The system was completed in 1991 at a total cost (adjusted to 1990 dollars) of $11.9 million (Nichols, 1992).

IV. STREAMBANK AND SHORELINE EROSION MANAGEMENT MEASURE

Streambank erosion is used in this guidance to refer to the loss of fastland along nontidal streams and rivers. *Shoreline erosion* is used in this guidance to refer to the loss of beach or fastland in tidal portions of coastal bays or estuaries. Erosion of ocean coastlines is not regarded as a substantial contributor of NPS pollution in coastal waterbodies and will not be considered in this guidance.

The force of water flowing in a river or stream can be regarded as the most important process causing erosion of a streambank. All of the eroded material is carried downstream and deposited in the channel bottom or in point bars located along bends in the waterway. The process is very different in coastal bays and estuaries, where waves and currents can sort the coarser-grained sands and gravels from eroded bank materials and move them in both directions along the shore, through a process called *littoral drift*, away from the area undergoing erosion. Thus, the materials in beaches of coastal bays and estuaries are derived from shore erosion somewhere else along the shore. Solving the erosion of the source area may merely create new problems with beach erosion over a much wider area of the shore.

The seepage of ground water and the overland flow of surface water runoff also contribute to the erosion of both streambanks and shorelines. The role of ground water is most important wherever permeable subsurface layers of sand or gravel are exposed in banks and high bluffs along streams, rivers, and coastal bays (Palmer, 1973; Leatherman, 1986; Figure 6-10). In these areas, the seepage of ground water into the waterway can cause erosion at the point of exit from the bank face, leading to bank failure. The surface flow of upland runoff across the bank face can also dislodge sediments through sheet flow, or through the creation of rills and gullies on the shoreline banks and bluffs.

The erosion of shorelines and streambanks is a natural process that can have either beneficial or adverse impacts on the creation and maintenance of riparian habitat. Sands and gravels eroded from streambanks are deposited in the channel and are used as instream habitat during the life stages of many benthic organisms and fish. The same materials eroded from the shores of coastal bays and estuaries maintain the beach as a natural barrier between the open water and coastal wetlands and forest buffers. Beaches are dynamic, ephemeral land forms that move back and forth onshore, offshore, and along shore with changing wave conditions (Bascom, 1964). The finer-grained silts and clays derived from the erosion of shorelines and streambanks are sorted and carried as far as the quiet waters of wetlands or tidal flats, where benefits are derived from addition of the new material.

There are also adverse impacts from shoreline and streambank erosion. Excessively high sediment loads can smother submerged aquatic vegetation (SAV) beds, cover shellfish beds and tidal flats, fill in riffle pools, and contribute to increased levels of turbidity and nutrients. However, there are few research results that can be used to identify levels below which streambank and shoreline erosion is beneficial and above which it is an NPS-related problem.

The Chesapeake Bay is one coastal waterbody for which sufficient data exist to characterize the relative importance of shore erosion as a source of sediment and nutrients (Ibison et al., 1990, 1992). Erosion of the shores above mean sea level contributes 6.9 million cubic yards of sediment per year, or 39 percent of the total annual sediment supply to the Chesapeake Bay (USACE, 1990). The contribution of nitrogen from shore erosion is estimated at 3.3 million pounds per year, which is 3.3 percent of the total nonpoint nitrogen load to the Bay. The contribution of phosphorus from shore erosion is estimated at 4.5 million pounds per year, which is approximately 46 percent of the total nonpoint phosphorus load to the Bay (USEPA-CBP, 1991).

For many watersheds, it will be necessary to consider four questions about streambank and shoreline erosion simultaneously in developing an NPS pollution reduction strategy:

(1) Is sediment derived from coastal erosion helping to maintain aquatic habitat elsewhere in the system?

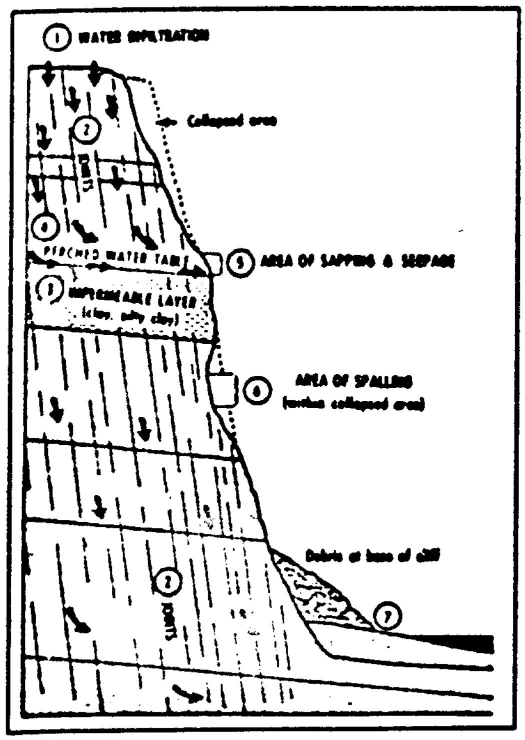
(2) Is coastal erosion a significant contributor of nonpoint sediment and nutrients?

(3) Is coastal erosion causing a loss of wetlands and riparian areas, with resultant loss of aquatic habitat and reduction of capacity to remove NPS pollutants from surface waters?

(4) Are activities along the shoreline and in adjacent surface waters increasing the rate of coastal erosion above natural (background) levels?

The answers to these questions will determine the emphasis that should be given to each of the three elements in the Management Measure for Eroding Streambanks and Shorelines.

Figure 6-10. The physical processes of bluff erosion in a coastal bay. 1. Water enters the ground by infiltration of rainwater or snowmelt. 2. Nearly vertical cracks called joints aid the downward movement of water. 3. Water moves toward the cliff face upon reaching an impermeable layer of sediment formed by clay. 4. A perched water table forms above the clay layer; the overlying sandy sediments become saturated with water. 5. As water seeps out of the cliff and runs down the cliff face, it may erode the sandy sediments above the clay layer, in a process called *sapping*. 6. *Spalling* is another process by which the bluff face breaks off along a more or less planar surface roughly parallel to the face. Spalling is continuous throughout the year, but it intensifies during the winter months when freezing and thawing occur along the joints and seepage zones. 7. Wave action at the base removes fallen debris, allowing cliff failure to continue. (After Leatherman, 1986.)



Management Measure for Eroding Streambanks and Shorelines

(1) Where streambank or shoreline erosion is a nonpoint source pollution problem, streambanks and shorelines should be stabilized. Vegetative methods are strongly preferred unless structural methods are more cost-effective, considering the severity of wave and wind erosion, offshore bathymetry, and the potential adverse impact on other streambanks, shorelines, and offshore areas.

(2) Protect streambank and shoreline features with the potential to reduce NPS pollution.

(3) Protect streambanks and shorelines from erosion due to uses of either the shorelands or adjacent surface waters.

1. Applicability

This management measure is intended to be applied by States to eroding shorelines in coastal bays, and to eroding streambanks in coastal rivers and creeks. The measure does not imply that all shoreline and streambank erosion must be controlled. Some amount of natural erosion is necessary to provide the sediment for beaches in estuaries and coastal bays, for point bars and channel deposits in rivers, and for substrate in tidal flats and wetlands. The measure, however, applies to eroding shorelines and streambanks that constitute an NPS problem in surface waters. It is not intended to hamper the efforts of any States or localities to retreat rather than to harden the shoreline. Under the Coastal Zone Act Reauthorization Amendments of 1990, States are subject to a number of requirements as they develop coastal NPS programs in conformity with this measure and will have some flexibility in doing so. The application of management measures by States is described more fully in *Coastal Nonpoint Pollution Control Program: Program Development and Approval Guidance*, published jointly by the U.S. Environmental Protection Agency (EPA) and the National Oceanic and Atmospheric Administration (NOAA) of the U.S. Department of Commerce.

2. Description

Several streambank and shoreline stabilization techniques will be effective in controlling coastal erosion wherever it is a source of nonpoint pollution. Techniques involving marsh creation and vegetative bank stabilization ("soil bioengineering") will usually be effective at sites with limited exposure to strong currents or wind-generated waves. In other cases, the use of engineering approaches, including beach nourishment or coastal structures, may need to be considered. In addition to controlling those sources of sediment input to surface waters which are causing NPS pollution, these techniques can halt the destruction of wetlands and riparian areas located along the shorelines of surface waters. Once these features are protected, they can serve as a filter for surface water runoff from upland areas, or as a sink for nutrients, contaminants, or sediment already present as NPS pollution in surface waters.

Stabilization practices involving vegetation or coastal engineering should be properly designed and installed. These techniques should be applied only when there will be no adverse effects to aquatic or riparian river habitat, or to the stability of adjacent shorelines, from stabilizing a source of shoreline sediments. Finally, it is the intent of this measure to promote institutional measures that establish minimum set-back requirements or measures that allow a buffer zone to reduce concentrated flows and promote infiltration of surface water runoff in areas adjacent to the shoreline.

3. Management Measure Selection

This management measure was selected for the following reasons:

(1) Erosion of shorelines and streambanks contributes significant amounts of NPS pollution in surface waters such as in the Chesapeake Bay;

(2) The loss of coastal land and streambanks due to shoreline and streambank erosion results in reduction of riparian areas and wetlands that have NPS pollution abatement potential; and

(3) A variety of activities related to the use of shorelands or adjacent surface waters can result in erosion of land along coastal bays or estuaries and losses of land along coastal rivers and streams.

4. Practices

As discussed more fully at the beginning of this chapter and in Chapter 1, the following practices are described for illustrative purposes only. State programs need not require the implementation of these practices. However, as a practical matter, EPA anticipates that the management measure set forth above generally will be implemented by applying one or more management practices appropriate to the source, location, and climate. The practices set forth below have been found by EPA to be representative of the types of practices that can be applied successfully to achieve the management measure described above.

Preservation and protection of shorelines and streambanks can be accomplished through many approaches, but preference in this guidance is for nonstructural practices, such as soil bioengineering and marsh creation.

■ a. ***Use soil bioengineering and other vegetative techniques to restore damaged habitat along shorelines and streambanks wherever conditions allow.***

Soil bioengineering is used here to refer to the installation of living plant material as a main structural component in controlling problems of land instability where erosion and sedimentation are occurring (USDA-SCS, 1992). Soil bioengineering largely uses native plants collected in the immediate vicinity of a project site. This ensures that the plant material will be well adapted to site conditions. While a few selected species may be installed for immediate protection, the ultimate goal is for the natural invasion of a diverse plant community to stabilize the site through development of a vegetative cover and a reinforcing root matrix (USDA-SCS, 1992).

Soil bioengineering provides an array of practices that are effective for both prevention and mitigation of NPS problems. This applied technology combines mechanical, biological, and ecological principles to construct protective systems that prevent slope failure and erosion. Adapted types of woody vegetation (shrubs and trees) are initially installed as key structural components, in specified configurations, to offer immediate soil protection and reinforcement. Soil bioengineering systems normally use cut, unrooted plant parts in the form of branches or rooted plants. As the systems establish themselves, resistance to sliding or shear displacement increases in streambanks and upland slopes (Schiechtl, 1980; Gray and Leiser, 1982; Porter, 1992).

Specific soil bioengineering practices include (USDA-SCS, 1992):

- **Live Staking.** Live staking involves the insertion and tamping of live, rootable vegetative cuttings into the ground (Figure 6-11). If correctly prepared and placed, the live stake will root and grow. A system of stakes creates a living root mat that stabilizes the soil by reinforcing and binding soil particles together and by extracting excess soil moisture. Most willow species are ideal for live staking because they root

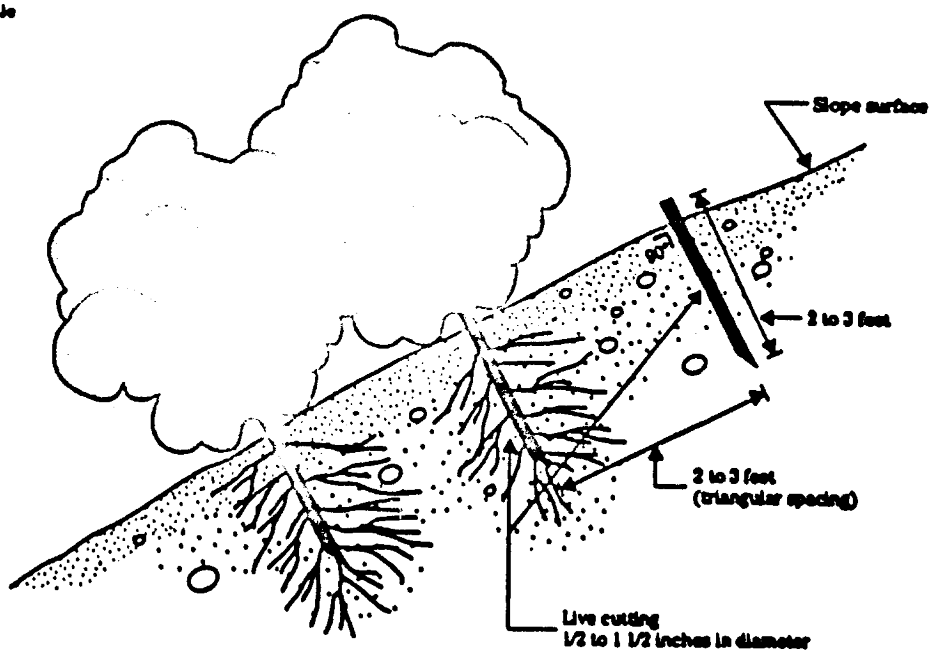


Figure 6-11. Schematic cross section of a live stake installation showing important design elements (USDA-SCS, 1992).

rapidly and begin to dry out a slope soon after installation. This is an appropriate technique for repair of small earth slips and slumps that frequently are wet.

- **Live Fascines.** Live fascines are long bundles of branch cuttings bound together into sausage-like structures (Figure 6-12). When cut from appropriate species and properly installed, they will root and immediately begin to stabilize slopes. They should be placed in shallow contour trenches on dry slopes and at an angle on wet slopes to reduce erosion and shallow face sliding. This system, installed by a trained crew, does not cause much site disturbance.

- **Brushlayering.** Brushlayering consists of placing live branch cuttings in small benches excavated into the slope. The width of the benches can range from 2 to 3 feet. The portions of the brush that protrude from the slope face assist in retarding runoff and reducing surface erosion. Brushlayering is somewhat similar to live fascine systems because both involve the cutting and placement of live branch cuttings on slopes. The two techniques differ principally in the orientation of the branches and the depth to which they are placed in the slope. In brushlayering, the cuttings are oriented more or less perpendicular to the slope

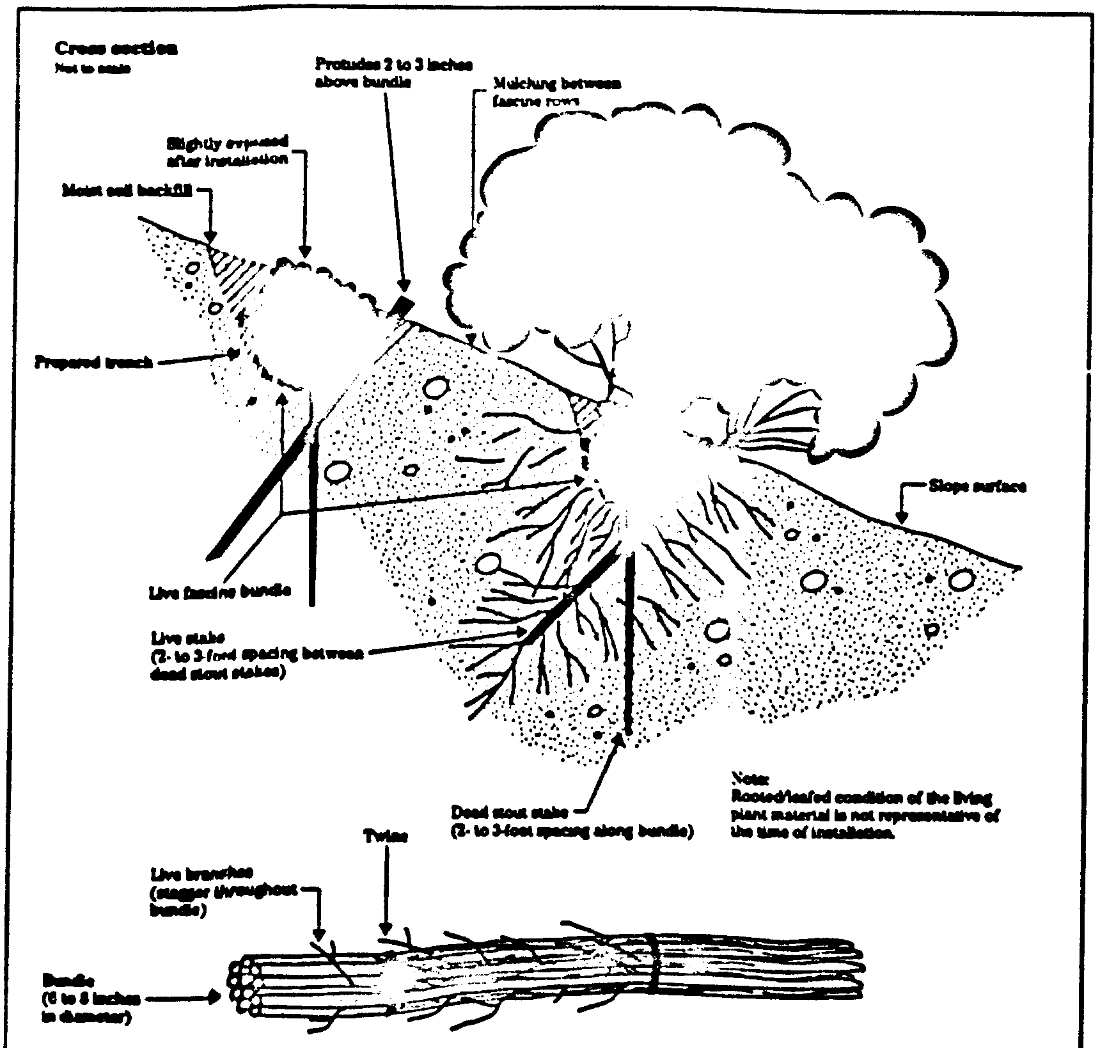


Figure 6-12. Schematic cross section of a live fascine showing important design elements (USDA-SCS, 1992).

contour. In live fascine systems, the cuttings are oriented more or less parallel to the slope contour. The perpendicular orientation is more effective from the point of view of earth reinforcement and mass stability of the slope.

- **Brush Mattressing.** Brush mattressing is commonly used in Europe for streambank protection. It involves digging a slight depression on the bank and creating a mat or mattress from woven wire or single strands of wire and live, freshly cut branches from sprouting trees or shrubs. Branches up to 2.5 inches in diameter are normally cut 3 to 10 feet long and laid in criss-cross layers with the butts in alternating directions to create a uniform mattress with few voids. The mattress is then covered with wire secured with wooden stakes up to 3 feet long. It is then covered with soil and watered repeatedly to fill voids with soil and facilitate sprouting; however, some branches should be left partially exposed on the surface. The structure may require protection from undercutting by placement of stones or burial of the lower edge. Brush mattresses are generally resistant to waves and currents and provide protection from the digging out of plants by animals. Disadvantages include possible burial with sediment in some situations and difficulty in making later plantings through the mattress.

- **Branchpacking**. Branchpacking consists of alternating layers of live branch cuttings and compacted backfill to repair small localized slumps and holes in slopes (Figure 6-13). Live branch cuttings may range from 1/2 inch to 2 inches in diameter. They should be long enough to touch the undisturbed soil at the back of the trench and extend slightly outward from the rebuilt slope face. As plant tops begin to grow, the branchpacking system becomes increasingly effective in retarding runoff and reducing surface erosion. Trapped sediment refills the localized slumps or holes, while roots spread throughout the backfill and surrounding earth to form a unified mass.

- **Joint Planting**. Joint planting (or vegetated riprap) involves tamping live cuttings of rootable plant material into soil between the joints or open spaces in rocks that have previously been placed on a slope (Figure 6-14). Alternatively, the cuttings can be tamped into place at the same time that rock is being placed on the slope face.

- **Live Cribwalls**. A live cribwall consists of a hollow, box-like interlocking arrangement of untreated log or timber members (Figure 6-15). The structure is filled with suitable backfill material and layers of live branch cuttings, which root inside the crib structure and extend into the slope. Once the live cuttings root

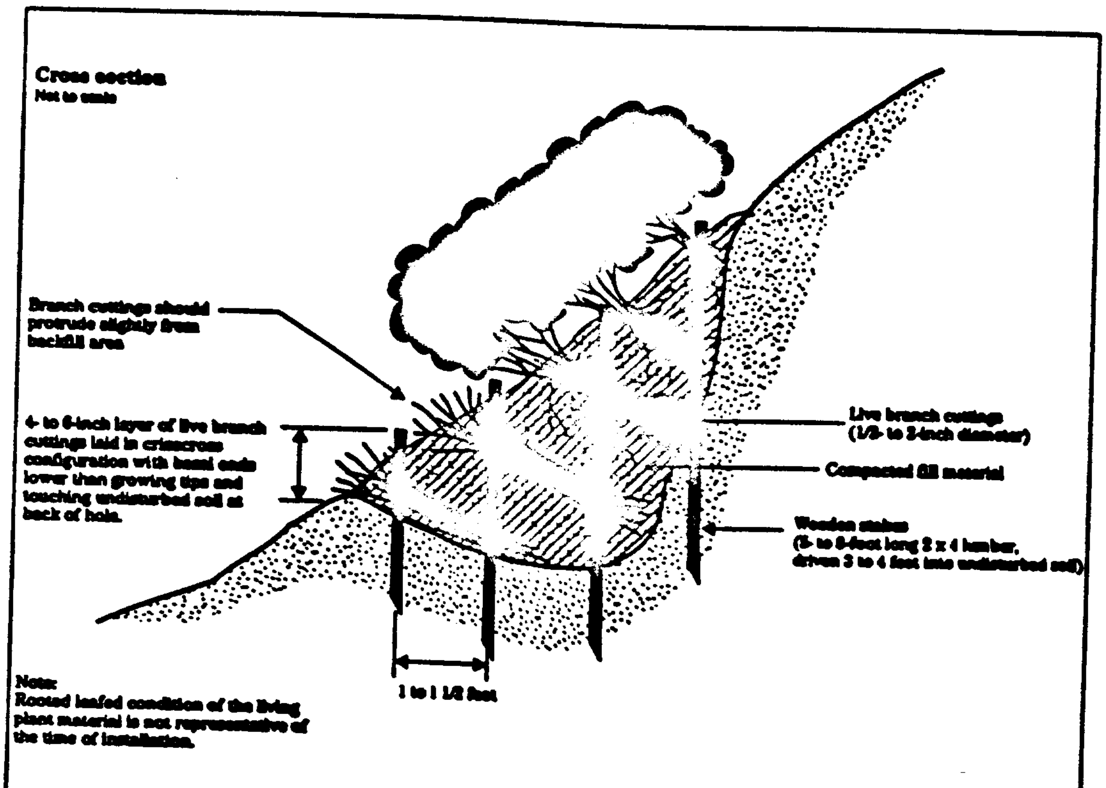


Figure 6-13. Schematic cross section of a branchpacking system showing important design details (USDA-SCS, 1992).

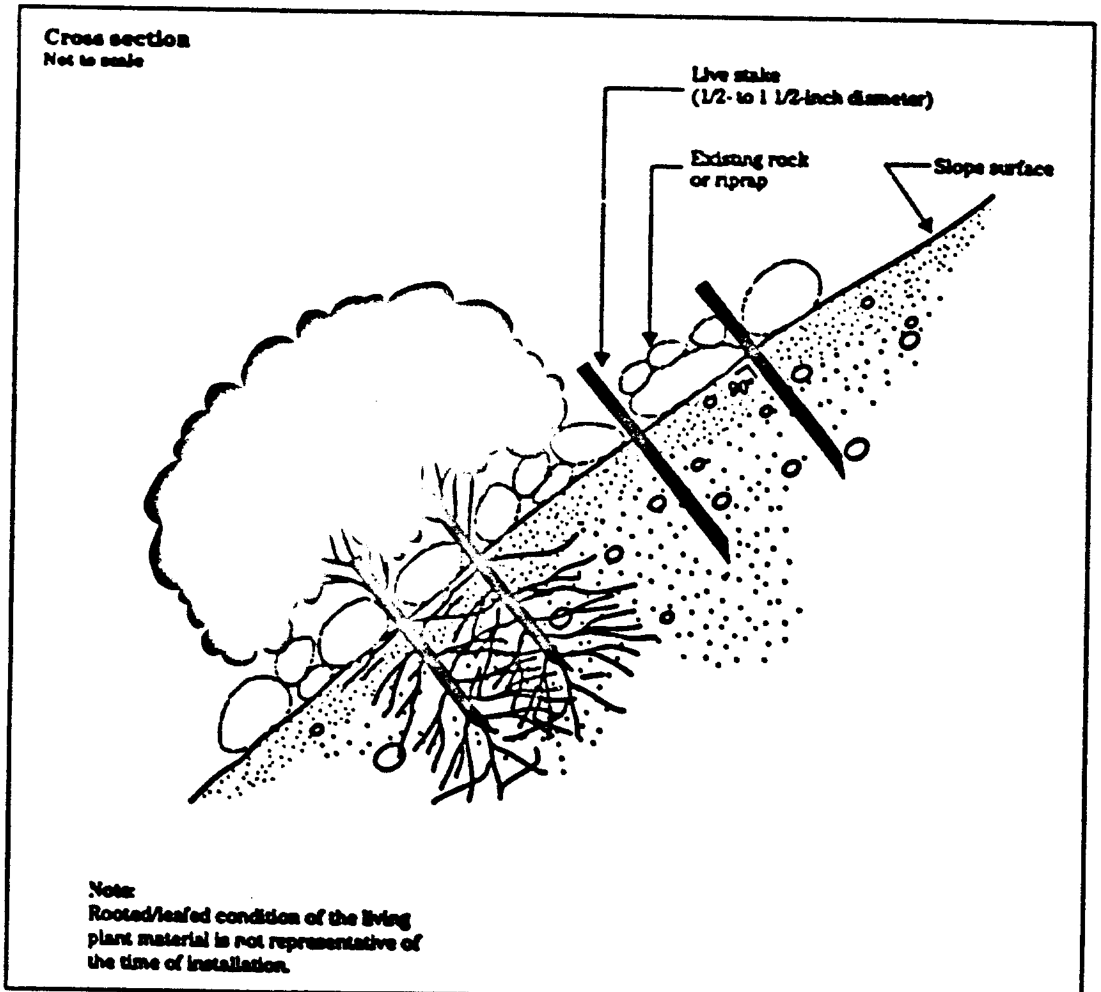


Figure 6-14. Schematic cross section of a joint planting system showing important design elements (USDA-SCS, 1992).

and become established, the subsequent vegetation gradually takes over the structural functions of the wood members.

These techniques have been used extensively in Europe for streambank and shoreline protection and for slope stabilization. They have been practiced in the United States only to a limited extent primarily because other engineering options, such as the use of riprap, have been more commonly accepted practices (Allen and Klimas, 1986). With the costs of labor, materials, and energy rapidly rising in the last two decades, however, less costly alternatives of stabilization are being pursued as alternatives to engineering structures for controlling erosion of streambanks and shorelines.

Additionally, bioengineering has the advantage of providing food, cover, and instream and riparian habitat for fish and wildlife and results in a more aesthetically appealing environment than traditional engineering approaches (Allen and Klimas, 1986).

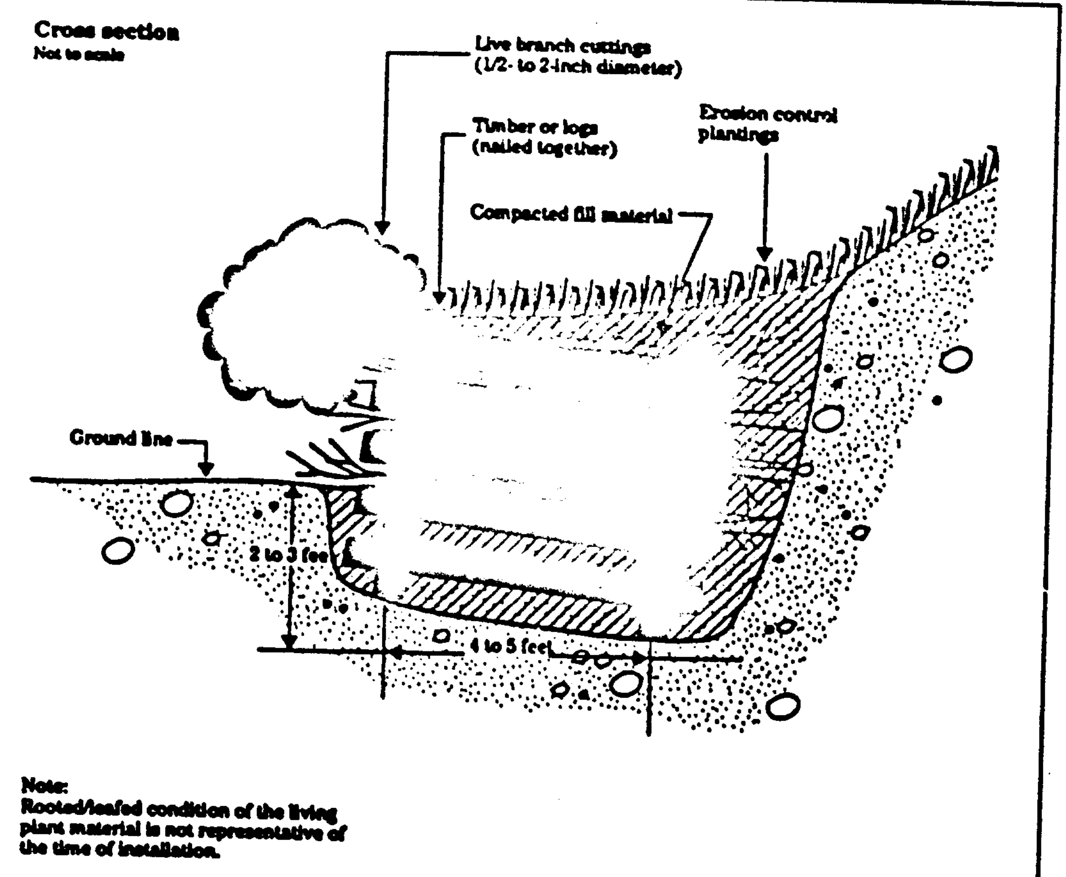


Figure 6-15. Schematic cross section of a live cribwall showing important design elements (USDA-SCS, 1992).

Local agencies such as the USDA Soil Conservation Service and Extension Service can be a useful source of information on appropriate native plant species that can be considered for use in bioengineering projects (USDA-SCS, 1992). For the Great Lakes, the U.S. Army Corps of Engineers has identified 33 upland plant species that have the potential to effectively decrease surface erosion of shorelines resulting from wind action and runoff (Hall and Ludwig, 1975). Michigan Sea Grant has also published two useful guides for shorefront property owners that provide information on vegetation and its role in reducing Great Lakes shoreline erosion (Tainter, 1982; Michigan Sea Grant College Program, 1988).

When considering a soil bioengineering approach to shoreline stabilization, several factors in addition to selection of plant materials are important. Shores subject to wave erosion will usually require structures or beach nourishment to dampen wave energy. In particular, the principles of soil bioengineering, discussed previously, will be ineffective at controlling that portion of streambank or shoreline erosion caused by wave energy. However, soil bioengineering will typically be effective on the portion of the eroding streambank or shoreline located above the zone of wave attack. Subsurface seepage and soil slumping may need to be prevented by dewatering the bank material. Steep banks may need to be reshaped to a more gentle slope to accommodate the plant material (Hall and Ludwig, 1975).

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Marsh creation and restoration is another useful vegetative technique that can be used to address problems with erosion of coastal shorelines. Marsh plants perform two functions in controlling shore erosion (Knutson, 1988). First, their exposed stems form a flexible mass that dissipates wave energy. As wave energy is diminished, both the offshore transport and longshore transport of sediment are reduced. Ideally, dense stands of marsh vegetation can create a depositional environment, causing accretion of sediments along the intertidal zone rather than continued erosion of the shore. Second, marsh plants form a dense mat of roots (called rhizomes), which can add stability to the shoreline sediments.

Techniques of marsh creation for shore erosion control have been described by researchers for various coastal areas of the United States, including North Carolina (Woodhouse et al., 1972; Knutson, 1977; Knutson and Inskeep, 1982; Knutson and Woodhouse, 1983), the Chesapeake Bay (Garbisch et al., 1973; Sharp et al., undated), and Florida and the Gulf Coast (Lewis, 1982). The basic approach is to plant a shoreline area in the vicinity of the tide line with appropriate marsh grass species. Suitable fill material may be placed in the intertidal zone to create a wetlands planting terrace of sufficient width (at least 18 to 25 feet) if such a terrace does not already exist at the project site.

For shoreline sites that are highly sheltered from the effects of wind, waves, or boat wakes, the fill material is usually stabilized with small structures, similar to groins (see practice b below), which extend out into the water from the land. For shorelines with higher levels of wave energy, the newly planted marsh can be protected with an offshore installation of stone that is built either in a continuous configuration (Figure 6-16) or in a series of breakwaters (Figure 6-17).

Knutson and Woodhouse (1983) have developed a method for evaluating the suitability of shoreline sites for successful creation of marshes. The method uses a Vegetative Stabilization Site Evaluation Form (Figure 6-18) to evaluate potential for planting success on a case-by-case basis. The user measures each of four characteristics for the area in question, identifies the categories on the form that best describe the area, calculates a cumulative score, and uses the score to determine the potential success rate for installation of wetland plants in the intertidal zone. Sites with a cumulative score of 300 or greater have been correlated with 100 percent success rates at actual field planting sites (Lewis, 1982). Sites with scores between 201 and 300 generally have a success rate of 50 percent, which often constitutes an acceptable risk for undertaking a shoreline erosion control project emphasizing marsh creation (Lewis, 1982).

■ *b. Use properly designed and constructed engineering practices for shore erosion control in areas where practices involving marsh creation and soil bioengineering are ineffective.*

Properly designed and constructed shore and streambank erosion control structures are used in areas where higher wave energy makes biostabilization and marsh creation ineffective. There are many sources of information

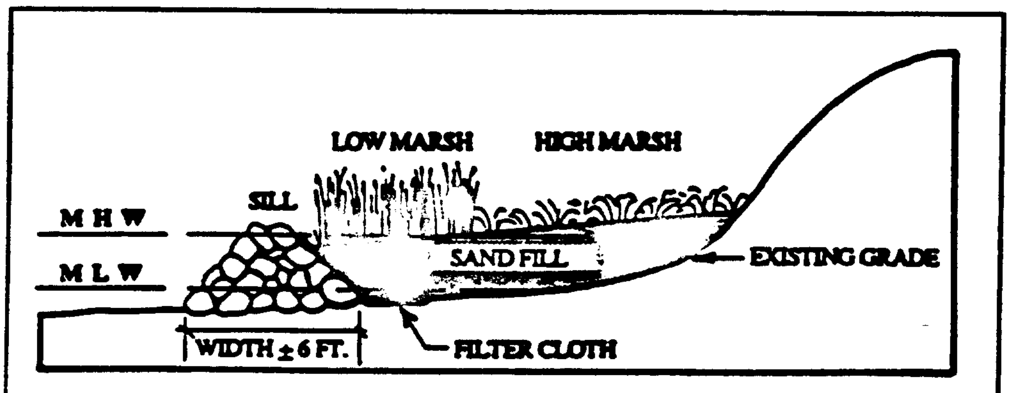

Figure 6-16. Continuous stone sill protecting a planted marsh (Environmental Concern, Inc., 1992).

Figure 6-17. Headland breakwater system at Drummonds Field, Virginia. The breakwaters control shoreline erosion and provide a community beach. (Hardaway and Gunn, 1991.)

concerning the proper design and construction of shoreline and streambank erosion control structures. Table 6-4 contains several useful sources of design information. In addition to careful consideration of the engineering design, the proper planning for a shoreline or streambank protection project will include a thorough evaluation of the physical processes causing the erosion. To complete the analysis of physical factors, the following steps are suggested (Hobbs et al., 1981):

1. SHORE CHARACTERISTICS	2. DESCRIPTIVE CATEGORIES (SCORE WEIGHTED BY PERCENT SUCCESSFUL)				3. WEIGHTED SCORE
a. FETCH-AVERAGE	LESS THAN 1.0 (0.6)	1.1 (0.7) to 3.0 (1.9)	3.1 (1.9) to 9.0 (5.6)	GREATER THAN 9.0 (5.6)	
	(87)	(66)	(44)	(37)	
b. FETCH-LONGEST	LESS THAN 2.0 (1.2)	2.1 (1.3) to 6.0 (3.7)	6.1 (3.8) to 18.0 (11.2)	GREATER THAN 18.0 (11.2)	
	(89)	(67)	(41)	(17)	
c. SHORELINE GEOMETRY	COVE	MEANDER OR STRAIGHT	HEADLAND		
	(85)	(62)	(50)		
d. SEDIMENT[1]	less than 0.4	0.4 – 0.8	greater than 0.8		
	(84)	(41)	(18)		
4. CUMULATIVE SCORE					

5. SCORE INTERPRETATION			
a. CUMULATIVE SCORE	122 – 200	201 – 300	300 – 345
b. POTENTIAL SUCCESS RATE	0 to 30%	30 to 80%	80 to 100%

[1]Grain-size scale for the Unified Soils Classification (Casagrande, 1948; U.S. Army Engineer Waterways Experiment Station, 1953):

Clay, silt, and find sand - 0.0024 to 0.42 millimeter
Medium sand - 0.42 to 2.0 millimeters
Coarse sand - 2.0 to 4.76 millimeters.

Figure 6-18. Vegetative Stabilization Site Evaluation Form (Knutson and Woodhouse, 1983).

Table 6-4. Sources for Proper Design of Shoreline and Streambank Erosion Control Structures

Index	Source	Location	Practices
1	USDA, Soil Conservation Service. 1985. *Streambank and Shoreline Protection.*	United States	• removal of debris • reduction of slope • heavy stone placement • deflectors • vegetation protection
2	Henderson, J.E. 1986. Environmental Designs for Streambank Protection Projects. *Water Resources Bulletin*, 22 (4) 549-558.	United States	• vegetative shoreline stabilization • structural shoreline stabilization
3	Porter, D.L. 1992. *Light Touch, Low Cost, Streambank and Shoreline Erosion Control Techniques.* Tennessee Valley Authority.	Tennessee	• piling revetment • tree revetment and breakwaters • board fence revetments and dikes • tire post retards and revetments • wire cribs • floating tire breakwater • sand bag revetment • toe protection • brush mat revetment • log and cable revetment • vegetative plantings
4	U.S. Army Corps of Engineers. 1983. *Streambank Protection Guidelines for Landowners and Local Governments.* Vicksburg, MS.	United States	• planning/land use management • stream rerouting • removal of obstructions • bed scour control • vegetative stabilization • bank shaping • gabions and wire mattresses • rubble • sacks • blocks • fences • kellner jacks • bulkheads • dikes
5	Hill, Lambert, and Ross. 1983. *Best Management Practices for Shoreline Erosion Control.* Virginia Cooperative Extension Service. Publication 447-004.	Virginia	• management of shorelines to prevent erosion • vegetative covers • bank grading • marsh creation • grassed filter strips
6	Gutman, A.L. 1979. Low-cost Shoreline Protection in Massachusetts. In *Proceedings of the Specialty Conference on Coastal Structures 1979*, Alexandria, VA, March 14-16, 1979.	Massachusetts	• sand-filled fabric bags

Table 6-4. (Continued)

Index	Source	Location	Practices
7	Graham, J.S. 1983. Design of Pressure-treated Wood Bulkheads. In *Coastal Structures '83.* U.S. Army Corps of Engineers.	United States	• wood bulkheads/retaining walls
8	Cumberland County SWCD, Knox-Lincoln SWCD, Maine Department of Environmental Protection, Maine Soil and Water Conservation Commission, Portland Water District, Time and Ride RC and D, USEPA, and USDA-SCS. Fact Sheet Series (2, 3, 4, 5, 8, 9, 10, 12)	Maine	• vegetative dune stabilization • vegetative streambank stabilization • vegetated buffer strips • culverts • grassed swales • diversion • minimization of cut and fill • structures to channelize water down steep slopes • shoreline riprap • streambank riprap • temporary check dams
9	Gloucester County, Virginia, Department of Conservation and Recreation, Division of Soil and Water Conservation, Shoreline Programs Bureau. June 1991. *Gloucester County Shoreline Erosion Control Guidance (Draft).*	Gloucester County, VA	• marsh establishment • bank grading and revegetation • riprap revetment • bulkheading • groins • gabions
10	Ehrlich, L.A., and F. Kulhawy. 1982. *Breakwaters, Jetties and Groins: A Design Guide.* New York Sea Grant Institute, Coastal Structures Handbook Series.	New York	• breakwaters • jetties • groins • mound structures • wall structures • longard tubes • sand-filled bags • rock mastic • precast concrete units
11	Saczynski, T.M., and F. Kulhawy. 1982. *Bulkheads.* New York Sea Grant Institute, Coastal Structures Handbook Series.	New York	• anchored walls • cantilevered walls • walls in clay
12	U.S. Army Corps of Engineers, Waterways Experimental Station. *Shoreline Protection Manual,* Volumes I and II. Vicksburg, MS.	United States	• seawalls and bulkheads • revetments • beach fill • groins • jetties • breakwaters

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Table 6-4. (Continued)

Index	Source	Location	Practices
13	Fulford, E.T. 1985 *Reef Type Breakwaters for Shoreline Stabilization.* In Proceedings of Coastal Zone '85, pp. 1776-1795. American Society of Civil Engineers.	Chesapeake Bay	• reef-type breakwaters: low-crested rubble-mound breakwaters built parallel to the shoreline • revetments • bulkheads • groins
14	Tainter, S.P. 1982. *Bluff Slumping and Stability: A Consumer's Guide.* Michigan Sea Grant.	United States	• reshaping bluff face • subsurface drainage • surface water control • vegetation
15	FEMA. 1986. *Coastal Construction Manual.* Federal Emergency Management Agency, Washington, DC.	United States	• structural design recommendations • landscaping • dune protection • bulkheads • use of earthfill
16	Hardaway, C.S., and J.R. Gunn. 1991. *Headland Breakwaters in Chesapeake Bay.*	Chesapeake Bay	• headland breakwater systems: series of headlands and pocket beaches

(1) **Determine the limits of the shoreline reach;**

(2) **Determine the rates and patterns of erosion and accretion and the active processes of erosion within the reach;**

(3) **Determine, within the reach of the sites of erosion-induced sediment supply, the volumes of that sediment supply available for redistribution within the reach, as well as the volumes of that sediment supply lost from the reach;**

(4) **Determine the direction of sediment transport and, if possible, estimation of the magnitude of the gross and net sediment transport rates; and**

(5) **Estimate factors such as ground-water seepage or surface water runoff that contribute to erosion.**

The most widely-accepted alternative engineering practices for streambank or shoreline erosion control are described below. These practices will have varying levels of effectiveness depending on the strength of waves, tides, and currents at the project site. They will also have varying degrees of suitability at different sites and may have varying types of secondary impacts. One important impact that must always be considered is the transfer of wave energy, which can cause erosion offshore or alongshore. Finding a satisfactory balance between these three factors (effectiveness, suitability, and secondary impacts) is often the key to a successful streambank or shore erosion control project.

Fixed engineering structures are built to protect upland areas when resources become impacted by erosive processes. Sound design practices for these structures are essential (Kraus and Pilkey, 1988). Not only are poorly designed structures typically unsuccessful in protecting the intended stretch of shoreline, but they also have a negative impact on other stretches of shoreline as well. One example of accelerated erosion of unprotected properties adjacent to shoreline erosion structures is the Siletz Spit, Oregon, site (Komar and McDougal, 1988).

For sites where soil bioengineering marsh creation would not be an effective means of streambank or shoreline stabilization, a variety of engineering approaches can be considered. One approach involves the design and installation of fixed engineering structures. Bulkheads and seawalls are two types of wave-resistant walls that are similar in design but slightly different in purpose. Bulkheads are primarily soil-retaining structures designed also to resist wave attack (Figure 6-19). Seawalls are principally structures designed to resist wave attack, but they also may retain some soil (USACE, 1984). Both bulkheads and seawalls may be built of many materials, including steel, timber, or aluminum sheet pile, gabions, or rubble-mound structures.

Although bulkheads and seawalls protect the upland area against further erosion and land loss, they often create a local problem. Downward forces of water, produced by waves striking the wall, can produce a transfer of wave energy and rapidly remove sand from the wall (Pilkey and Wright, 1988). A stone apron is often necessary to prevent scouring and undermining. With vertical protective structures built from treated wood, there are also concerns about the leaching of chemicals used in the wood preservatives (Baechler et al., 1970; Arsenault, 1975). Chromated copper arsenate (CCA), the most popular chemical used for treating the wood used in docks, pilings, and bulkheads, contains elements of chromium, copper, and arsenic, which have some value as nutrients in the marine environment but are toxic above trace levels (Weis et al., 1991; Weis et al., 1992).

A revetment is another type of vertical protective structure used for shoreline protection. One revetment design contains several layers of randomly shaped and randomly placed stones, protected with several layers of selected armor units or quarry stone (Figure 6-20). The armor units in the cover layer should be placed in an orderly manner to obtain good wedging and interlocking between individual stones. The cover layer may also be constructed of specially shaped concrete units (USACE, 1984).

Sometimes gabions (stone-filled wire baskets) or interlocking blocks of precast concrete are used in the construction of revetments. In addition to the surface layer of armor stone, gabions, or rigid blocks, successful revetment designs also include an underlying layer composed of either geotextile filter fabric and gravel or a crushed stone filter and bedding layer. This lower layer functions to redistribute hydrostatic uplift pressure caused by wave action in the foundation substrate. Precast cellular blocks, with openings to provide drainage and to allow vegetation to grow through the blocks, can be used in the construction of revetments to stabilize banks. Vegetation roots add additional strength to the bank. In situations where erosion can occur under the blocks, fabric filters can be used to prevent the erosion. Technical assistance should be obtained to properly match the filter and soil characteristics. Typically blocks are hand placed when mechanical access to the bank is limited or costs need to be minimized. Cellular block revetments have the additional benefit of being flexible to conform to minor changes in the bank shape (USACE, 1983).

Groins are structures that are built perpendicular to the shore and extend into the water. Groins are generally constructed in series, referred to as a groin field, along the entire length of shore to be protected. Groins trap sand in littoral drift and halt its longshore movement along beaches. The sand beach trapped by each groin acts as a protective barrier that waves can attack and erode without damaging previously unprotected upland areas. Unless the groin field is artificially filled with sand from other sources, sand is trapped in each groin by interrupting the natural supply of sand moving along the shore in the natural littoral drift. This frequently results in an inadequate natural supply of sand to replace that which is carried away from beaches located farther along the shore in the direction of the littoral drift. If these "downdrift" beaches are kept starved of sand for sufficiently long periods of time, severe beach erosion in unprotected areas can result.

As with bulkheads and revetments, the most durable materials used in the construction of groins are timber and stone. Less expensive techniques for building groins use sand- or concrete-filled bags or tires. It must be recognized that the use of lower-cost materials in the construction of bulkheads, revetments, or groins frequently results in less durability and reduced project life.

Breakwaters are wave energy barriers designed to protect the land or nearshore area behind them from the direct assault of waves. Breakwaters have traditionally been used only for harbor protection and navigational purposes; in recent years, however, designs of shore-parallel segmented breakwaters, such as the one shown in Figure 6-17,

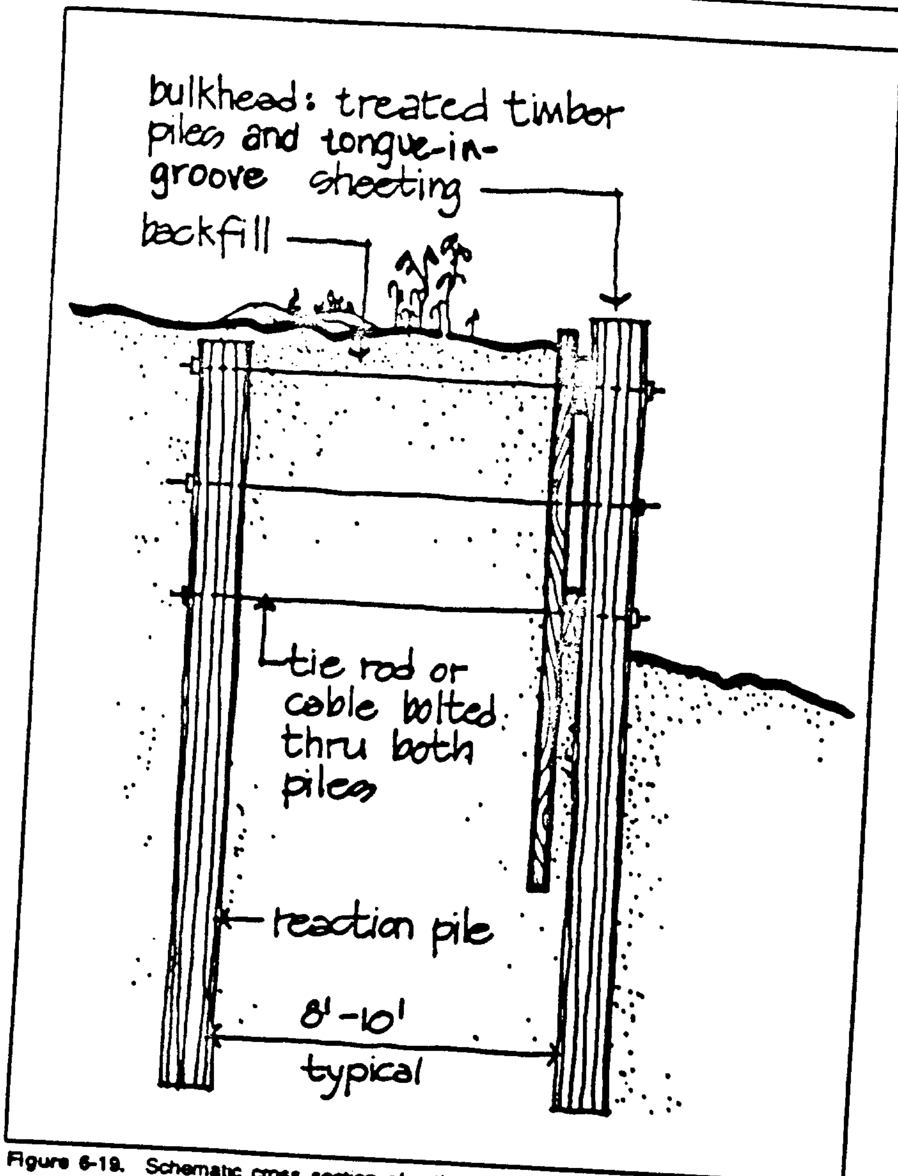

Figure 6-19. Schematic cross section of a timber bulkhead showing important design elements (FEMA, 1986).

have been used for shore protection purposes (Fulford, 1985; USACE, 1990; Hardaway and Gunn, 1989; Hardaway and Gunn, 1991). Segmented breakwaters can be used to provide protection over longer sections of shoreline than is generally affordable through the use of bulkheads or revetments. Wave energy is able to pass through the breakwater gaps, allowing for the maintenance of some level of longshore sediment transport, as well as mixing and flushing of the sheltered waters behind the structures. The cost per foot of shore for the installation of segmented offshore breakwaters is generally competitive with the costs of stone revetments and bulkheads (Hardaway et al., 1991).

Selection of Structural Stabilization Techniques

Five factors are typically taken into consideration when choosing from among the various alternatives of engineering practices for protection of eroding shorelines (USACE, 1984):

(1) Foundation conditions;
(2) Level of exposure to wave action;
(3) Availability of materials;
(4) Initial costs and repair costs; and
(5) Past performance.

Foundation conditions may have a significant influence on the selection of the type of structure to be used for shoreline or streambank stabilization. Foundation characteristics at the site must be compatible with the structure that is to be installed for erosion control. A structure such as a bulkhead, which must penetrate through the existing substrate for stability, will generally not be suitable for shorelines with a rocky bottom. Where foundation conditions are poor or where little penetration is possible, a gravity-type structure such as a stone revetment may be preferable. However, all vertical protective structures (revetments, seawalls, and bulkheads) built on sites with soft or unconsolidated bottom materials can experience scouring as incoming waves are reflected off the structures. In the absence of additional toe protection in these circumstances, the level of scouring and erosion of bottom sediments at the base of the structure may be severe enough to contribute to structural failure at some point in the lifetime of the installation.

Along streambanks, the force of the current during periods of high streamflow will influence the selection of bank stabilization techniques and details of the design. For coastal bays, the levels of wave exposure at the site will also generally influence the selection of shoreline stabilization techniques and details of the design. In areas of severe wave action or strong currents, light structures such as timber cribbing or light riprap revetment should not be used.

The effects of winter ice along the shoreline or streambank also need to be considered in the selection and design of erosion control projects. The availability of materials is another key factor influencing the selection of suitable

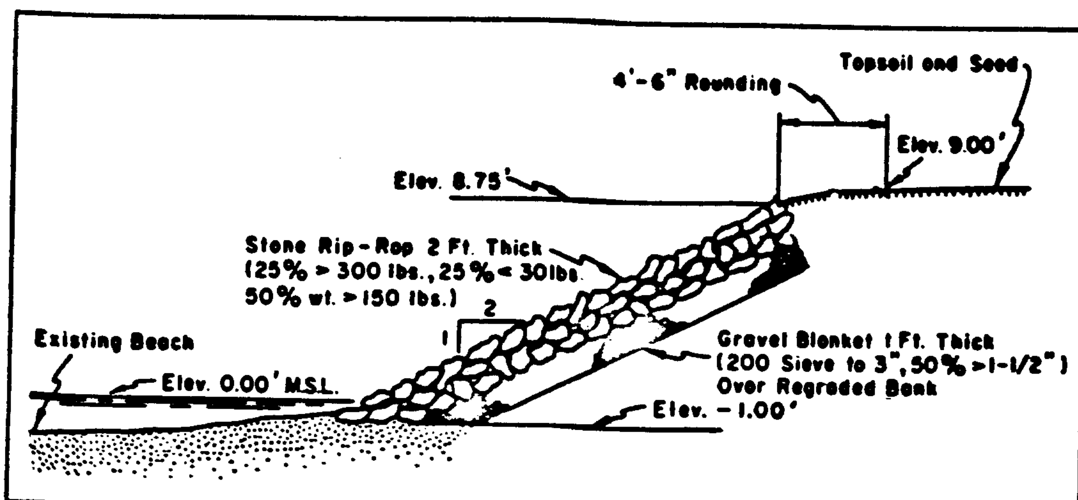

Figure 6-20. Schematic cross section of a stone revetment showing important design elements (USACE, 1984).

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structures for an eroding streambank or shoreline. A particular type of bulkhead, seawall, or revetment may not be economically feasible if materials are not readily available near the construction site. Installation methods may also preclude the use of specific structures in certain situations. For instance, the installation of bulkhead pilings in coastal areas near wetlands may not always be permissible due to disruptive impacts in locating pile-driving equipment at the project site.

Costs are influenced not only by the availability of materials but also by the type of structure that is selected for protection of the shoreline. The total cost of a shoreline or streambank protection project should be viewed as including both the initial costs of materials and the annual costs of maintenance. In some parts of the country, the initial costs of timber bulkheads may be less than the cost of stone revetments. However, stone structures typically require less maintenance and have a longer life than timber structures. Other types of structures whose installation costs are similar may actually have a wide difference in overall cost when annual maintenance and the anticipated lifetime of the structure are considered (USACE, 1984).

Other engineering practices for stabilizing shorelines and streambanks rely less on fixed structures. The creation or nourishment of existing beaches provides protection to the eroding area and can also provide a riparian habitat function, particularly when portions of the finished project are planted with beach or dune grasses (Woodhouse, 1978). Beach nourishment requires a readily available source of suitable fill material that can be effectively transported to the erosion site for reconstruction of the beach (Hobson, 1977). Dredging or pumping from offshore deposits is the method most frequently used to obtain fill material for beach nourishment. A second possibility is the mining of suitable sand from inland areas and overland hauling and dumping by trucks. To restore an eroded beach and stabilize it at the restored position, fill is placed directly along the eroded sector (USACE, 1984). In most cases, plans must be made to periodically obtain and place additional fill on the nourished beach to replace sand that is carried offshore into the zone of breaking waves or alongshore in littoral drift (Houston, 1991; Pilkey, 1992).

One important task that should not be overlooked in the planning process for beach nourishment projects is the proper identification and assessment of the ecological and hydrodynamic effects of obtaining fill material from nearby submerged coastal areas (Thompson, 1973). Removal of substantial amounts of bottom sediments in coastal areas can disrupt populations of fish, shellfish, and benthic organisms. Grain size analysis should be performed on sand from both the borrow area and the beach area to be nourished. Analysis of grain size should include both size and size distribution, and fill material should match both of these parameters. Fill materials should also be analyzed for the presence of contaminants, and contaminated sediment should not be used. Turbidity levels in the overlying waters can also be raised to undesirable levels (Sherk et al., 1976; O'Connor et al., 1976). Certain coastal areas may have seasonal restrictions on obtaining fill from nearby submerged coastal areas (Profiles Research and Consulting Group, Inc., 1980). Timing of nourishment activities is frequently a critical factor since the recreational demand for beach use frequently coincides with the best months for completing the beach nourishment. These may also be the worst months from the standpoint of impacts to aquatic life and the beach community such as turtles seeking nesting sites.

Design criteria should include proper methods for stabilizing the newly created beach and provisions for long-term monitoring of the project to document the stability of the newly created beach and the recovery of the riparian habitat and wildlife in the area.

■ c. ***In areas where existing protection methods are being flanked or are failing, implement properly designed and constructed shore erosion control methods such as returns or return walls, toe protection, and proper maintenance or total replacement.***

Toe Protection. A number of qualitative advantages are to be gained by providing toe protection for vertical bulkheads. Toe protection usually takes the form of a stone apron installed at the base of the vertical structure to reduce wave reflection and scour of bottom sediments during storms (Figure 6-21). The installation of rubble toe protection should include filter cloth and perhaps a bedding of small stone to reduce the possibility of rupture of the filter cloth. Ideally, the rubble should extend to an elevation such that waves will break on the rubble during storms.

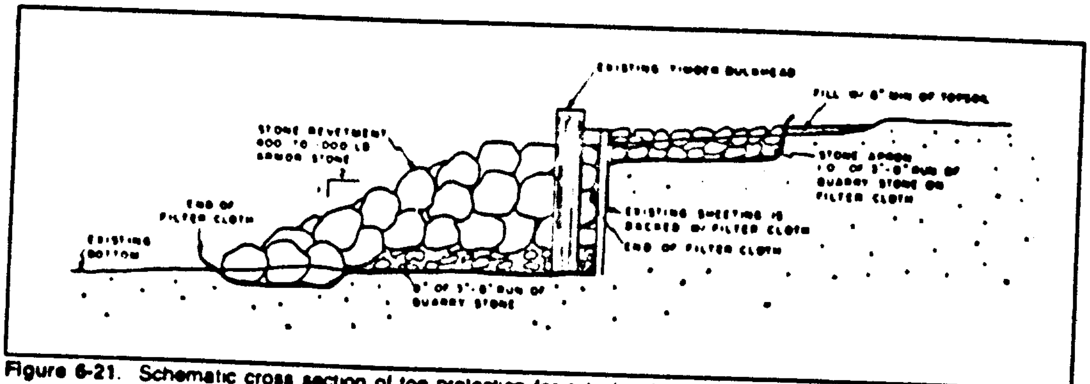

Figure 6-21. Schematic cross section of toe protection for a timber bulkhead showing important design elements (Maryland Department of Natural Resources, 1982).

Return Walls. Whenever shorelines or streambanks are "hardened" through the installation of bulkheads, seawalls, or revetments, the design process must include consideration that waves and currents can continue to dislodge the substrate at both ends of the structure, resulting in very concentrated erosion and rapid loss of fastland. This process is called flanking (Figure 6-22). To prevent flanking, return walls should be provided at either end of a vertical protective structure and should extend landward for a horizontal distance consistent with the local erosion rate and the design life of the structure.

Maintenance of Structures. Periodic maintenance of structures is necessary to repair the damage from storms and winter ice and to address the effects of flanking and off-shore profile deepening. The maintenance varies with the structural type, but annual inspections should be made by the property owners. For stone revetments, the replacement of stones that have been dislodged is necessary; timber bulkheads need to be backfilled if there has been a loss of upland material, and broken sheet pile should be replaced as necessary. Gabion baskets should be inspected for corrosion failure of the wire, usually caused either by improper handling during construction or by abrasion from the stones inside the baskets. Baskets should be replaced as necessary since waves will rapidly empty failed baskets.

Steel, timber, and aluminum bulkheads should be inspected for sheet pile failure due to active earth pressure or debris impact and for loss of backfill. For all structural types not contiguous to other structures, lengthening of flanking walls may be necessary every few years. Through periodic monitoring and required maintenance, a substantially greater percentage of coastal structures will perform effectively over their design life.

■ ***d. Plan and design all streambank, shoreline, and navigation structures so that they do not transfer erosion energy or otherwise cause visible loss of surrounding streambanks or shorelines.***

Many streambank or shoreline protection projects result in a transfer of energy from one area to another, which causes increased erosion in the adjacent area (USACE, 1981a). Property owners should consider the possible effects of erosion control measures on other properties located along the shore.

■ ***e. Establish and enforce no-wake zones to reduce erosion potential from boat wakes.***

No-wake zones should be given preference over posted speed limits in shallow coastal waters for reducing the erosion potential of boat wakes on streambanks and shorelines. Posted speed limits on waterways generally restrict the movement of recreational boating traffic to speeds in the range of 6-8 knots, but motorboats traveling at these speeds in shallow waters can be expected to throw wakes whose wave heights will be at or near the maximum size that can be produced by the boats.

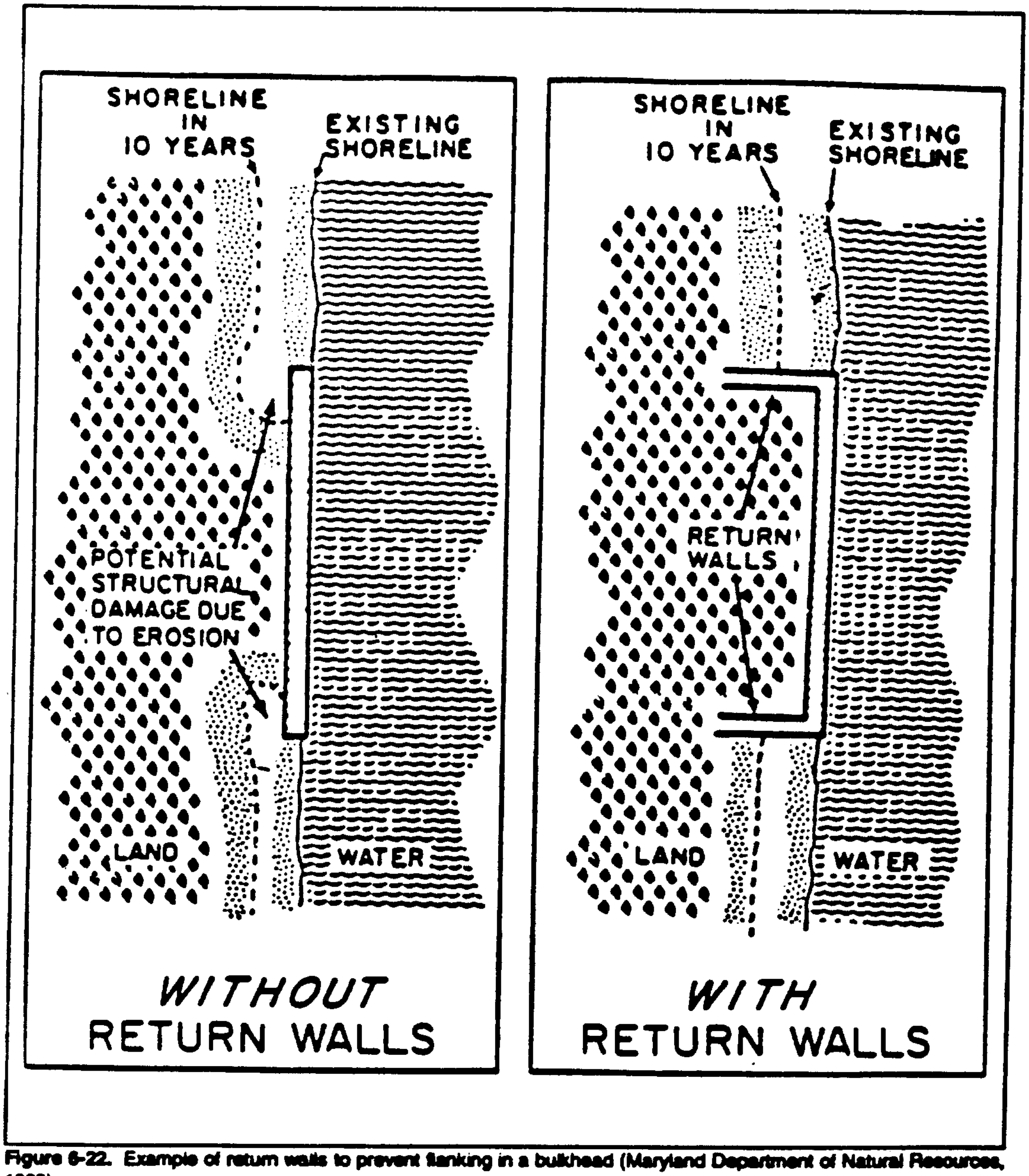

Figure 6-22. Example of return walls to prevent flanking in a bulkhead (Maryland Department of Natural Resources, 1982).

In theory, the boat speed that will produce the maximum wake depends on the depth of the water and the speed of the boat (Johnson, 1957). The ratio of these variables is called the Froude Number, named after an early scientific investigator of fluid mechanics. As the Froude Number (F) approaches 1, the wakes produced by a boat will reach their maximum value. The relationship between the Froude Number, the boat speed, and the basin depth is described by the following equation (Johnson, 1957):

$$F = V_s / \sqrt{gd}$$

where:

V_s = Velocity of boat speed (knots)
g = Gravity constant (ft/sec^2)
d = Basin depth (ft)

It is important to note that this equation can be used only to describe the boat speed at which a maximum wake will occur in water of a known depth. The equation cannot be used to calculate the actual height of the maximum wake.

Table 6-5 contains values for F calculated for different combinations of boat speed and water depth, prepared as part of a study of wakes produced by recreational boating traffic on the Chesapeake Bay in Maryland (Maryland Department of Natural Resources, 1980). The dotted line drawn through this table shows those combinations for which F approximately equals 1. For instance, boats traveling 6 to 8 knots can be expected to produce their maximum wake in water depths of 4 to 6 feet, while boats traveling 10 to 12 knots can be expected to produce their maximum wake in water depths of 12 feet. These depths are typical of conditions in small creeks and coves in coastal areas where there is generally the greatest concern about shore erosion resulting from recreational motorboat traffic.

Table 6-5 was verified with field data collected in a shallow creek in Maryland's Chesapeake Bay for two types of motorboats. The results are presented in Figure 6-23. As predicted from Table 6-5, maximum wake heights were produced at speeds ranging from 6 to 8 knots. Wake heights did not increase with increasing speed.

These results show that boats can be expected to still produce damaging wakes as they slow from high speed to enter a narrow creek or cove with a posted 6-knot limit. Locating the speed reduction zones in open water, so that boats are slowing through the critical range of velocities far from shore, would reduce the potential for shore erosion from boat wakes. The designation of no-wake zones, rather than posted speed limits, would also reduce the potential for shore erosion from boat wakes.

f. Establish setbacks to minimize disturbance of land adjacent to streambanks and shorelines to reduce other impacts. Upland drainage from development should be directed away from bluffs and banks so as to avoid accelerating slope erosion.

In addition to the soil bioengineering, marsh creation, beach nourishment, and structural practices discussed on the preceding pages of this guidance, another approach that should be considered in the planning process for shoreline and streambank erosion involves the designation of setbacks. Setbacks most often take the form of restrictions on the siting and construction of new standing structures along the shoreline. Where setbacks have been implemented to reduce the hazard of coastal land loss, they have also included requirements for the relocation of existing structures located within the designated setback area. Setbacks can also include restrictions on uses of waterfront areas that are not related to the construction of new buildings (Davis, 1987).

A recent report, *Managing Coastal Erosion* (NRC, 1990), summarizes the experience of coastal States in the implementation and administration of regulatory setback programs. The NRC report also discusses "the taking issue," which views setbacks as a severe restriction on the rights of private landowners to fill or build in designated setback areas. Setback regulations implemented in some States have been challenged in the courts on the grounds of "the taking issue," i.e., that the setback requirements are so restrictive that they "take" the value of the property without providing compensation to the property owners, violating the Fifth Amendment to the U.S. Constitution. The courts, however, have provided general approval of floodplain and wetlands regulations, and the NRC report concludes: "there is a strong legal basis for the broader use of setbacks for coastal construction based on the best available scientific estimates of future erosion rates."

Table 6-5. Froude Number for Combinations of Water Depth and Boat Speed (Maryland Department of Natural Resources, 1980)

DEPTH (ft)	SPEED (Knots)								
	2	4	6	8	10	12	14	16	18
2	0.42	0.83	1.25	1.66	2.08	2.49	2.91	3.32	3.74
4	0.29	0.59	0.88	1.17	1.47	1.76	2.06	2.35	2.64
6	0.24	0.48	0.72	0.96	1.20	1.44	1.68	1.92	2.16
8	0.21	0.42	0.62	0.83	1.04	1.25	1.45	1.66	1.87
10	0.18	0.37	0.56	0.74	0.93	1.11	1.30	1.49	1.67
12	0.17	0.34	0.51	0.68	0.85	1.02	1.19	1.36	1.52
14	0.16	0.31	0.47	0.63	0.78	0.94	1.10	1.26	1.41
16	0.15	0.29	0.44	0.59	0.73	0.88	1.03	1.17	1.32
18	0.14	0.28	0.42	0.55	0.69	0.83	0.97	1.11	1.25

Table 6-6 contains a summary of State programs and experiences with setbacks. In most cases, States have used the local unit of government to administer the program on either a mandatory or voluntary basis. This allows local government to retain control of its land use activities and to exceed the minimum State requirements if this is deemed desirable (NRC, 1990).

Technical standards for defining and delineating setbacks also vary from State to State. One approach is to establish setback requirements for any "high hazard area" eroding at greater than 1 foot per year. Another approach is to establish setback requirements along all erodible shores because even a small amount of erosion can threaten homes constructed too close to the streambank or shoreline. Several States have general setback requirements that, while not based on erosion hazards, have the effect of limiting construction near the streambank or shoreline.

The basis for variations in setback regulations between States seems to be based on several factors, including (NRC, 1990):

- The language of the law being enacted;
- The geomorphology of the coast;
- The result of discretionary decisions;
- The years of protection afforded by the setback; and
- Other variables decided at the local level of government.

From the perspective of controlling NPS pollution resulting from erosion of shorelines and streambanks, the use of setbacks has the immediate benefit of discouraging concentrated flows and other impacts of storm water runoff from new development in areas close to the streambank or shoreline. These effects are described and discussed in Chapter 4 of this guidance document. In particular, the concentration of storm water runoff can aggravate the erosion of shorelines and streambanks, leading to the formation of gullies, which are not easily repaired. Therefore, drainage of storm water from developed areas and development activities located along the shoreline should be directed inland to avoid accelerating slope erosion.

The best NPS benefits are provided by setbacks that not only include restrictions on new construction along the shore but also contain additional provisions aimed at preserving and protecting coastal features such as beaches, wetlands,

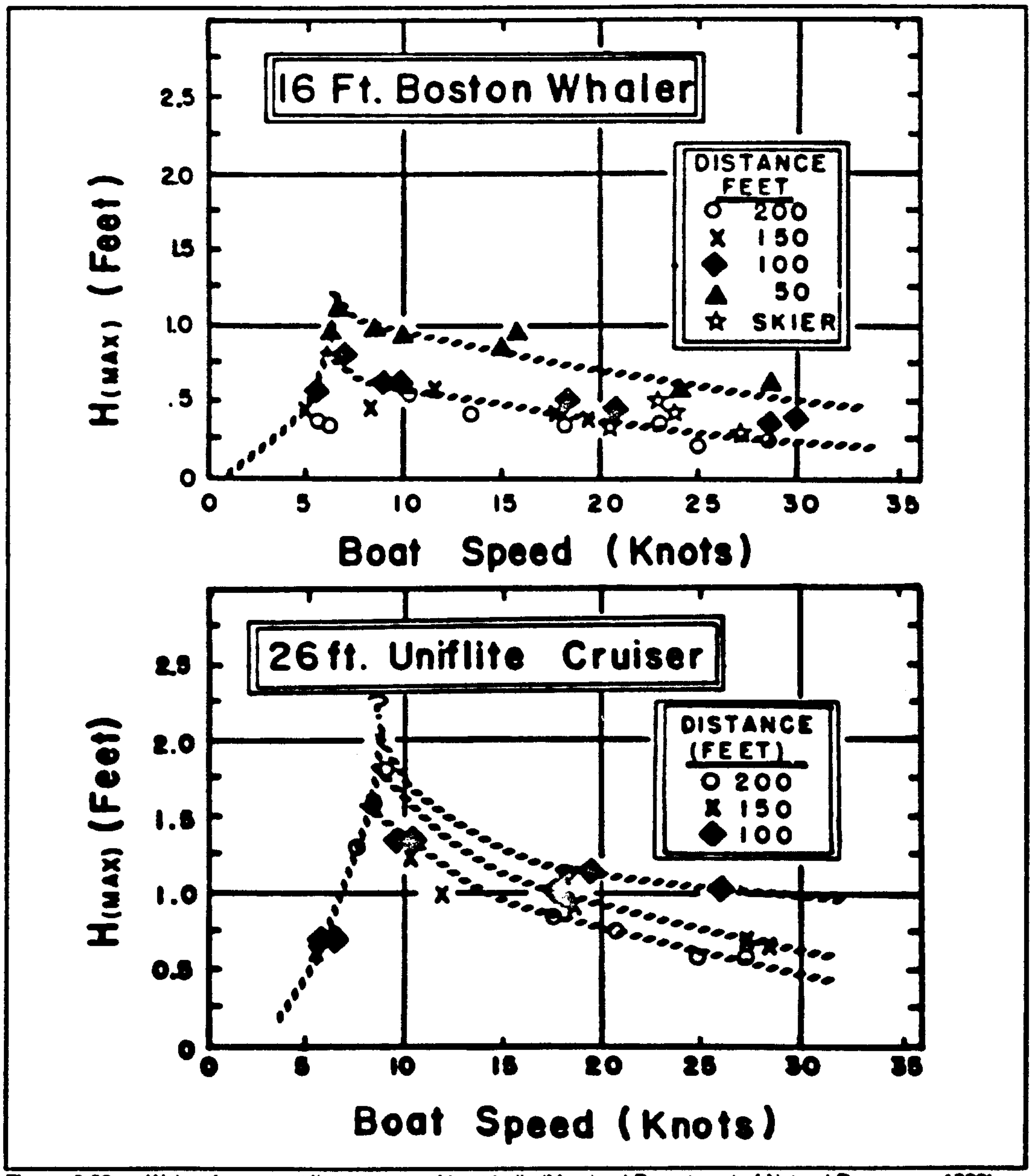

Figure 6-23. Wakes from two different types of boat hulls (Maryland Department of Natural Resources, 1980).

and riparian forests. This approach promotes the natural infiltration of surface water runoff before it passes over the edge of the bank or bluff and flows directly into the coastal waterbody. This approach also helps protect zones of naturally occurring vegetation growing along the shore. As discussed in the section on "bioengineering practices," the presence of undisturbed shoreline vegetation itself can help to control erosion by removing excess water from the bank and by anchoring the individual soil particles of the substrate.

Table 6-6. Examples of State Programs Defining Minimum Set-Backs (National Research Council, 1990)

State/Territory	Recession Rates from Aerial Photos	Recession Rates from Charts	Recession Rates from Ground Surveys	Erosion Setbacks Established*	Reference Feature	Years of Setback	Local Administration	One Foot per Year Standard	Fixed Setback	Floating Setback
Alabama	Y	Y	N	Y	MHW	NA	N	Y	N	
Alaska	Y	Y		N	NA	NA	NA	NA	NA	NA
American Samoa	N	N	N	N	NA	NA	NA	NA	NA	NA
California	Y	Y	Y	N	NA	NA	Y	NA	NA	NA
Connecticut	Y	Y		N	NA	NA	NA	NA	NA	NA
Delaware	Y	Y		Y4	TD	NA	Y	N	Y	N
Florida	Y	Y		Y5	NA	30	Y	N	Y	N
Georgia	Y	Y		N	NA	NA	NA	NA	NA	NA
Hawaii	N	N	N	Y	6	N	Y	N	Y	N
Indiana	Y	N	Y	N	NA	NA	NA	Y	NA	NA
Illinois	Y	Y	Y	N	NA	NA	NA		NA	NA
Louisiana	Y	Y	N	N	NA	NA	NA	NA	NA	NA
Maine	N	N	Y	N7	NA	NA	NA	NA	NA	NA
Maryland	Y	Y		N	NA	NA	NA	NA	NA	NA
Massachusetts	Y	Y	N	N	NA	NA	NA	NA	NA	NA
Michigan	Y	N	N	Y	BC2	30	Y	Y	N	Y
Minnesota	Y	N	N	N	NA	NA	NA	Y	NA	NA
Mississippi	N	N	N	N	NA	NA	NA	NA	NA	NA
New Hampshire	N	N	N	N	NA	NA	NA	NA	NA	NA
New Jersey	Y	Y	Y	Y	MHW	60				
New York	Y	Y	N	Y	BC	30-40	Y	Y	Y	N
North Carolina	Y	N		Y	DC	30-60	Y	N	N	Y
N. Mariana's	N	N	N	N	NA	NA	NA	NA	NA	NA
Ohio	Y	Y	N	N1	BC	30	NA	Y	Y	N
Oregon				N		NA	NA	NA	NA	NA
Pennsylvania	Y	N	Y	Y	BC	50+	Y	Y	N	Y
Puerto Rico	N	N	N	N	NA	NA	NA	NA		
Rhode Island	N	N	Y	Y	DC	30	N	N7	Y	N
South Carolina			Y	Y		40	BL		Y	N
Texas	Y	Y	Y	N	NA	NA	NA	NA	NA	NA
Virgin Islands	N	N	N	N	NA	NA	NA	NA	NA	NA
Virginia	Y	Y		N	MHW	NA	Y			
Washington				N	NA	NA	NA	NA	NA	NA
Wisconsin	Y	Y	N	N3	NA	NA	NA		N	Y

Note: 1 = setbacks may be established within 2 years; 2 = bluff crest or edge of active erosion; 3 = some counties have setbacks; 4 = has 100-foot setback regulation over new subdivisions and parcels where sufficient room exists landward of setback; 5 = not all counties have coastal construction control lines established; 6 = storm debris line or vegetation line; 7 = 2 feet per year standard. Y, yes; N, no; NA, not applicable; BC, bluff crest; MHW, mean high water; TD, toe of dune; DC, dune crest, toe of frontal dune or vegetation line; BL, base line. A blank means no information was available.

*Most States have setbacks from water line but not based on an erosion hazard.

Almost all States with setback regulations have modified their original programs to improve effectiveness or correct unforeseen problems (NRC, 1990). States' experiences have shown that procedures for updating or modifying the setback width need to be included in the regulations. For instance, application of a typical 30-year setback standard in an area whose rate of erosion is 2 feet per year results in the designation of a setback width of 60 feet. This width may not be sufficient to protect the beaches, wetlands, or riparian forests whose presence improves the ability of the streambank or shoreline to respond to severe wave and flood conditions, or to high levels of surface water runoff during extreme precipitation events. A setback standard based on the landward edge of streambank or shoreline vegetation is one alternative that has been considered (NRC, 1990; Davis, 1987).

From the standpoint of NPS pollution control, the approach that best designates coastal wetlands, beaches, or riparian forests as a special protective feature, allows no development on the feature, and measures the setback from the landward side of the feature is recommended (NRC, 1990). In some cases, provisions for soil bioengineering, marsh creation, beach nourishment, or engineering structures may also be appropriate since the special protective features within the designated setbacks can continue to be threatened by uncontrolled erosion of the shoreline or streambank. Finally, setback regulations should recognize that some special features of the streambank or shoreline will change position. For instance, beaches and wetlands can be expected to migrate landward if water levels continue to rise as a result of global warming. Alternatives for managing these situations include flexible criteria for designating setbacks, vigorous maintenance of beaches and other special features within the setback area, and frequent monitoring of the rate of streambank or shoreline erosion and corresponding adjustment of the setback area.

5. Costs for All Practices

This section describes costs for representative activities that would be undertaken in support of one or more of the practices listed under this management measure. The description of the costs is grouped into the following three categories: (1) costs for streambank and shoreline stabilization with vegetation; (2) costs for streambank and shoreline stabilization with engineering structures; and (3) costs for designation and enforcement of boating speed limits.

a. Vegetative Stabilization for Shorelines and Streambanks

Representative costs for this practice can include costs for wetland plants and riparian area vegetation, including trees and shrubs. Additional costs could be incurred depending on the level of site preparation that is required. The items of work could include (1) clearing the site of fallen trees and debris; (2) extensive site work requiring heavy construction equipment; (3) application of seed stock or sprigging of nursery-reared plants; (4) application of fertilizer (most typically for marsh creation); and (5) postproject maintenance and monitoring. For a more extensive description of these tasks, refer to the sections of Chapter 7 describing marsh restoration efforts.

(1) Costs reported in 1989 for bottomland forest plants using direct seeding were $40 to $60 per acre (NRC, 1991). If vegetation is assumed to be planted across a 50-foot width along the shoreline or streambank, the cost per linear foot of shore or streambank, in 1990 dollars, can be calculated as $0.05 - $0.08/foot.

(2) Costs reported in 1990 for nursery-reared tree seedlings were $212.50 per acre (Illinois Department of Conservation, 1990). If vegetation is assumed to be planted across a 50-foot width along the shoreline or streambank, the costs per linear foot of shore or streambank, in 1990 dollars, can be calculated as $0.25/foot.

(3) Costs reported for restoration of riparian areas in Utah between 1985 and 1988 included extensive site work: bank grading, installation of riprap and sediment traps in deep gullies, planting of juniper trees and willows, and fencing to protect the sites from intrusion by livestock. Assuming a 100-foot width along the shore or streambank for this work, the reported costs, in 1990 dollars, of $2,527 per acre can be calculated as $5.94 per foot.

(4) Costs were reported in 1988 for vegetative erosion control projects involving creation of tidal fringe marsh, using nursery-reared *Spartina alterniflora* and *S. patens* along the shorelines of the Chesapeake

Bay in Maryland (Maryland Eastern Shore Resource Conservation and Development Area). Two projects involving marsh creation along a total of 4,650 linear feet of shoreline averaged $20.48 per foot. Costs of 12 projects involving marsh creation combined with grading and seeding of the shoreline bank ranging in height from 5 to 12 feet averaged $54.82 per foot along a total of 8,465 feet. These costs can be calculated in 1990 dollars as:

Marsh creation - no bank grading .... $21.44 per foot
Marsh creation - bank grading .... $57.40 per foot

b. Structural Stabilization for Shorelines and Streambanks

Representative costs for structural stabilization typically include costs for survey and design and for extensive site work, including costs to gain access for trucks and front-end loaders necessary to place the stone (for revetments) or sheet pile (for bulkheads). As indicated in the data described below for specific projects, costs frequently vary depending on the level of wave exposure at the site and on the overall length of shoreline or streambank that is being protected in a single project. In some of the examples shown below, construction costs were reported along with design and administration costs. For cases where only installation costs were reported in the source document, a total project cost was computed by adding 15 percent of first construction costs to the reported installation cost, and then dividing by the reported project length to compute cost per foot. Thus, all costs shown below include design and administration costs.

(1) Costs for timber bulkhead on private property along 100 linear feet of shore on Cabin Creek, York County, Virginia (less than 2 miles of wave exposure), in 1990 dollars, were $69 per foot (Virginia Department of Conservation and Recreation, undated).

(2) Costs for replacement of timber bulkhead on private property along 375 linear feet of shore on the Rappahannock River, Middlesex County, Virginia (2 to 5 miles of wave exposure), in 1990 dollars, were $60 per foot (Virginia Department of Conservation and Recreation, undated).

(3) Costs for timber bulkhead at Whidbey Island Naval Air Station, Oak Harbor, Washington (more than 5 miles of wave exposure), in 1990 dollars, were $129 per foot (USACE, 1981a).

(4) Costs for timber and steel bulkhead along 200 feet of shoreline of a County park at Port Wing, Bayfield County, Wisconsin (more than 5 miles of exposure), in 1990 dollars, were $356 per foot (USACE, 1981a).

(5) Costs for stone revetment on private property along 270 feet of shoreline on Linkhorn Bay, Virginia Beach, Virginia (less than 2 miles of wave exposure), in 1990 dollars, were $63 per foot (Virginia Department of Conservation and Recreation, undated).

(6) Costs for stone revetment and bank grading along 420 linear feet of shoreline on James River, Surry County, Virginia (2 to 5 miles of exposure), in 1990 dollars, were $342 per foot (Virginia Department of Conservation and Recreation, undated).

(7) Costs for stone revetment on private community property along 2000 linear feet of shoreline on Lorain Harbor, Ohio (more than 5 miles of exposure), in 1990 dollars, were $1,093 per foot (USACE, 1981b).

(8) Costs for beachfill and dune construction on a city public beach along 10,000 feet of shoreline at North Nantasket Beach, Hull, Massachusetts (more than 5 miles of exposure), in 1990 dollars, were $162 per foot (USACE, 1988).

(9) Costs for six riprap and six gabion breakwaters with beachfill on State Wildlife Management Area property along 1250 linear feet of shore on the James River, Surry County, Virginia (2 to 5 miles of exposure), in 1990 dollars, were $62 per foot (Hardaway et al., 1991).

(10) Costs for breakwaters, beachfill, and beachgrass planting at a County park along 1100 feet of shoreline at Elm's Beach, Chesapeake Bay, Maryland (more than 5 miles of exposure), in 1990 dollars, were $292 per foot (Hardaway and Gunn, 1991).

(11) Costs for breakwaters, beachfill, and revetment along 11,000 feet of shoreline at Maumee Bay State Park, Ohio (more than 5 miles of exposure), in 1990 dollars, were $961 per foot (USACE, 1982).

c. Designation and Enforcement of Boating Speed Limits

Representative costs for this practice can be broken down into the following two tasks:

(1) Providing notification of a posted speed limit or "no-wake" zone in navigational channels along coastal waterways. One approach used to advise boaters of posted speed limits is the placement of marked buoys along the channel in speed reduction zones. Alternatively, signs designating speed reduction zones can be placed on pilings that are driven into the bottom of the coastal creek or bay. In narrow creeks or coves, signs can be mounted onshore along the streambank. The number of signs, buoys, or beacons that will be required will depend on the length and configuration of the channel. For a channel 1 mile in length that is fairly straight and linear, with good visibility on both the downstream and upstream approaches, three posted speed limit signs could be deployed for upstream traffic and three for downstream traffic. Representative costs for this practice, in 1990 dollars, can be estimated from data provided by the Maryland Department of Natural Resources Marine Police Administration. These costs include all labor, materials, and installation:

(a) Costs for purchasing, marking, and setting six buoys at $285 each are $1,710.

(b) Costs for six onshore signs mounted on 2-ft by 3-ft by 8-ft posts at $165 each are $990.

(c) Costs for six channel beacons mounted on offshore 4-ft by 4-ft by 42-ft pilings at $1,850 each are $11,100.

(2) The enforcement of designated boating speed limit zones, which can be expected to include costs for the acquisition and maintenance of marine police vessels and costs for marine police personnel to monitor boating patterns. Representative costs, in 1990 dollars, which are incurred for these items by the Maryland Department of Natural Resources (Gwynne Schultz, personal communication, 1992) are listed below:

(a) One large patrol boat (suitable for areas of open water in coastal bays or rivers):

Acquisition	$180,000
Annual maintenance per vessel per year	$ 2,000
Crew of three marine police	$ 90,000

(b) One small patrol boat (suitable for protected creeks and coves):

Acquisition	$20,000
Annual maintenance per vessel per year	$ 2,000
Crew of two marine police	$60,000

These costs do not consider overtime that is provided to members of the Maryland Marine Police for any shift greater than 8 hours in length. No overtime is paid for holidays.

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V. GLOSSARY

Accretion: May be either *natural* or *artificial*. Natural accretion is the buildup of land, solely by the action of the forces of nature, on a beach by deposition of waterborne or airborne material. Artificial accretion is a similar buildup of land by reason of an act of humans, such as the accretion formed by a groin, breakwater, or beach fill deposited by mechanical means. Also known as aggradation. (USACE, 1984)

Alongshore: Parallel to and near the shoreline; *longshore* (USACE, 1984).

Armor unit: A relatively large quarrystone or concrete shape that is selected to fit specified geometric characteristics and density. Armor units are usually uniform in size and usually large enough to require individual placement. In normal cases armor units are used as primary wave protection and are placed in thicknesses of at least two units. (USACE, 1984)

Artificial nourishment: The process of replenishing a beach with material (usually sand) obtained from another location (USACE, 1984).

Backshore: That zone of the shore or beach lying between the foreshore and the coastline comprising the *berm* or *berms* and acted upon by waves only during severe storms, especially when combined with exceptionally high water (USACE, 1984).

Bank: (1) The rising ground bordering a lake, river, or sea; or of a river or channel, for which it is designated as right or left as the observer is facing downstream. (2) An elevation of the sea floor or large area, located on a continental (or island) shelf and over which the depth is relatively shallow but sufficient for safe surface navigation; a group of shoals. (3) In its secondary sense, used only with a qualifying word such as "sandbank" or "gravelbank," a shallow area consisting of shifting forms of silt, sand, mud, and gravel. (USACE, 1984)

Bar: A submerged or emerged embankment of sand, gravel, or other unconsolidated material built on the sea floor in shallow water by waves and currents (USACE, 1984).

Barrier beach: A bar essentially parallel to the shore, the crest of which is above normal high water level (USACE, 1984).

Basin, boat: A naturally or artificially enclosed or nearly enclosed harbor area for small craft (USACE, 1984).

Bathymetry: The measurement of depths of water in oceans, seas, and lakes; also information derived from such measurements (USACE, 1984).

Bay: A recess in the shore or an inlet of a sea between two capes or headlands, not so large as a gulf but larger than a cove (USACE, 1984).

Bayou: A minor sluggish waterway or estuarine creek, tributary to, or connecting, other stream or bodies of water, whose course is usually through lowlands or swamps (USACE, 1984).

Beach: The zone of unconsolidated material that extends landward from the low water line to the place where there is marked change in material or physiographic form, or to the line of permanent vegetation (usually the effective limit of storm waves). The seaward limit of a beach—unless otherwise specified—is the mean low water line. A beach includes *foreshore* and *backshore*. See also *shore*. (USACE, 1984)

Beach planting: The placement of vegetation in the zone of sedimentary material that extends landward from the low water line to the place where there is marked change in material or form, or to the line of permanent vegetation.

Beach accretion: See *accretion* (USACE, 1984).

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Beach berm: A nearly horizontal part of the beach or backshore formed by the deposit of material by wave action. Some beaches have no berms; others have one or several. (USACE, 1984)

Beach erosion: The carrying away of beach materials by wave action, tidal currents, littoral currents, or wind (USACE, 1984).

Beach face: The section of the beach normally exposed to the action of the wave uprush. The *foreshore* of a *beach* (not synonymous with *shoreface*). (USACE, 1984)

Beach fill: Material placed on a beach to renourish eroding shores (USACE, 1984).

Beach width: The horizontal dimension of the beach measured normal to the shoreline (USACE, 1984).

Bench mark: A permanently fixed point of known elevation. A primary bench mark is one close to a tide station to which the tide staff and tidal datum originally are referenced. (USACE, 1984)

Bluff: A high, steep bank or cliff (USACE, 1984).

Bottom: The ground or bed under any body of water; the bottom of the sea (USACE, 1984).

Bottom (nature of): The composition or character of the bed of an ocean or other body of water (e.g., clay, coral, gravel, mud, ooze, pebbles, rock, shell, shingle, hard, or soft) (USACE, 1984).

Boulder: A rounded rock more than 10 inches in diameter; larger than a cobblestone. See *soil classification*. (USACE, 1984)

Breakwater: A structure or partition to retain or prevent sliding of the land. A secondary purpose is to protect the upland against damage from wave action. (USACE, 1984)

Bulkhead: A structure or partition to retain or prevent sliding of the land. A secondary purpose is to protect the upland against damage from wave action. (USACE, 1984)

Bypassing, sand: Hydraulic or mechanical movement of sand from the accreting updrift side to the eroding downdrift side of an inlet or harbor entrance. The hydraulic movement may include natural movement as well as movement caused by humans. (USACE, 1984)

Canal: An artificial watercourse cut through a land area for such uses as navigation and irrigation (USACE, 1984).

Cape: A relatively extensive land area jutting seaward from a continent or large island that prominently marks a change in, or interrupts notably, the coastal trend; a prominent feature (USACE, 1984).

Channel: (1) A natural or artificial waterway or perceptible extent that either periodically or continuously contains moving water, or that forms a connecting link between two bodies of water. (2) The part of a body of water deep enough to be used for navigation through an area otherwise too shallow for navigation. (3) A large strait, as the English Channel. (4) The deepest part of a stream, bay, or strait through which the main volume or current of water flows. (USACE, 1984)

Channelization and channel modification: River and stream channel engineering for the purpose of flood control, navigation, drainage improvement, and reduction of channel migration potential; activities include the straightening, widening, deepening, or relocation of existing stream channels, clearing or snagging operations, the excavation of borrow pits, underwater mining, and other practices that change the depth, width, or location of waterways or embayments in coastal areas.

Clay: See *soil classification* (USACE, 1984).

Cliff: A high, steep face of rock; a precipice (USACE, 1984).

Coast: A strip of land of indefinite width (may be several kilometers) that extends from the shoreline inland to the first major change in terrain features (USACE, 1984).

Coastal area: The land and sea area bordering the shoreline (USACE, 1984).

Coastal plain: The plain composed of horizontal or gently sloping strata of clastic materials fronting the coast, and generally representing a strip of sea bottom that has emerged from the sea in recent geologic time (USACE, 1984).

Coastline: (1) Technically, the line that forms the boundary between the *coast* and the *shore*. (2) Commonly, the line that forms the boundary between the land and the water. (USACE, 1984)

Cobble (cobblestone): See *soil classification* (USACE, 1984).

Continental shelf: The zone bordering a continent and extending from the low water line to the depth (usually about 180 meters) where there is a marked or rather steep descent toward a greater depth.

Contour: A line on a map or chart representing points of equal elevation with relation to a datum. It is called an isobath when it connects points of equal depth below a datum. Also called depth contour. (USACE, 1984)

Controlling depth: The least depth in the navigable parts of a waterway, governing the maximum draft of vessels that can enter (USACE, 1984).

Convergence: (1) In refraction phenomena, the decreasing of the distance between orthogonals in the direction of wave travel. Denotes an area of increasing wave height and energy concentration. (2) In wind-setup phenomena, the increase in setup observed over that which would occur in an equivalent rectangular basin of uniform depth, caused by changes in plainform or depth; also the decrease in basin width or depth causing such an increase in setup (USACE, 1984).

Cove: A small, sheltered recess in a coast, often inside a larger embayment. (USACE, 1984)

Current: A flow of water (USACE, 1984).

Current, coastal: One of the offshore currents flowing generally parallel to the shoreline in the deeper water beyond and near the surf zone. Such currents are not related genetically to waves and resulting surf, but may be related to tides, winds, or distribution of mass. (USACE, 1984)

Current, drift: A broad, shallow, slow-moving ocean or lake current. Opposite of *current, stream*. (USACE, 1984)

Current, ebb: The tidal current away from shore or down a tidal stream. Usually associated with the decrease in the height of the tide. (USACE, 1984)

Current, flood: The tidal current toward shore or up a tidal stream. Usually associated with the increase in the height of the tide. (USACE, 1984)

Current, littoral: Any current in the littoral zone caused primarily by wave action; e.g., longshore current, rip current. See also *current, nearshore*. (USACE, 1984)

Current, longshore: The littoral current in the breaker zone moving essentially parallel to the shore, usually generated by waves breaking at an angle to the shoreline (USACE, 1984).

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Current, nearshore: A current in the *nearshore zone* (USACE, 1984).

Current, offshore: See *offshore current* (USACE, 1984).

Current, tidal: The alternating horizontal movement of water associated with the rise and fall of the tide caused by the astronomical tide-producing forces. Also *current, periodic*. See also *current, flood* and *current, ebb*. (USACE, 1984)

Cutoff: Wall, collar, or other structure, such as a trench, filled with relatively impervious material intended to reduce seepage of water through porous strata; in river hydraulics, the new and shorter channel formed either naturally or artificially when a stream cuts through the neck of a bend.

Deep water: Water so deep that surface waves are little affected by the ocean bottom. Generally, water deeper than one-half the surface wavelength is considered deep water. Compare *shallow water*. (USACE, 1984)

Delta: An alluvial deposit, roughly triangular or digitate in shape, formed at a river mouth (USACE, 1984).

Depth: The vertical distance from a specified tidal datum to the sea floor (USACE, 1984).

Depth of breaking: The still-water depth at the point where the wave breaks (USACE, 1984).

Detritus: Loose material worn or broken away from a mass, as by the action of water, usually carried from inland sources by streams (USACE, 1981a).

Dike (dyke): A channel stabilization structure sited in a river or stream perpendicular to the bank.

Downdrift: The direction of predominant movement of littoral materials (USACE, 1984).

Drift (noun): (1) Sometimes used as a short form for *littoral drift*. (2) The speed at which a current runs. (3) Floating material deposited on a beach (driftwood). (4) A deposit of a continental ice sheet; e.g., a drumlin. (USACE, 1984)

Dunes: (1) Ridges or mounds of loose, wind-blown material, usually sand. (2) Bed forms smaller than bars but larger than ripples that are out of phase with any water-surface gravity waves associated with them (USACE, 1984).

Ebb tide: The period of tide between high water and the succeeding low water; a falling tide (USACE, 1984).

Embankment: An artificial bank such as a mound or dike, generally built to hold back water or to carry a roadway (USACE, 1984).

Embayment: An indentation in the shoreline forming an open bay (USACE, 1984).

Ephemeral: Lasting for a brief time; short-lived; transitory (Morris, 1978).

Erosion: The wearing away of land by the action of natural forces. On a beach, the carrying away of beach material by wave action, tidal currents, littoral currents, or by deflation (USACE, 1984).

Estuary: (1) The part of the river that is affected by tides. (2) The region near a river mouth in which the fresh water in the river mixes with the salt water of the sea (USACE, 1984).

Eutrophication: The alteration of lake ecology through excessive nutrient input, characterized by excessive growth of aquatic plants and algae and low levels of dissolved oxygen (USEPA, 1992).

Fastland: Land near the shoreline that is safely above the erosive zone of waves and tides. The area landward of the bank.

Fetch: The area in which seas are generated by a wind having a fairly constant direction and speed. Sometimes used synonymously with fetch length (USACE, 1984).

Flood tide: The period of tide between low water and the succeeding high water; a rising tide (USACE, 1984).

Flow alteration: A category of hydromodification activities that results in either an increase or a decrease in the usual supply of fresh water to a stream, river, or estuary.

Foreshore: The part of the shore, lying between the crest of the seaward berm (or upper limit of wave wash at high tide) and the ordinary low-water mark, that is ordinarily traversed by the uprush and back rush of the waves as the tides rise and fall. See *beach face*. (USACE, 1984)

Freeboard: The additional height of a structure above design high-water level to prevent overflow. Also, at a given time, the vertical distance between the water level and the top of the structure. On a ship, the distance from the waterline to main deck or gunwale (USACE, 1984).

Froude number: The dimensionless ratio of the inertial force to the force of gravity for a given fluid flow. It may be given as Fr = V/Lg ,where V is a characteristic velocity, L is a characteristic length, and g the acceleration of gravity—or as the square root of this number. (USACE, 1984)

Gabion: A rectangular basket or mattress made of galvanized, and sometimes PVC-coated, steel wire in a hexagonal mesh. Gabions are generally subdivided into equal-sized cells that are wired together and filled with 4- to 8-inch-diameter stone, forming a large, heavy mass that can be used as a shore-protection device. (USACE, 1990)

Generation of waves: (1) The creation of waves by natural or mechanical means. (2) The creation and growth of waves caused by a wind blowing over a water surface for a certain period of time (USACE, 1984).

Geomorphology: That branch of both physiography and geology that deals with the form of the Earth, the general configuration of its surface, and the changes that take place in the evolution of landform (USACE, 1984).

Grade stabilization structure: A structure used to control the grade and head cutting in natural or artificial channels (USDA-SCS, 1988).

Gradient (grade): See *slope*. With reference to winds or currents, the rate of increase or decrease in speed, usually in the vertical; or the curve that represents this rate (USACE, 1984).

Gravel: See *soil classification* (USACE, 1984).

Groin: A shore protection structure built (usually perpendicular to the shoreline) to trap littoral drift or retard erosion of the shore (USACE, 1984).

Groin system: A series of groins acting together to protect a section of beach. Commonly called a groin field. (USACE, 1984)

Ground water: Subsurface water occupying the zone of saturation. In a strict sense, the term is applied only to water below the water table (USACE, 1984).

Habitat: The place where an organism naturally lives or grows.

Harbor: Any protected water area affording a place of safety for vessels. See also *port*. (USACE, 1984)

Headland breakwater: A shore-connected breakwater (USACE, 1990).

Headland (head): A high, steep-faced promontory extending into the sea (USACE, 1984).

Height of wave: See *wave height* (USACE, 1984).

High tide, high water: The maximum elevation reached by each rising tide (USACE, 1984).

High water line: The intersection of the plane of mean high water with the shore. The shoreline delineated on the nautical charts of the National Ocean Service is an approximation of the high water line. For specific occurrences, the highest elevation on the shore reached during a storm or rising tide, including meteorological effects (USACE, 1984).

Hurricane: An intense tropical cyclone in which winds tend to spiral inward toward a core of low pressure, with maximum surface wind velocities that equal or exceed 33.5 meters per second (75 mph or 65 knots) for several minutes or longer at some points. *Tropical storm* is the term applied if maximum winds are less than 33.5 meters per second. (USACE, 1984)

Hydrography: (1) A configuration of an underwater surface including its relief, bottom materials, coastal structures, etc. (2) The description and study of seas, lakes, rivers, and other waters (USACE, 1984).

Hydrologic modification: The alteration of the natural circulation or distribution of water by the placement of structures or other activities (USEPA, 1992).

Hydromodification: Alteration of the hydrologic characteristics of coastal and noncoastal waters, which in turn could cause degradation of water resources.

Impoundment: The collection and confinement of water as in a reservoir or dam.

Inlet: (1) A short, narrow waterway connecting a bay, lagoon, or similar body of water with a large parent body of water. (2) An arm of the sea (or other body of water) that is long compared to its width and may extend a considerable distance inland. See also *tidal inlet*. (USACE, 1984)

Inshore (zone): In beach terminology, the zone of variable width extending from the low water line through the breaker zone. See also *shoreface*. (USACE, 1984)

Jetty: (United States usage) On open seacoasts, a structure extending into a body of water, which is designed to prevent shoaling of a channel by littoral materials and to direct and confine the stream or tidal flow. Jetties are built at the mouths of rivers or tidal inlets to help deepen and stabilize a channel. (USACE, 1984)

Lagoon: A shallow body of water, like a pond or lake, usually connected to the sea (USACE, 1984).

Levee: An embankment or shaped mound for flood control or hurricane protection (USACE, 1981a).

Littoral: Of or pertaining to a shore, especially of the sea (USACE, 1984).

Littoral current: See *current, littoral* (USACE, 1984).

Littoral drift: The sedimentary material moved in the littoral zone under the influence of waves and currents (USACE, 1984).

Littoral transport: The movement of littoral drift in the littoral zone by waves and currents. Includes movement parallel (longshore transport) and perpendicular (on-offshore transport) to the shore (USACE, 1984).

Littoral zone: In beach terminology, an indefinite zone extending seaward from the shoreline to just beyond the breaker zone (USACE, 1984).

Load: The quantity of sediment transported by a current. It includes the suspended load of small particles and the bedload of large particles that move along the bottom. (USACE, 1984)

Longshore: Parallel to and near the shoreline; *alongshore* (USACE, 1984).

Longshore current: See *current, longshore*.

Longshore transport rate: Rate of transport of sedimentary material parallel to the shore. Usually expressed in cubic meters (cubic yards) per year. Commonly synonymous with *littoral transport rate*. (USACE, 1984)

Low tide, low water: The minimum elevation reached by each falling tide. See *tide*. (USACE, 1984)

Low water datum: An approximation to the plane of mean low water that has been adopted as a standard reference plane (USACE, 1984).

Mangrove: A tropical tree with interlacing prop roots, confined to low-lying brackish areas (USACE, 1984).

Marsh: An area of soft, wet, or periodically inundated land, generally treeless and usually characterized by grasses and other low growth (USACE, 1984).

Marsh, salt: A marsh periodically flooded by salt water (USACE, 1984).

Marsh vegetation: Plants that grow naturally in a marsh.

Mean high water: The average height of the high waters over a 19-year period. For shorter periods of observations, corrections are applied to eliminate known variations and reduce the results to the equivalent of a mean 19-year value. All low-water heights are included in the average where the type of field is either semidiurnal or mixed. Only lower-low water heights are included in the average where the type of tide is diurnal. So determined, mean low water in the latter case is the same as mean lower low water.

Mean sea level: The average height of the surface of the sea for all stages of the tide over a 19-year period, usually determined from hourly height readings. Not necessarily equal to *mean tide level*. (USACE, 1984)

Mean tide level: A plane midway between *mean high water* and *mean low water*. Not necessarily equal to *mean sea level*. (USACE, 1984)

Meander: A bend in a river.

Mud: A fluid-to-plastic mixture of finely divided particles of solid material and water (USACE, 1984).

Nearshore (zone): In beach terminology an indefinite zone extending seaward from the shoreline well beyond the breaker zone. It defines the area of *nearshore currents*. (USACE, 1984)

Nearshore current system: The current system that is caused primarily by wave action in and near the breaker zone and consists of four parts: the shoreward mass transport of water; longshore currents; the seaward return flow, including rip currents; and the longshore movement of the expanding heads of rip currents (USACE, 1984).

Nourishment: The process of replenishing a beach. It may be brought about naturally by longshore transport or artificially by the deposition of dredged materials. (USACE, 1984)

Oceanography: The study of the sea, embracing and indicating all knowledge pertaining to the sea's physical boundaries, the chemistry and physics of seawater, and marine biology (USACE, 1984).

Offshore: (1) In beach terminology, the comparatively flat zone of variable width, extending from the breaker zone to the seaward edge of the Continental Shelf. (2) A direction seaward from the shore. (USACE, 1984)

Offshore current: (1) Any current in the offshore zone. (2) Any current flowing away from shore. (USACE, 1984)

Onshore: A direction landward from the sea (USACE, 1984).

Overtopping: Passing of water over the top of a structure as a result of wave runup or surge action (USACE, 1984).

Overwash: That portion of the uprush that carries over the crest of a berm or of a structure (USACE, 1984).

Oxbow: An isolated lake formed by a bend in a river that becomes disconnected from the river channel.

Parapet: A low wall built along the edge of a structure such as a seawall or quay (USACE, 1984).

Peninsula: An elongated body of land nearly surrounded by water and connected to a large body of land (USACE, 1984).

Percolation: The process by which water flows through the interstices of a sediment. Specifically, in wave phenomena, the process by which wave action forces water through the interstices of the bottom sediment and which tends to reduce wave heights. (USACE, 1984)

Pier: A structure, usually of open construction, extending out into the water from the shore, to serve as a landing place, recreational facility, etc., rather than to afford coastal protection. In the Great Lakes, a term sometimes improperly applied to jetties. (USACE, 1984)

Pile: A long, heavy timber or section of concrete or metal to be driven or jetted into the earth or seabed to serve as a support or protection (USACE, 1984).

Pile, sheet: A pile with a generally slender flat cross section to be driven into the ground or seabed and meshed or interlocked with like members to form a diaphragm, wall, or bulkhead (USACE, 1984).

Piling: A group of piles (USACE, 1984).

Plain, coastal: See *coastal plain* (USACE, 1984).

Plainform: The outline or shape of a body of water as determined by the stillwater line (USACE, 1984).

Point: The extreme end of a cape; the outer end of any land area protruding into the water, usually less prominent than a cape (USACE, 1984).

Port: A place where vessels may discharge or receive cargo; it may be the entire harbor, including its approaches and anchorages, or only the commercial part of a harbor where quays, wharves, facilities for transfer of cargo, docks, and repair shops are situated (USACE, 1984).

Preexisting: Existing before a specified time or event (Morris, 1978).

Profile, beach: The intersection of the ground surface with a vertical plane; may extend from the top of the dune line to the seaward limit of sand movement (USACE, 1984).

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Quarrystone: Any stone processed from a quarry (USACE, 1984).

Recession (of a beach): (1) A continuing landward movement of the shoreline. (2) A net landward movement of the shoreline over a specified time (USACE, 1984).

Reflected wave: That part of an incident wave that is returned seaward when a wave impinges on a steep beach, barrier, or other reflecting surface (USACE, 1984).

Refraction (of water waves): (1) The process by which the direction of a wave moving in shallow water at an angle to the contours is changed; the part of the wave advancing in shallower water moves more slowly than that part still advancing in deeper water, causing the wave crest to bend toward alignment with the underwater contours. (2) The bending of wave crests by currents. (USACE, 1984)

Retreat: To move in a landward direction away from an eroding streambank or shoreline.

Revetment: A facing of stone, concrete, etc., built to protect a scarp, embankment, or shore structure against erosion by wave action or currents (USACE, 1984).

Riparian: Pertaining to the banks of a body of water (USACE, 1984).

Riparian area: Vegetated ecosystems along a waterbody through which energy, materials, and water pass. Riparian areas characteristically have a high water table and are subject to periodic flooding and influence from the adjacent waterbody. These systems encompass wetlands, uplands, or some combination of these two land forms; they will not in all cases have all of the characteristics necessary for them to be classified as wetlands. (Mitsch and Gosselink, 1986; Lowrance et al., 1988)

Riprap: A protective layer or facing of quarrystone, usually well graded within wide size limit, randomly placed to prevent erosion, scour, or sloughing of an embankment of bluff; also the stone so used. The quarrystone is placed in a layer at least twice the thickness of the 50 percent size, or 1.25 times the thickness of the largest size stone in the gradation.

Rubble: (1) Loose, angular, waterworn stones along a beach. (2) Rough, irregular fragments of broken rock. (USACE, 1984)

Rubble-mound structure: A mound of randomly-shaped and randomly-placed stones protected with a cover layer of selected stones or specially shaped concrete armor units. (Armor units in a primary cover layer may be placed in an orderly manner or dumped at random.) (USACE, 1984)

Run-of-the-river dam: Usually a low dam with small hydraulic head, limited storage area, short detention time, and no positive control over lake storage.

Runup: The rush of water up a structure or beach on the breaking of a wave. Also *uprush*, *swash*. The amount of runup is the vertical height above still-water level to which the rush of water reaches. (USACE, 1984)

Salt marsh: A marsh periodically flooded by salt water (USACE, 1984).

Sand: See *soil classification* (USACE, 1984).

Sandbar: (1) See *bar*. (2) In a river, a ridge of sand built up to or near the surface by river currents. (USACE, 1984)

Sand bypassing: See *bypassing, sand* (USACE, 1984).

Scour: Removal of underwater material by waves and currents, especially at the base or toe of a shore structure (USACE, 1984).

Seawall: A structure separating land and water areas, primarily designed to prevent erosion and other damage due to wave action (USACE, 1984).

Shoal (noun): A detached elevation of the sea bottom, composed of any material except rock or coral, which may endanger surface navigation (USACE, 1984).

Shoal (verb): (1) To become shallow gradually. (2) To cause to become shallow. (3) To proceed from a greater to a lesser depth of water. (USACE, 1984)

Shore: The narrow strip of land in immediate contact with the sea, including the zone between high and low water lines. A shore of unconsolidated material is usually called a *beach*. (USACE, 1984)

Shoreface: The narrow zone seaward from the low tide *shoreline*, covered by water, over which the beach sands and gravels actively oscillate with changing wave conditions (USACE, 1984).

Shoreline: The intersection of a specified plane of water with the shore or beach (e.g., the high water shoreline would be the intersection of the plane of mean high water with shore or beach). The line delineating the shoreline on National Ocean Service nautical charts and surveys approximates the mean high water line. (USACE, 1984)

Silt: See *soil classification* (USACE, 1984).

Slip: A berthing space between two piers (USACE, 2984).

Slope: The degree of inclination to the horizontal. Usually expressed as a ratio, such as 1:25 or 1 on 25, indicating 1 unit vertical rise in 25 units of horizontal distance, or in a decimal fraction (0.04); degrees (2° 18'), or percent (4 percent). (USACE, 1984)

Soil classification (size): An arbitrary division of a continuous scale of grain sizes such that each scale unit or grade may serve as a convenient class interval for conducting the analysis or for expressing the results of an analysis (USACE, 1984).

Spit: A small point of land or a narrow shoal projecting into a body of water from the shore (USACE, 1984).

Splash zone: Area along the shoreline above the zone of influence of waves and tides that is still wetted by the spray from breaking waves.

Storage dam: Typically a high dam with large hydraulic head, long detention time, and positive control over the volume of water released from the impoundment.

Stream: (1) A course of water flowing along a bed in the earth. (2) A current in the sea formed by wind action, water density differences, etc.; e.g., the Gulf Stream. See also *current, stream*. (USACE, 1984)

Suspended load: (1) The material moving in suspension in a fluid, kept up by the upward components of the turbulent currents or by colloidal suspension. (2) The material collected in or computed from samples collected with a suspended load sampler. Where it is necessary to distinguish between the two meanings given above, the first one may be called the "true suspended load." (USACE, 1984)

Tailwater: Channel or stream below a dam (Walberg et al., 1981).

Tidal flats: Marshy or muddy land areas that are covered and uncovered by the rise and fall of the tide (USACE, 1984).

Tidal inlet: (1) A natural inlet maintained by tidal flow. (2) Loosely, an inlet in which the tide ebbs and flows. Also *tidal outlet*. (USACE, 1984)

Tidal period: The interval of time between two consecutive, like phases of the tide (USACE, 1984).

Tidal range: The difference in height between consecutive high and low (or higher high and lower low) waters (USACE, 1984).

Tide: The periodic rising and falling of the water that results from gravitational attraction of the Moon and Sun and other astronomical bodies acting upon the rotating Earth. Although the accompanying horizontal movement of the water resulting from the same cause is also sometimes called the tide, it is preferable to designate the latter as *tidal current*, reserving the name *tide* for the vertical movement. (USACE, 1984)

Topography: The configuration of a surface, including its relief and the positions of its streams, roads, building, etc. (USACE, 1984).

Tropical storm: A tropical cyclone with maximum winds of less than 34 meters per second (75 miles per hour). Compare *hurricane*. (USACE, 1984)

Updrift: The direction opposite that of the predominant movement of littoral materials (USACE, 1984).

Upland: Ground elevated above the lowlands along rivers or between hills (Merriam-Webster, 1991).

Waterline: A juncture of land and sea. This line migrates, changing with the tide or other fluctuation in the water level. Where waves are present on the beach, this line is also known as the limit of backrush. (Approximately, the intersection of the land with the still-water level.) (USACE, 1984)

Wave: A ridge, deformation, or undulation of the surface of a liquid (USACE, 1984).

Wave height: The vertical distance between a crest and the preceding trough (USACE, 1984).

Wave period: The time required for a wave crest to traverse a distance equal to one wavelength. The time required for two successive wave crests to pass a fixed point. (USACE, 1984)

Wave, reflected: That part of an incident wave that is returned seaward when a wave impinges on a steep beach, barrier, or other reflecting surface (USACE, 1984).

Wetlands: Those areas that are inundated or saturated by surface water or ground water at a frequency and duration to support, and that under normal circumstances do support, a prevalence of vegetation typically adapted for life in saturated soil conditions; wetlands generally include swamps, marshes, bogs, and similar areas. (This definition is consistent with the Federal definition at 40 CFR 230.3, promulgated December 24, 1980. As amendments are made to the wetland definition, they will be considered applicable to this guidance.)

Wind waves: (1) Waves being formed and built up by the wind. (2) Loosely, any waves generated by wind. (USACE, 1984)

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CHAPTER 7: Management Measures for Wetlands, Riparian Areas, and Vegetated Treatment Systems

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I. INTRODUCTION

A. What "Management Measures" Are

This chapter specifies management measures to protect and restore wetlands and riparian areas to protect coastal waters from coastal nonpoint pollution. "Management measures" are defined in section 6217 of the Coastal Zone Act Reauthorization Amendments of 1990 (CZARA) as economically achievable measures to control the addition of pollutants to our coastal waters, which reflect the greatest degree of pollutant reduction achievable through the application of the best available nonpoint pollution control practices, technologies, processes, siting criteria, operating methods, or other alternatives.

These management measures will be incorporated by States into their coastal nonpoint programs, which under CZARA are to provide for the implementation of management measures that are "in conformity" with this guidance. Under CZARA, States are subject to a number of requirements as they develop and implement their Coastal Nonpoint Pollution Control Programs in conformity with this guidance and will have some flexibility in doing so. The application of these management measures by States to activities causing nonpoint pollution is described more fully in *Coastal Nonpoint Pollution Control Program: Program Development and Approval Guidance*, published jointly by the U.S. Environmental Protection Agency (EPA) and the National Oceanic and Atmospheric Administration (NOAA).

B. What "Management Practices" Are

In addition to specifying management *measures*, this chapter also lists and describes management *practices* for illustrative purposes only. While State programs are required to specify management *measures* in conformity with this guidance, State programs need not specify or require the implementation of the particular management *practices* described in this document. However, as a practical matter, EPA anticipates that the management measures generally will be implemented by applying one or more management practices appropriate to the source, location, and climate. The practices listed in this document have been found by EPA to be representative of the types of practices that can be applied successfully to achieve the management measures. EPA has also used some of these practices, or appropriate combinations of these practices, as a basis for estimating the effectiveness, costs, and economic impacts of achieving the management measures. (Economic impacts of the management measures are addressed in a separate document entitled *Economic Impacts of EPA Guidance Specifying Management Measures for Sources of Nonpoint Pollution in Coastal Waters*.)

EPA recognizes that there is often site-specific, regional, and national variability in the selection of appropriate practices, as well as in the design constraints and pollution control effectiveness of practices. The list of practices for each management measure is not all-inclusive and does not preclude States or local agencies from using other technically and environmentally sound practices. In all cases, however, the practice or set of practices chosen by a State needs to achieve the management measure.

C. Scope of This Chapter

This chapter contains management measures that address multiple categories of nonpoint source (NPS) pollution that affect coastal waters. The primary NPS pollutants addressed are sediment, nitrogen, phosphorus, and temperature. This chapter is divided into three management measures:

(1) Protection of Wetlands and Riparian Areas;
(2) Restoration of Wetlands and Riparian Areas; and
(3) Promoting the Use of Vegetated Treatment Systems, such as Constructed Wetlands and Vegetated Filter Strips.

Each category of management measure is addressed in a separate section of this guidance. Each section contains (1) the management measure; (2) an applicability statement that describes, when appropriate, specific activities and locations for which the measure is suitable; (3) a description of the management measure's purpose; (4) the basis for the management measure's selection; (5) information on management practices that are suitable, either alone or in combination with other practices, to achieve the management measure; (6) information on the effectiveness of the management measure and/or of practices to achieve the measure; and (7) information on costs of the measure and/or of practices to achieve the measure.

CZARA requires EPA to specify management measures to control nonpoint pollution from various sources. Wetlands, riparian areas, and vegetated treatment systems have important potential for reducing nonpoint pollution in coastal waters from a variety of sources. Degradation of existing wetlands and riparian areas can cause the wetlands or riparian areas themselves to become sources of nonpoint pollution in coastal waters. Such degradation can result in the inability of existing wetlands and riparian areas to treat nonpoint pollution. Therefore, management measures are presented in this chapter specifying the control of nonpoint pollution through (1) protection of the full range of functions of wetlands and riparian areas to ensure continuing nonpoint source pollution abatement, (2) restoration of degraded systems, and (3) the use of vegetated treatment systems.

The intent of the three wetlands management measures is to ensure that the nonpoint benefits of protecting and restoring wetlands and riparian areas, and of constructing vegetated treatment systems, will be considered in all coastal watershed water pollution control activities. These management measures form an essential element of any State Coastal Nonpoint Pollution Control Program.

There is substantial evidence in the literature, and from case studies, that one important function of both natural and human-made wetlands is the removal of nonpoint source pollutants from storm water. Much of this literature is cited in this chapter. These pollutants include sediment, nitrogen, and phosphorus (Whigham et al., 1988; Cooper et al., 1987; Brinson et al., 1984). Also, wetlands and riparian areas have been shown to attenuate flows from higher-than-average storm events, thereby protecting receiving waters from peak flow hydraulic impacts such as channel scour, streambank erosion, and fluctuations in temperature and chemical characteristics of surface waters (Mitsch and Gosselink, 1986; Novitzki, 1979).

A degraded wetland has less ability to remove nonpoint source pollutants and to attenuate storm water peak flows (Richardson and Davis, 1987; Bedford and Preston, 1988). Also, a degraded wetland can deliver increased amounts of sediment, nutrients, and other pollutants to the adjoining waterbody, thereby acting as a source of nonpoint pollution instead of a treatment (Brinson, 1988).

Therefore, the first management measure is intended to protect the full range of functions for wetlands and riparian areas serving a nonpoint source abatement function. This protection will preserve their value as a nonpoint source control and help to ensure that they do not become a significant nonpoint source due to degradation.

The second management measure promotes the restoration of degraded wetlands and riparian systems with nonpoint source control potential for similar reasons: the increase in pollutant loadings that can result from degradation of wetlands and riparian areas, and the substantial evidence in the literature on effectiveness of wetlands and riparian areas for nonpoint pollution abatement. In addition, there may be other benefits of restoration to wildlife and aquatic

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organisms. This measure provides for evaluation of degraded wetlands and riparian systems, and for restoration if the systems will serve a nonpoint source pollution abatement function (e.g., by cost-effectively treating nonpoint source pollution or by attenuating peak flows).

The third management measure promotes the use of vegetated treatment systems because of their wide-scale ability to treat a variety of sources of nonpoint pollution. This measure will apply, as appropriate, to all other chapters in this guidance. Placing the large amount of information on vegetated treatment systems in one management measure avoids duplication in most other 6217(g) measures and thereby limits the potential for confusion. All descriptions, applications, case studies, and costs are in one measure within the CZARA 6217(g) guidance and are cross-referenced in the management measures for which these systems are a potential nonpoint pollution control. Also, all positive and negative aspects of design, construction, and operation have been included in one place to avoid confusion in applications due to potential inconsistencies from placement in multiple measures.

D. Relationship of This Chapter to Other Chapters and to Other EPA Documents

1. Chapter 1 of this document contains detailed information on the legislative background for this guidance, the process used by EPA to develop this guidance, and the technical approach used by EPA in the guidance.

2. Chapter 3 of this document contains a management measure and accompanying information on forestry practices in wetlands and protection of wetlands subject to forestry operations.

3. Chapter 8 of this document contains information on recommended monitoring techniques (1) to ensure proper implementation, operation, and maintenance of the management measures and (2) to assess over time the success of the measures in reducing pollution loads and improving water quality.

4. EPA has separately published a document entitled *Economic Impacts of EPA Guidance Specifying Management Measures for Sources of Nonpoint Pollution in Coastal Waters.*

5. NOAA and EPA have jointly published guidance entitled *Coastal Nonpoint Pollution Control Program: Program Development and Approval Guidance*. This guidance contains details on how State Coastal Nonpoint Pollution Control Programs are to be developed by States and approved by NOAA and EPA. It includes guidance on the following:

   - The basis and process for EPA/NOAA approval of State Coastal Nonpoint Pollution Control Programs;
   - How NOAA and EPA expect State programs to provide for the implementation of management measures "in conformity" with this management measures guidance;
   - How States may target sources in implementing their Coastal Nonpoint Pollution Control Programs;
   - Changes in State coastal boundaries; and
   - Requirements concerning how States are to implement their Coastal Nonpoint Pollution Control Programs.

E. Definitions and Background Information

The preceding five chapters of this guidance have specified management measures that represent the most effective systems of practices that are available to prevent or reduce coastal nonpoint source (NPS) pollution from five specific categories of sources. In this chapter, management measures that apply to a broad variety of sources, including the five categories of sources addressed in the preceding chapters, are specified. These measures promote the protection and restoration of wetlands and riparian areas and the use of vegetated treatment systems as means to control the nonpoint pollution emanating from such nonpoint sources. Management measures for protection and restoration of wetlands and riparian areas are developed as part of NPS and coastal management programs to take into consideration the multiple functions and values these ecosystems provide to ensure continuing nonpoint source pollution abatement.

1. Wetlands and Riparian Areas

For purposes of this guidance, *wetlands* are defined as:

> Those areas that are inundated or saturated by surface or ground water at a frequency and duration sufficient to support, and that under normal circumstances do support, a prevalence of vegetation typically adapted for life in saturated soil conditions. Wetlands generally include swamps, marshes, bogs, and similar areas.[1]

Wetlands are usually waters of the United States and as such are afforded protection under the Clean Water Act (CWA). Although the focus of this chapter is on the function of wetlands in reducing NPS pollution, it is important to keep in mind that wetlands are ecological systems that perform a range of functions (e.g., hydrologic, water quality, or aquatic habitat), as well as a number of pollutant removal functions.

For purposes of this guidance, *riparian areas* are defined as:

> Vegetated ecosystems along a waterbody through which energy, materials, and water pass. Riparian areas characteristically have a high water table and are subject to periodic flooding and influence from the adjacent waterbody. These systems encompass wetlands, uplands, or some combination of these two land forms. They will not in all cases have all of the characteristics necessary for them to be classified as wetlands.[2]

Figure 7-1 illustrates the general relationship between wetlands, uplands, riparian areas, and a stream channel. Identifying the exact boundaries of wetlands or riparian areas is less critical than identifying ecological systems of concern. For instance, even those riparian areas falling outside wetland boundaries provide many of the same important water quality functions that wetlands provide. In many cases, the area of concern may include an upland buffer adjacent to sensitive wetlands or riparian areas that protects them from excessive NPS impacts or pretreats the inflowing surface waters.

Wetlands and riparian areas can play a critical role in reducing NPS pollution, by intercepting surface runoff, subsurface flow, and certain ground-water flows. Their role in water quality improvement includes processing, removing, transforming, and storing such pollutants as sediment, nitrogen, phosphorus, and certain heavy metals. Thus, wetlands and riparian areas buffer receiving waters from the effects of pollutants, or they prevent the entry of pollutants into receiving waters.

The functions of wetlands and riparian areas include water quality improvement, aquatic habitat, stream shading, flood attenuation, shoreline stabilization, and ground-water exchange. Wetlands and riparian areas typically occur as natural buffers between uplands and adjacent waterbodies. Loss of these systems allows for a more direct contribution of NPS pollutants to receiving waters. The pollutant removal functions associated with wetlands and riparian area vegetation and soils combine the physical process of filtering and the biological processes of nutrient uptake and denitrification (Lowrance et al., 1983; Peterjohn and Correll, 1984). Riparian forests, for example, have been found to contribute to the quality of aquatic habitat by providing cover, bank stability, and a source of organic

[1] This definition is consistent with the Federal definition at 40 CFR 230.3, promulgated December 24, 1980. As amendments are made to the wetland definition, they will be considered applicable to this guidance.

[2] This definition is adapted from the definitions offered previously by Mitsch and Gosselink (1986) and Lowrance et al. (1988).

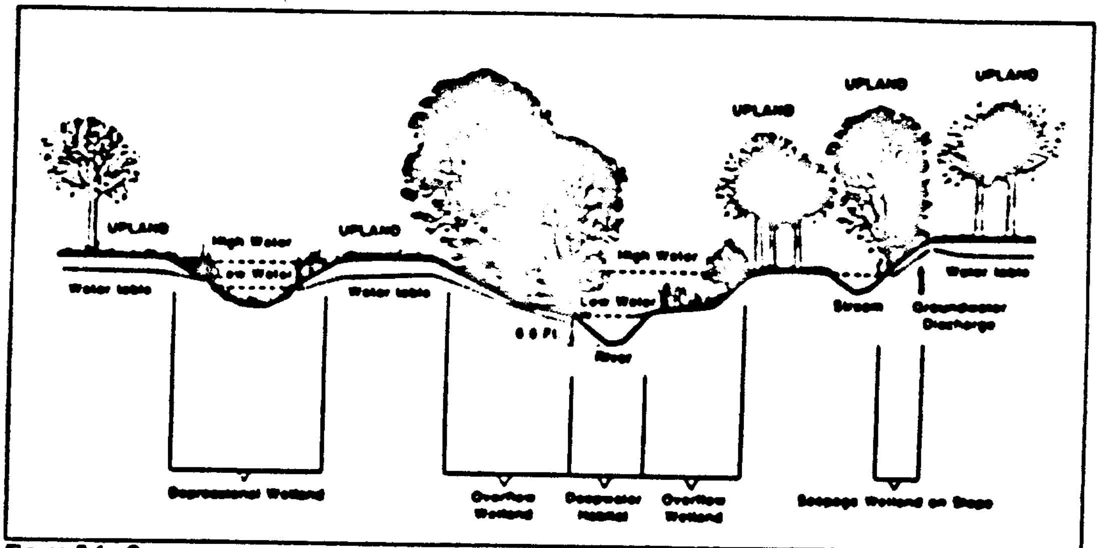

Figure 7-1. Cross section showing the general relationship between wetlands, uplands, riparian areas, and a stream channel (Burke et al., 1988).

carbon for microbial processes such as denitrification (James et al., 1990; Pinay and Decamps, 1988). Riparian forests have also been found to be effective at reducing instream pollution during flood flows (Karr and Gorman, 1975; Kleiss et al., 1989).

In highly developed urban areas, wetlands and riparian areas may be virtually destroyed by construction, filling, channelization, or other significant alteration. In agricultural areas, wetlands and riparian areas may be impacted by overuse of the area for grazing or by removal of native vegetation and replacement by annual crops or perennial cover. In addition, significant hydrologic alterations may have occurred to expedite drainage of farmland. Other significant impacts may occur as a result of various activities such as highway construction, surface mining, deposition of dredged material, and excavation of ports and marinas. All of these activities have the potential to degrade or destroy the water quality improvement functions of wetlands and riparian areas and may exacerbate NPS problems.

A wetland's position in the landscape affects its water quality functions. Some cases have been studied sufficiently to predict how an individual wetland will affect water quality on a landscape scale (Whigham et al., 1988). Wetlands that border first-order streams were found by Whigham and others (1988) to be efficient at removing nitrate from ground water and sediment from surface waters. They were not found to be as efficient in removing phosphorus. When located downstream from first-order streams, wetlands and riparian areas were found to be less effective at removing sediment and nutrient from the stream itself because of a smaller percentage of stream water coming into contact with the wetlands (Whigham et al., 1988). It has also been estimated that the portion of a wetland or riparian area immediately below the source of nonpoint pollution may be the most effective filter (Cooper et al., 1986; Lowrance et al., 1983; Phillips, 1989).

Although wetlands and riparian areas reduce NPS pollution, they do so within a definite range of operational conditions. When hydrologic changes or NPS pollutants exceed the natural assimilative capacity of these systems, wetland and riparian areas become stressed and may be degraded or destroyed. Therefore, wetlands and riparian areas should be protected from changes that would degrade their existing functions. Furthermore, degraded wetlands and riparian areas should be restored, where possible, to serve an NPS pollution abatement function.

2. Vegetated Buffers

For the purpose of this guidance, *vegetated buffers* are defined as:

> Strips of vegetation separating a waterbody from a land use that could act as a nonpoint pollution source. Vegetated buffers (or simply buffers) are variable in width and can range in function from a vegetated filter strip to a wetland or riparian area.

This term is currently used in many contexts, and there is no agreement on any single concept of what constitutes a buffer, what activities are acceptable in a buffer zone, or what is an appropriate buffer width. In one usage, the term *vegetated buffer* refers to natural riparian areas that are either set aside or restored to filter pollutants from runoff and to maintain the ecological integrity of the waterbody and the land adjacent to it (Nieswand et al., 1989). In another usage, the term *vegetated buffer* refers to constructed strips of vegetation used in various settings to remove pollutants in runoff from a developed site (Nieswand et al., 1989). Finally, the term *vegetated buffer* can be used to describe a transition zone between an urbanized area and a naturally occurring riparian forest (Faber et al., 1989). In this context, buffers can be designed to provide value to wildlife as well as aesthetic value.

A vegetated buffer usually has a rough surface and typically contains a heterogeneous mix of ground cover, including herbaceous and woody species of vegetation (Stewardship Incentive Program, 1991; Swift, 1986). This mix of vegetation allows the buffer to function more like a wetland or riparian area. A vegetated filter strip (see below) can also be constructed to remove pollutants in runoff from a developed site, but a filter strip differs from a vegetated buffer in that a filter strip typically has a smooth surface and a vegetated cover made up of a homogeneous species of vegetation (Dillaha et al., 1989a).

Vegetated buffers can possess characteristics and functions ranging from those of a riparian area to those of a vegetated filter strip. To avoid confusion, the term *vegetated buffer* will not be discussed further in this chapter although the term is used in other chapters of this guidance.

3. Vegetated Treatment Systems

For purposes of this guidance, *vegetated treatment systems* (VTS) are defined to include either of the following or a combination of both: vegetated filter strips and constructed wetlands. Both of these systems have been defined in the scientific literature and have been studied individually to determine their effectiveness in NPS pollutant removal.

In this guidance, *vegetated filter strips* (VFS) are defined as (Dillaha et al., 1989a):

> Created areas of vegetation designed to remove sediment and other pollutants from surface water runoff by filtration, deposition, infiltration, adsorption, absorption, decomposition, and volatilization. A vegetated filter strip is an area that maintains soil aeration as opposed to a wetland that, at times, exhibits anaerobic soil conditions.

In this guidance, *constructed wetlands* are defined as (Hammer, 1992):

> Engineered systems designed to simulate natural wetlands to exploit the water purification functional value for human use and benefits. Constructed wetlands consist of former upland environments that have been modified to create poorly drained soils and wetlands flora and fauna for the primary purpose of contaminant or pollutant removal from wastewaters or runoff. Constructed wetlands are essentially wastewater treatment systems and are designed and operated as such though many systems do support other functional values.

In areas where naturally occurring wetlands or riparian areas do not exist, VTS can be designed and constructed to perform some of the same functions. When such engineered systems are installed for a specific NPS-related purpose, however, they may not offer the same range of functions that naturally occurring wetlands or riparian areas offer.

Vegetated treatment systems have been installed in a wide range of settings, including cropland, pastureland, forests, and developed, as well as developing, urban areas, where the systems can perform a complementary function of sediment control and surface water runoff management. Practices for use of vegetated treatment systems are discussed in other chapters of this guidance, and VTS should be considered to have wide-ranging applicability to various NPS categories.

When properly installed and maintained, VFS have been shown to effectively prevent the entry of sediment, sediment-bound pollutants, and nutrients into waterbodies. Vegetated filter strips reduce NPS pollutants primarily by filtering water passing over or through the strips. Properly designed and maintained vegetated filter strips can substantially reduce the delivery of sediment and some nutrients to coastal waters from nonpoint sources. With proper planning and maintenance, vegetated filter strips can be a beneficial part of a network of NPS pollution control measures for a particular site. Vegetated filter strips are often coupled with practices that reduce nutrient inputs, minimize soil erosion, or collect runoff. Where wildlife needs are factored into the design, vegetated filter strips or buffers in urban areas can add to the urban environment by providing wildlife nesting and feeding sites, in addition to serving as a pollution control measure. However, some vegetated filter strips require maintenance such as mowing of grass or removal of accumulated sediment. These and other maintenance activities may preclude much of their value for wildlife, for example by disturbing or destroying nesting sites.

Constructed wetlands are designed to mimic the pollutant-removal functions of natural wetlands but usually lack aquatic habitat functions and are not intended to provide species diversity. Pollutant removal in constructed wetlands is accomplished by several mechanisms, including sediment trapping, plant uptake, bacterial decomposition, and adsorption. Properly designed constructed wetlands filter and settle suspended solids. Wetland vegetation used in constructed wetlands converts some pollutants (i.e., nitrogen, phosphorus, and metals) into plant biomass (Watson et al., 1988). Nitrification, denitrification, and organic decomposition are bacterial processes that occur in constructed wetlands. Some pollutants, such as phosphorus and most metals, physically attach or adsorb to soil and sediment particles. Therefore, constructed wetlands, used as a management practice, could be an important component in managing NPS pollution from a variety of sources. They are not intended to replace or destroy natural wetland areas, but to remove NPS pollution before it enters a stream, natural wetland, or other waterbody.

It is important to note that aquatic plants and benthic organisms used in constructed wetlands serve primarily to remove pollutants. Constructed wetlands may or may not be designed to provide flood storage, ground-water exchange, or other functions associated with natural wetlands. In fact, if there is a significant potential for contamination or other detrimental impacts to wildlife, constructed wetlands should be designed to discourage use by wildlife.

II. MANAGEMENT MEASURES

Protect from adverse effects wetlands and riparian areas that are serving a significant NPS abatement function and maintain this function while protecting the other existing functions of these wetlands and riparian areas as measured by characteristics such as vegetative composition and cover, hydrology of surface water and ground water, geochemistry of the substrate, and species composition.

1. Applicability

This management measure is intended to be applied by States to protect wetlands and riparian areas from adverse NPS pollution impacts. Under the Coastal Zone Act Reauthorization Amendments of 1990, States are subject to a number of requirements as they develop coastal NPS programs in conformity with this management measure and will have flexibility in doing so. The application of management measures by States is described more fully in *Coastal Nonpoint Pollution Control Program: Program Development and Approval Guidance*, published jointly by the U.S. Environmental Protection Agency (EPA) and the National Oceanic and Atmospheric Administration (NOAA) of the U.S. Department of Commerce.

2. Description

The purpose of this management measure is to protect the existing water quality improvement functions of wetlands and riparian areas as a component of NPS programs. The overall approach is to establish a set of practices that maintains functions of wetlands and riparian areas and prevents adverse impacts to areas serving an NPS pollution abatement function. The ecosystem and water quality functions of wetlands and riparian areas serving an NPS pollution abatement function should be protected by a combination of programmatic and structural practices.

The term *NPS pollution abatement function* refers to the ability of a wetland or riparian area to remove NPS pollutants from runoff passing through the wetland or riparian area. Acting as a sink for phosphorus and converting nitrate to nitrogen gas through denitrification are two examples of the important NPS pollution abatement functions performed by wetlands and riparian areas.

This management measure provides for NPS pollution abatement through the protection of wetland and riparian functions. The permit program administered by the U.S. Army Corps of Engineers, EPA, and approved States under section 404 of the Clean Water Act regulates the discharge of dredged or fill material into waters of the United States, including wetlands. The measure and section 404 program complement each other, but the focus of the two is different.

The measure focuses on nonpoint source problems in wetlands, as well as on maintaining the functions of wetlands that are providing NPS pollution abatement. The nonpoint source problems addressed include impacts resulting from upland development and upstream channel modifications that erode wetlands, change salinity, kill existing vegetation, and upset sediment and nutrient balances. The section 404 program focuses on regulating the discharge of dredged or fill materials in wetlands, thereby protecting wetlands from physical destruction and other pollutant problems that could result from discharges of dredged or fill material.

The nonpoint source pollution abatement functions performed by wetlands and riparian areas are most effective as parts of an integrated land management system that combines nutrient, sediment, and soil erosion control. These areas consist of a complex organization of biotic and abiotic elements. Wetlands and riparian areas are effective in removing suspended solids, nutrients, and other contaminants from upland runoff, as well as maintaining stream channel temperature (Table 7-1). In addition, some studies suggest that wetland and riparian vegetation acts as a nutrient sink (Table 7-1), taking up and storing nutrients (Richardson, 1988). This function may be related to the age of the wetland or riparian area (Lowrance et al., 1983). The processes that occur in these areas include sedimentation, microbial and chemical decomposition, organic export, filtration, adsorption, complexation, chelation, biological assimilation, and nutrient release.

Pollutant-removal efficiencies for a specific wetland or riparian area may be the result of a number of different factors linked to the various removal processes:

(1) Frequency and duration of flooding;
(2) Types of soils and slope;
(3) Vegetation type;
(4) The nitrogen-carbon balance for denitrifying activity (nitrate removal); and
(5) The edge-to-area ratio of the wetland or riparian area.

Watershed-specific factors include land use practices and the percentage of watershed dominated by wetlands or riparian areas.

A study performed in the southeastern United States coastal plain illustrates dramatically the role that wetlands and riparian areas play in abating NPS pollutants. Lowrance and others (1983) examined the water quality role played by mixed hardwood forests along stream channels adjacent to agricultural lands. These streamside forests were shown to be effective in retaining nitrogen, phosphorus, calcium, and magnesium. It was projected that total conversion of the riparian forest to a mix of crops typically grown on uplands would result in a twenty-fold increase in nitrate-nitrogen loadings to the streams (Lowrance et al., 1983). This increase resulted from the introduction of nitrates to promote crop development and from the loss of nitrate removal functions previously performed by the riparian forest.

3. Management Measure Selection

Selection of this management measure was based on:

(1) The opportunity to gain multiple benefits, such as protecting wetland and riparian area systems, while reducing NPS pollution;

(2) The nonpoint pollution abatement function of wetlands and riparian areas, i.e., their effectiveness in reducing loadings of NPS pollutants, especially sediment, nitrogen, and phosphorus, and in maintaining stream temperatures; and

(3) The localized increase in NPS pollution loadings that can result from degradation of wetlands and riparian areas.

Separate sections below explain each of these points in more detail.

Table 7-1. Effectiveness of Wetlands and Riparian Areas for NPS Pollution Control

No.	Location	Wetland/ Riparian	Summary of Observations	Source
1	Tar River Basin, North Carolina	Riparian Forests	This study looks at how various soil types affect the buffer width necessary for effectiveness of riparian forests to reduce loadings of agricultural nonpoint source pollutants. • A hypothetical buffer with a width of 30 m and designed to remove 90% of the nitrate nitrogen from runoff volumes typical of 50 acres of row crop on relatively poorly drained soils was used as a standard. • Udic upland soils and sandy entisols met or exceeded these standards. • The study also concluded that slope gradient was the most important contributor to the variation in effectiveness.	Phillips, J.D. 1989. Nonpoint Source Pollution Control Effectiveness of Riparian Forests Along a Coastal Plain River. *Journal of Hydrology,* 110 (1989):221-237.
2	Lake Tahoe, Nevada	Riparian	Three years of research on a headwaters watershed has shown this area to be capable of removing over 99% of the incoming nitrate nitrogen. Wetlands and riparian areas in a watershed appear to be able to "clean up" nitrate-containing waters with a very high degree of efficiency and are of major value in providing natural pollution controls for sensitive waters.	Rhodes, J., C.M. Skau, D. Greenlee, and D. Brown. 1985. Quantification of Nitrate Uptake by Riparian Forests and Wetlands in an Undisturbed Headwaters Watershed. In *Riparian Ecosystems and Their Management: Reconciling Conflicting Issues.* USDA Forest Service GTR RM-120, pp. 175-179.
3	Atchafalaya, Louisiana	Riparian	Overflow areas in the Atchafalaya Basin had large areal net exports of total nitrogen (predominantly organic nitrogen) and dissolved organic carbon but acted as a sink for phosphorus. Ammonia levels increased dramatically during the summer. The Atchafalaya Basin floodway acted as a sink for total organic carbon mainly through particulate organic carbon (POC). Net export of dissolved organic carbon was very similar to that of POC for all three areas.	Lambou, V.W. 1985. Aquatic Organic Carbon and Nutrient Fluxes, Water Quality, and Aquatic Productivity in the Atchafalaya Basin, Louisiana. In *Riparian Ecosystems and Their Management: Reconciling Conflicting Issues.* USDA Forest Service GTR RM-120, pp. 180-185.

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Table 7-1. (Continued)

No.	Location	Wetland/ Riparian	Summary of Observations	Source
4	Wyoming	Riparian	The Green River drains 12,000 mi^2 of western Wyoming and northern Utah and incorporates a diverse spectrum of geology, topography, soils, and climate. Land use is predominantly range and forest. A multiple regression model was used to associate various riparian and nonriparian basin attributes (geologic substrate, land use, channel slope, etc.) with previous measurements of phosphorus, nitrate, and dissolved solids.	Fannin, T.E., M. Parker, and T.J. Maret. 1985. Multiple Regression Analysis for Evaluating Non-point Source Contributions to Water Quality in the Green River, Wyoming. In *Riparian Ecosystems and Their Management: Reconciling Conflicting Issues*. USDA Forest Service GTR RM-120, pp. 201-205.
5	Rhode River Subwatershed, Maryland	Riparian	A case study focusing on the hydrology and below-ground processing of nitrate and sulfate was conducted on a riparian forest wetland. Nitrate and sulfate entered the wetland from cropland ground-water drainage and from direct precipitation. Data collected for 3 years to construct monthly mass balances of the fluxes of nitrate and sulfate into and out of the soils of the wetland showed: • Averages of 86% of nitrate inputs were removed in the wetland. • Averages of 25% of sulfates were removed in the wetland. • Annual removal of nitrates varied from 87% in the first year to 84% in the second year. • Annual removal of sulfate varied from 13% in the second year to 43% in the third year. • On average, inputs of nitrate and sulfate were highest in the winter. • Nitrate outputs were always highest in the winter. • Nitrate removal was always highest in the fall (average of 96%) when input fluxes were lowest and lowest in winter (average of 81%) when input fluxes were highest.	Correll, D.L., and D.E. Weller. 1989. Factors Limiting Processes in Freshwater: An Agricultural Primary Stream Riparian Forest. In *Freshwater Wetlands and Wildlife*, ed. R.R. Sharitz and J.W. Gibbons, pp. 9-23. U.S. Department of Energy, Office of Science and Technology, Oak Ridge, Tennessee. DOE Symposium Series #61.

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Table 7-1. (Continued)

No.	Location	Wetland/ Riparian	Summary of Observations	Source
6	Carmel River, California	Riparian	Ground water is closely coupled with streamflow to maintain water supply to riparian vegetation, particularly where precipitation is seasonal. A case study is presented where Mediterranean climate and ground-water extraction are linked with the decline of riparian vegetation and subsequent severe bank erosion on the Carmel River.	Groenveld, D. P., and E. Gnepentrog. 1985. Interdependence of Groundwater, Riparian Vegetation, and Streambank Stability: A Case Study. In *Riparian Ecosystems and their Management: Reconciling Conflicting Issues.* USDA Forest Service GTR RM-120, pp. 201-205.
7	Cashe River, Arkansas	Riparian	A long-term study is being conducted to determine the chemical and hydrological functions of bottomland hardwood wetlands. Hydrologic gauging stations have been established at inflow and outflow points on the river, and over 25 chemical constituents have been measured. Preliminary results for the 1988 water year indicated: • Retention of total and inorganic suspended solids and nitrate; • Exportation of organic suspended solids, total and dissolved organic carbon, inorganic carbon, total phosphorus, soluble reactive phosphorus, ammonia, and total Kjeldahl nitrogen; • All measured constituents were exported during low water when there was limited contact between the river and the wetlands; and • All measured constituents were retained when the Cypress-Tupelo part of the floodplain was inundated.	Kleiss, B. et al. 1989. Modification of Riverine Water Quality by an Adjacent Bottomland Hardwood Wetland. In *Wetlands: Concerns and Successes*, pp. 429-438. American Water Resources Association.
8	Scotsman Valley, New Zealand	Riparian	Nitrate removal in riparian areas was determined using a mass balance procedure in a small New Zealand headwater stream. The results of 12 surveys showed: • The majority of nitrate removal occurred in riparian organic soils (56-100%) even though the soils occupied only 12% of the stream's border. • The disproportionate role of organic soils in removing nitrate was due in part to their location in the riparian zone. A high percentage (37-81%) of ground water flowed through these areas on its passage to the stream. • Anoxic conditions and high concentrations of denitrifying enzymes and available carbon in the soils also contributed to the role of the organic soils in removing nitrates.	Cooper, A.B. 1990. Nitrate Depletion in the Riparian Zone and Stream Channel of a Small Headwater Catchment. *Hydrobiologia*, 202:13-26.

Table 7-1. (Continued)

No.	Location	Wetland/ Riparian	Summary of Observations	Source
9	Wye Island, Maryland	Riparian	Changes in nitrate concentrations in ground water between an agricultural field planted in tall fescue (*Festuca arundinacea*) and riparian zones vegetated by leguminous or nonleguminous trees were measured to: • Determine the effectiveness of riparian vegetation management practices in the reduction of nitrate concentrations in ground water; • Identify effects of leguminous and nonleguminous trees on riparian attenuation of nitrates; and • Measure the seasonal variability of riparian vegetation's effect on the chemical composition of ground water. Based on the analysis of shallow ground-water samples, the following patterns were observed: • Ground-water nitrate concentrations beneath non-leguminous riparian trees decreased toward the shoreline, and removal of the trees resulted in increased nitrate concentrations. • Nitrate concentrations did not decrease from the field to the riparian zone in ground water below leguminous trees, and removal of the trees resulted in decreased ground-water nitrate concentrations. • Maximum attenuation of nitrate concentrations occurred in the fall and winter under non-leguminous trees.	James, B.R., B.B. Bagley, and P.H. Gallagher, P.H. 1990. Riparian Zone Vegetation Effects on Nitrate Concentrations in Shallow Groundwater. Submitted for publication in the *Proceedings of the 1990 Chesapeake Bay Research Conference.* University of Maryland, Soil Chemistry Laboratory, College Park, Maryland.
10	Little Lost Man Creek, Humboldt, California	Riparian	Nitrate retention was evaluated in a third-order stream under background conditions and during four intervals of modified nitrate concentration caused by nutrient amendments or storm-enhanced discharge. Measurements of the stream response to nitrate loading and storm discharge showed: • Under normal background conditions, nitrate was exported from the subsurface (11% greater than input). • With increased nitrate input, there was an initial 39% reduction from the subsurface followed by a steady state reduction of 14%. • During a storm event, the subsurface area exported an increase of 6%.	Triska, F.J., V.C. Kennedy, R.J. Avanzino, G.W. Zellweger, and K.E. Bencala. 1990. In Situ Retention-Transport Response to Nitrate Loading and Storm Discharge in a Third-Order Stream. *Journal of North American Benthological Society,* 9(3):229-239.

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Table 7-1. (Continued)

No.	Location	Wetland/ Riparian	Summary of Observations	Source
11	Toronto, Ontario, Canada	Riparian	Field enrichments of nitrate in two spring-fed drainage lines showed an absence of nitrate depletion within the riparian zone of a woodland stream. The results of the study indicated: • The efficiency of nitrate removal within the riparian zone may be limited by short water residence times. • The characteristics of the substrate and the routes of ground-water movement are important in determining nitrate attenuation within riparian zones.	Warwick, J., and A.R. Hill. 1988. Nitrate Depletion in the Riparian Zone in a Small Woodland Stream. *Hydrobiologia*, 157:231-240.
12	Little River, Tifton, Georgia	Riparian	A study was conducted on riparian forests located adjacent to agricultural uplands to test their ability to intercept and utilize nutrients (N, P, K, Ca) transported from these uplands. Tissue nutrient concentrations, nutrient accretion rates, and production rates of woody plants on these sites were compared to control sites. Data from this study provide evidence that young (bloom state) riparian forests within agricultural ecosystems absorb nutrients lost from agricultural uplands.	Fail, J.L. Jr., Haines, B.L., and Todd, R.L. Undated. Riparian Forest Communities and Their Role in Nutrient Conservation in an Agricultural Watershed. *American Journal of Alternative Agriculture*, II(3):114-120.
13	Chowan River Watershed, North Carolina	Riparian	A study was conducted to determine the trapping efficiency for sediments deposited over a 20-year period in the riparian areas of two watersheds. ^{137}CS data and soil morphology were used to determine areal extent and thickness of the sediments. Results of the study showed: • Approximately 80% of the sediment measured was deposited in the floodplain swamp. • Greater than 50% of the sediment was deposited within the first 100 m adjacent to cultivated fields. • Sediment delivery estimates indicated that 84% to 90% of the sediment removed from cultivated fields remained in the riparian areas of a watershed.	Cooper, J.R., J.W. Gilliam, R.B. Daniels, and W.P. Robarge. 1987. Riparian Areas as Filters for Agriculture Sediment. *Soil Science Society of America Journal*, 51(6):417-420.
14	New Zealand	Riparian	Several recent studies in agricultural fields and forests showed evidence of significant nitrate removal from drainage water by riparian zones. The results of these studies showed: • A typical removal of nitrate of greater than 85% and • An increase of nitrate removal by denitrification where greater contact occurred between leaching nitrate and decaying vegetative matter.	Schipper, L.A., A.B. Cooper, and W.J. Dyck. 1989. Mitigating Non-point Source Nitrate Pollution by Riparian Zone Denitrification. Forest Research Institute, Rotorua, New Zealand.

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Table 7-1. (Continued)

No.	Location	Wetland/ Riparian	Summary of Observations	Source
15	Georgia	Riparian	A streamside, mixed hardwood, riparian forest near Tifton, Georgia, set in an agricultural watershed was effective in retaining nitrogen (67%), phosphorus (25%), calcium (42%), and magnesium (22%). Nitrogen was removed from subsurface water by plant uptake and microbial processes. Riparian land use was also shown to affect the nutrient removal characteristics of the riparian area. Forested areas were more effective in nutrient removal than pasture areas, which were more effective than croplands.	Lowrance, R.R., R.L. Todd, and L.E. Asmussen. 1983. Waterborne Nutrient Budgets for the Riparian Zone of an Agricultural Watershed. *Agriculture, Ecosystems and Environment*, 10:371-384.
16	North Carolina	Riparian	Riparian forests are effective as sediment and nutrient (N and P) filters. The optimal width of a riparian forest for effective filtering is based on the contributing area, slope, and cultural practices on adjacent fields.	Cooper, J. R., J. W. Gilliam, and T. C. Jacobs. 1986. Riparian Areas as a Control of Nonpoint Pollutants. In *Watershed Research Perspectives*, ed. D. Correll, Smithsonian Institution Press, Washington, DC.
17	Unknown	Riparian	A riparian forest acted as an efficient sediment trap for most observed flow rates, but in extreme storm events suspended solids were exported from the riparian area.	Karr, J.R., and O.T. Gorman. 1975. Effects of Land Treatment on the Aquatic Environment. In *U.S. EPA Non-Point Source Pollution Seminar*, pp. 4-1 to 4-18. U.S. Environmental Protection Agency, Washington, DC. EPA 905/9-75-007.
18	Arkansas	Riparian	The Army Corps of Engineers studied a 20-mile stretch of the Cashe River in Arkansas where floodplain deposition reduced suspended solids by 50%, nitrates by 80%, and phosphates by 50%.	Stuart, G., and J. Greis. 1991. *Role of Riparian Forests in Water Quality on Agricultural Watersheds.*

Table 7-1. (Continued)

No.	Location	Wetland/ Riparian	Summary of Observations	Source
19	Maryland	Riparian	Phosphorus export from the forest was nearly evenly divided between surface runoff (59%) and ground-water flow (41%), for a total P removal of 80%. The mean annual concentration of dissolved total P changed little in surface runoff. Most of the concentration changes occurred during the first 19 m of the riparian forest for both dissolved and particulate pollutants. Dissolved nitrogen compounds in surface runoff also declined. Total reductions of 79% for nitrate, 73% for ammonium-N and 62% for organic N were observed. Changes in mean annual ground-water concentrations indicated that nitrate concentrations decreased significantly (90-98%) while ammonium-N concentrations increased in concentration greater than threefold. Again, most of the nitrate loss occurred within the first 19 m of the riparian forest. Thus it appears that the major pathway of nitrogen loss from the forest was in subsurface flow (75% of the total N), with a total removal efficiency of 89% total N.	Peterjohn, W.T., and D.L. Correll. 1984. Nutrient Dynamics in an Agricultural Watershed: Observations on the Role of a Riparian Forest. *Ecology*, 65:1466-1475.
20	France	Riparian	Denitrification explained the reduction of the nitrate load in ground water beneath the riparian area. Models used to explain the nitrogen dynamics in the riparian area of the Lounge River indicate that the frequency, intensity, and duration of flooding influence the nitrogen-removal capacity of the riparian area. Three management practices in riparian areas would enhance the nitrogen-removal characteristics, including: • River flow regulation to enhance flooding in riparian areas, which increases the waterlogged soil areas along the entire stretch of river; • Reduced land drainage to raise the water table, which increases the duration and area of waterlogged soils; and • Decreased deforestation of riparian forests, which maintains the amount of carbon (i.e., the energetic input that allows for microbial denitrification).	Pinay, G., and H. Decamps. 1988. The Role of Riparian Woods in Regulating Nitrogen Fluxes Between the Alluvial Aquifer and Aurface Water: A Conceptual Model. *Regulated Rivers: Research and Management*, 2:507-516.

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Table 7-1. (Continued)

No.	Location	Wetland/ Riparian	Summary of Observations	Source
21	Georgia	Riparian	Processes within the riparian area apparently converted primarily inorganic N (76% nitrate, 6% ammonia, 18% organic N) into primarily organic N (10% nitrate, 14% ammonia, 76% organic N).	Lowrance, R.R., R.L. Todd, and L.E. Asmussen. 1984. Nutrient Cycling in an Agricultural Watershed: Phreatic Movement. *Journal of Environmental Quality*, 13(1):22-27.
22	North Carolina	Riaprian	Subsurface nitrate leaving agricultural fields was reduced by 93% on average.	Jacobs, T.C., and J.W. Gilliam. 1985. Riparian Losses of Nitrate from Agricultural Drainage Waters. *Journal of Environmental Quality*, 14(4):472-478.
23	North Carolina	Riparian	Over the last 20 years, a riparian forest provided a sink for about 50% of the phosphate washed from cropland.	Cooper, J.R., and J.W. Gilliam. 1987. Phosphorus Redistribution from Cultivated Fields into Riparian Areas. *Soil Science Society of America Journal*, 51(6):1600-1604.
24	Illinois	Riparian	Small streams on agriculture watersheds in Illinois had the greatest water temperature problems. The removal of shade increased water temperature 10-15 degrees Fahrenheit. Slight increases in water temperature over 60 °F caused a significant increase in phosphorus release from sediments.	Karr, J.R., and I.J. Schlosser. 1977. *Impact of Nearstream Vegetation and Stream Morphology on Water Quality and Stream Biota*. Ecological Research Series, EPA-600/3-77-097, U.S. Environmental Protection Agency, Washington, DC.

a. Multiple Benefits

The preservation and protection of wetlands and riparian areas are encouraged because these natural systems have been shown to provide many benefits, in addition to providing the potential for NPS pollution reduction (Table 7-2). The basis of protection involves minimizing impacts to wetlands and riparian areas serving to control NPS pollution by maintaining the existing functions of the wetlands and riparian areas, including vegetative composition and cover, flow characteristics of surface water and ground water, hydrology and geochemical characteristics of substrate, and species composition (Azous, 1991; Hammer, 1992; Mitsch and Gosselink, 1986; Reinelt and Horner, 1990; Richter et al., 1991; Stockdale, 1991).

Wetlands and riparian areas perform important functions such as providing a source of food for a variety of wildlife, a source of nesting material, habitat for aquatic animals, and nursery areas for fish and wildlife (Atcheson et al., 1979). Animals whose development histories include an aquatic phase—amphibians, some reptiles, and invertebrates—need wetlands to provide aquatic habitat (Mitsch and Gosselink, 1986). Other important functions of wetlands and riparian areas include floodwater storage, erosion control, and ground-water recharge. Protection of wetlands and riparian areas should allow for both NPS control and other corollary benefits of these natural aquatic systems.

b. Nonpoint Pollution Abatement Function

Table 7-1 is a representative listing of the types of research results that have been compiled to document the effectiveness of wetlands and riparian areas in serving an NPS pollution abatement function. Wetlands and riparian areas remove more than 50 percent of the suspended solids entering them (Karr and Gorman, 1975; Lowrance et al., 1984; Stuart and Greis, 1991). Sixty to seventy-five percent of total nitrogen loads are typically removed from surface and ground waters by wetlands and riparian areas (Cooper, 1990; Jacobs and Gilliam, 1985; James et al., 1990; Lowrance et al., 1983; Lowrance et al., 1984; Peterjohn and Correll, 1984; Pinay and Decamps, 1988; Stuart and Greis, 1991). Phosphorus removal in wetlands and riparian areas ranges from 50 percent to 80 percent (Cooper and Gilliam, 1987; Peterjohn and Correll, 1984; Stuart and Greis, 1991).

c. Degradation Increases Pollution

Tidal wetlands perform many water quality functions; when severely degraded, however, they can be a source of nonpoint pollution (Richardson, 1988). For example, the drainage of tidal wetlands underlain by a layer of organic peat can cause the soil to rapidly decompose and release sulfuric acid, which may significantly reduce pH in surrounding waters. Removal of wetland or riparian area vegetation along the shorelines of streams, bays, or estuaries makes these areas more vulnerable to erosion from storm events, wave action, or concentrated runoff. Activities such as channelization, which modify the hydrology of floodplain wetlands, can alter the ability of these areas to retain sediment when they are flooded and result instead in erosion and a net export of sediment from the wetland (Reinelt and Horner, 1990).

4. Practices

As discussed more fully at the beginning of this chapter and in Chapter 1, the following practices are described for illustrative purposes only. State programs need not require implementation of these practices. However, as a practical matter, EPA anticipates that the management measure set forth above generally will be implemented by applying one or more management practices appropriate to the source, location, and climate. The practices set forth below have been found by EPA to be representative of the types of practices that can be applied successfully to achieve the management measure described above.

Table 7-2. Range of Functions of Wetlands and Riparian Areas
(adapted from National Research Council, 1991)

Function	Example
Flood conveyance	Riverine wetlands and adjacent floodplain lands often form natural floodways that convey floodwaters from upstream to downstream areas.
Protection from storm waves and erosion	Coastal wetlands and inland wetlands adjoining larger lakes and rivers reduce the impact of storm tides and waves before they reach upland areas.
Flood storage	Inland wetlands may store water during floods and slowly release it to downstream areas, lowering flood peaks.
Sediment control	Wetlands reduce flood flows and the velocity of floodwaters, reducing erosion and causing floodwaters to release sediment.
Habitat for fish and shellfish	Wetlands are important spawning and nursery areas and provide sources of nutrients for commercial and recreational fin and shellfish industries, particularly in coastal areas.
Habitat for waterfowl and other wildlife	Both coastal and inland wetlands provide essential breeding, nesting, feeding, and refuge sites for many forms of waterfowl, other birds, mammals, and reptiles.
Habitat for rare and endangered species	Almost 35 percent of all rare and endangered animal species either are located in wetland areas or are dependent on them, although wetlands constitute only about 5 percent of the coterminous United States.
Recreation	Wetlands serve as recreation sites for fishing, hunting, and observing wildlife.
Source of water supply	Wetlands are important in replacing and maintaining supplies of ground water and surface water.
Natural products	Under proper management, forested wetlands are an important source of timber, despite the physical problems of timber removal. Under selected circumstances, natural products such as timber and furs can be harvested from wetlands.
Preservation of historic, archaeological values	Some wetlands are of archaeological interest. Native American settlements were sometimes located in coastal and inland wetlands, which served as sources of fish and shellfish.
Education and research	Tidal, coastal, and inland wetlands provide educational opportunities for nature observation and scientific study.
Source of open space and contribution to aesthetic values	Both tidal and inland wetlands are areas of great diversity and beauty, and they provide open space for recreational and visual enjoyment.

a. Consider wetlands and riparian areas and their NPS control potential on a watershed or landscape scale.

Wetlands and riparian areas should be considered as part of a continuum of filters along rivers, streams, and coastal waters that together serve an important NPS abatement function. Examples of the practice were outlined by Whigham and others (1988). They found that a landscape approach can be used to make reasonable decisions about how any particular wetland might affect water quality parameters. Wetlands in the upper parts of the drainage systems in particular have a greater impact on water quality. Hanson and others (1990) used a model to determine the effect of riparian forest fragmentation on forest dynamics. They concluded that increased fragmentation would lead to lower species diversity and an increased prevalence of species that are adapted to isolated conditions. Naiman and others (1988) discussed the importance of wetlands and riparian areas as boundary ecosystems, providing a boundary between terrestrial and aquatic ecosystems. Wetlands and riparian areas are particularly sensitive to landscape changes and fragmentation. Wetland and riparian boundaries covering large areas may persist longer than those on smaller spatial scales and probably have different functional values (Mitsch, 1992).

Several States have outlined the role of wetlands and riparian areas in case studies of basinwide and statewide water quality plans. A basinwide plan for the restoration of the Anacostia River and associated tributaries considered in detail the impacts of wetlands creation and riparian plantings (USACE, 1990). In Louisiana and Washington State, EPA has conducted studies that use the synoptic approach to consider wetlands' water quality function on a landscape scale (Abbruzzese et al., 1990a, 1990b). The synoptic approach considers the environmental effects of cumulative wetlands losses. In addition, this approach involves assembling a framework that ranks watersheds according to the relative importance of wetland functions and losses. States are also encouraged to refine their water quality standards applicable to wetlands by assigning wetlands-specific designated uses to classes of wetlands.

b. Identify existing functions of those wetlands and riparian areas with significant NPS control potential when implementing NPS management practices. Do not alter wetlands or riparian areas to improve their water quality function at the expense of their other functions.

In general, the following practices should be avoided: (1) location of surface water runoff ponds or sediment retention basins in healthy wetland systems and (2) extensive dredging and plant harvesting as part of nutrient or metals management in natural wetlands. Some harvesting may be necessary to control the invasion of exotic plants. Extensive harvesting for surface water runoff or nutrient management, however, can be very disruptive to the existing plant and animal communities.

c. Conduct permitting, licensing, certification, and nonregulatory NPS pollution abatement activities in a manner that protects wetland functions.

There are many possible programs, both regulatory and nonregulatory, to protect wetland functions. Table 7-3 contains a representative listing of Federal, State, and Federal/State programs whose primary goals involve the identification, technical study, or management of wetlands protection efforts. Table 7-4 provides a list of Federal programs involved in the protection and restoration of wetlands and riparian areas on private lands. Federal programs with cost-share funds are designated as such in Table 7-4. The list of possible programmatic approaches to wetlands protection includes the following:

Acquisition. Obtain easements or full acquisition rights for wetlands and riparian areas along streams, bays, and estuaries. Numerous Federal programs, such as the U.S. Department of Agriculture (USDA) Wetlands Reserve, administered by USDA's Agricultural Stabilization and Conservation Service (USDA-ASCS) with technical assistance provided by USDA's Soil Conservation Service (USDA-SCS) and U.S. Department of the Interior - Fish and Wildlife Service (USDOI-FWS), and the Fish and Wildlife Service North American Waterfowl Management Plan can provide assistance for acquiring easements or full title. Acquisition of water rights to ensure maintenance of minimum instream flows is another means to protect riparian/wetland areas, and it can be a critical issue in the arid West. In Arizona, The Nature Conservancy has acquired an instream water rights certificate for its Ramsey Canyon preserve

Table 7-3. Federal, State, and Federal/State Programs for Wetlands Identification, Technical Study, or Management of Wetlands Protection Efforts

No.	Location	Type of Wetland	Summary of Observations	Source
1	New Mexico	Riparian/ Wetland	This Bureau of Land Management (BLM) document identifies planning strategies and needs for future planning for riparian-wetland area resource management in New Mexico.	USDOI, BLM, New Mexico State Office. 1990. *New Mexico Riparian-Wetland 2000: A Management Strategy.* U.S. Department of the Interior, Bureau of Land Management.
2	Washington and Oregon	Riparian	Riparian areas on BLM lands in OR and WA are managed by a combination of land-use allocations and management practices designed to protect and restore their natural functions. The riparian-stream ecosystem is managed as one unit, designated as a Riparian Management Area (RMA). Riparian areas are classified by stream order. Timber harvesting is generally restricted from those riparian areas with the highest nontimber resource values. Mitigation measures are also used to reduce impacts from timber harvesting in riparian areas with minor nontimber values.	Oakely, A.L. 1988. Riparian Management Practices of the Bureau of Land Management. In *Streamside Management: Riparian Wildlife and Forestry Interactions*, pp. 191-198.
3	Pacific Northwest	Riparian	The Bureau of Indian Affairs has no formal riparian management policy because BIA management must be done in cooperation with the tribe. This situation creates tremendous variation in Indian lands management because the individual management plans must be tailored to the needs of the individual tribe.	Bradley, W.P. 1988. Riparian Management Practices on Indian Lands. In *Streamside Management: Riparian Wildlife and Forestry Interactions*, pp. 201-206.
4	Washington	Riparian	This article discusses the riparian management policies of the Washington State Dept. of Natural Resources, including design and concerns of Riparian Management Zones.	Calhoun, J.M. 1988. Riparian Management Practices of the Department of Natural Resources. In *Streamside Management: Riparian Wildlife and Forestry Interactions*, pp. 207-211.
5		Riparian	The Tennessee Valley Authority, since its inception, has promoted the protection and management of the riparian resources of the Tennessee River drainage basin. Current policies, practices, and major programs providing for protection of the riparian environment are described.	Allen, R.T., and R.J. Field. 1985. Riparian Zone Protection by TVA: An Overview of Policies and Programs. In *Riparian Ecosystems and Their Management: Reconciling Conflicting Issues.* USDA Forest Service GTR RM-120, pp. 23-26.

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Table 7-3. (Continued)

No.	Location	Type of Wetland	Summary of Observations	Source
6		Riparian	Riparian zones play a major role in water quality management. Water supply considerations and maintenance of streamside zones from the municipal watershed manager's viewpoint are detailed. Management impacts affecting water quality and quantity on forested municipal watersheds are discussed in relation to the structure of the riparian zone. The impacts of management are often integrated in the channel area and in the quality of streamflow. Learning to read early signs of stress here will aid in evaluating how much "management" a watershed can take.	Corbet, E.S., and J.A. Lynch. 1985. Management of Streamside Zones on Municipal Watersheds. In *Riparian Ecosystems and Their Management: Reconciling Conflicting Issues.* USDA Forest Service GTR RM-120, pp. 187-190.
7		Riparian	Construction of small dams, suppression of woody vegetation in riparian zones, and removal of livestock from streamsides have all led to summer streamflow increase. Potential may exist to manage small valley bottoms for summer flow increase while maintaining or improving habitat, range, and watershed values.	Stabler, D.F. 1985. Increasing Summer Flow in Small Streams Through Management of Riparian Areas and Adjacent Vegetation: A Synthesis. In *Riparian Ecosystems and Their Management: Reconciling Conflicting Issues.* USDA Forest Service GTR RM-120, pp. 206-210.
8	Queen Creek, Arizona	Riparian	The interrelationships between riparian vegetation development and hydrologic regimes in an ephemeral desert stream were examined at Whitlow Ranch Dam along Queen Creek in Pinal County, Arizona. The data indicate that a flood control structure can have a positive impact on riparian ecosystem development and could be used as a mitigation tool to restore this critically threatened habitat. Only 7 years after dam completion, aerial photos documented a dramatic change in the vegetation. The riparian vegetation consisted of a vigorously expanding Sonoran deciduous forest of Gooding willow and saltcedar occupying an area of approximately 17.7 ha.	Szaro, R.C., and L.F. DeBano. 1985. The Effects of Streamflow Modification on the Development of a Riparian Ecosystem. In *Riparian Ecosystems and Their Management: Reconciling Conflicting Issues.* USDA Forest Service GTR RM-120, pp. 211-215.

Table 7-3. (Continued)

No.	Location	Type of Wetland	Summary of Observations	Source
9	Southwest	Riparian	Native American and Spanish American farmers of the arid Southwest have managed riparian vegetation adjacent to their agricultural fields for centuries. They have planted, pruned, and encouraged phreatophytic tree species for flood erosion control, soil fertility renewal, buffered field microclimate, and fuel-wood production. These practices benefit wildlife and plant genetic diversity. The benefits and stability of native riparian vegetative mosaics are difficult to assess in monetary or energetic terms, but are nonetheless significant.	Nabhan, G.P. 1985. Riparian Vegetation and Indigenous Southwestern Agriculture: Control of Erosion, Pests, and Microclimate. In *Riparian Ecosystems and Their Management: Reconciling Conflicting Issues.* USDA Forest Service GTR RM-120, pp. 232-236.
10		Riparian	Many management goals can be developed for riparian habitats. Each goal may dictate different management policies and tactics and result in different impacts on wildlife. Vegetation structure of riparian areas, expressed in terms of habitat layers, can provide a useful framework for developing effective strategies for a variety of management goals because many different land uses can be associated with habitat layers. Well-developed goals are essential both for purposeful habitat management and for monitoring the impacts of different land uses on habitats.	Short, H.L. 1985. Management Goals and Habitat Structure. In *Riparian Ecosystems and Their Management: Reconciling Conflicting Issues.* USDA Forest Service GTR RM-120, pp. 232-236.
11	Maine	Riparian	Riparian zones serve important functions for fisheries and aquatic systems: shading, bank stability, prevention of excess sedimentation, overhanging cover for fish, and energy input from invertebrates and allochtonous material. Impacts from loss of riparian areas are discussed in relation to aquatic ecosystems, and the results of two recent studies in Maine are reviewed. Intact riparian zones have inherent values to aquatic systems and though 23-m intact riparian strips are often recommended for stream protection, wildlife biologists are often recommending wider zones because of their value as animal corridors and winter deer yards.	Moring, J.R., G.C. Carman, and D.M. Mullen. 1985. The Value of Riparian Zones for Protecting Aquatic Systems: General Concerns and Recent Studies in Maine. In *Riparian Ecosystems and Their Management: Reconciling Conflicting Issues.* USDA Forest Service GTR RM-120, pp. 315-319.

Table 7-3. (Continued)

No.	Location	Type of Wetland	Summary of Observations	Source
12	Siskiyou National Forest	Riparian	The Siskiyou National Forest in Oregon has managed riparian areas along the Pacific coast where high-value conifers stand near streams bearing salmonid fisheries. Riparian areas are managed by setting objectives that allow for limited timber harvest along with stream protection. The annual sale quantity from the forest is reduced by 13% to protect riparian areas and the fishery resource. Typically, timber harvest will remove 40-50% of the standing timber volume within nonfish-bearing riparian areas and 0-10% along streams that support fish.	Anderson, M.T. 1985. Riparian Management of Coastal Pacific Ecosystems. In *Riparian Ecosystems and Their Management: Reconciling Conflicting Issues*. USDA Forest Service GTR RM-120, pp. 364-368.
13	California	Riparian	A riparian reserve has been established on the UC Davis campus. The 80-acre Putah Cr. Reserve offers the opportunity to research issues related to the typically leveed floodways that flow through California's agricultural landscape. With over 90% of the original riparian systems of California completely eliminated, the remaining "altered "systems represent environmental corridors of significant value to conservation. The key to improving the habitat value of these systems is researching floodway management alternatives that use an integrated approach.	Dawson, K.J., and G.E. Sutter. 1985. Research Issues in Riparian Landscape Planning. In *Riparian Ecosystems and Their Management: Reconciling Conflicting Issues*. USDA Forest Service GTR RM-120, pp. 408-412.
14	Pacific Northwest	Riparian	Since 1970 the National Forests in Oregon and Washington have been operating under a Regionally developed streamside management unit (SMU) concept, which is essentially a stream classification system based on the use made of the water with specific water quality objectives established for each of the four classes of streams. Inherent in the concept is the underlying premise that the land immediately adjacent to streams is key to protecting water quality. This land can be managed to protect the riparian values and in most cases still achieve a reasonable return of other resource values.	Swank, G.W. 1985. Streamside Management Units in the Pacific Northwest. In *Riparian Ecosystems and Their Management: Reconciling Conflicting Issues*. USDA Forest Service GTR RM-120, pp. 435-438.
15	Pacific Northwest	Riparian	The USDA Forest Service's concepts of multiple-use and riparian-area-dependent resources were incorporated into a district-level riparian area management policy. Identifying the degree of dependence on forest resource values and uses on specific characteristics of the riparian area is a key to determining which resources are to be emphasized during management. The linkage of riparian areas to the aquatic resource and cumulative processes is integrated into the policy designed to provide consistent direction for on-the-ground management.	Vanderhayden, J. 1985. Managing Multiple Resources in Western Cascades Forest Riparian Areas: An Example. In *Riparian Ecosystems and Their Management: Reconciling Conflicting Issues*. USDA Forest Service GTR RM-120, pp. 448-452.

Table 7-4. Federal Programs Involved in the Protection and Restoration of Wetlands and Riparian Areas on Private Lands

Agency	Type of Program	Cost Share Program	Activities and Funding
U.S. Department of the Army - Army Corps of Engineers	Dredged and fill permit program	No	• Regulates the discharge of dredged or fill material into waters of the United States, including wetlands.
U.S. Dept. of the Interior - Fish and Wildlife Service	Private Lands Program	No	• Provides funding to aid in the restoration of wetland functions. • Many efforts are targeted at restoring wetlands that offer important habitat for migratory birds and other Federal Trust species.
USDOI - FWS	North American Waterfowl Management Plan	No	• The plan includes the restoration and enhancement of several million acres of wetlands for migratory birds in Canada, Mexico, and the United States. • The NAWMP is being implemented through innovative Federal-State-private partnerships within and between States and Provinces. • Currently, a grants program exists for acquisition, restoration, enhancement, creation, management, and other activities that conserve wetlands and fish and wildlife that depend upon such habitats. Research, planning, payment of interest, conservation education programs, and construction of buildings are activities that are ineligible for funds under this program.
USDOI-FWS	Coastal Wetlands Conservation Grants Program	Yes	• Provides 50% matching grants to coastal States for acquisition, restoration, and enhancement of coastal wetlands. • States with established trust funds for acquiring coastal wetlands, other natural areas, or open spaces are eligible for 75% matching grants.
USDOI - Office of Surface Mining	Experimental practices programs	No	• Although the agency does not have a cost share program for wetlands restoration, it does assist coal companies in developing experimental practices that will provide environmental protection. • The agency also pays States for the reclamation of lands previously left by coal companies.
U.S. Dept. of Agriculture Cooperative Extension Service		No	• The national office encourages each State extension service to assist private landowners in the management and restoration of wetlands. Most State extension services provide information and technical assistance to landowners.

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Table 7-4. (Continued)

Agency	Type of Program	Cost Share Program	Activities and Funding
USDA - Agricultural Stabilization and Conservation Service	Conservation Reserve Program	Yes	• More than 5,000 ha of wetlands have been restored under the CRP. • 380,000 ha of cropped wetlands and associated uplands have been reestablished in natural vegetation under 10-year contracts of up to $50,000 per person per year. • The Secretary of Agriculture shares 50% of the total cost of establishing vegetative cover and 50% of the cost to maintain hardwood trees, shelterbelts, windbreaks, or wildlife corridors for a 2- to 4-year period.
USDA - ASCS	The Water Bank Program	Yes	• Objectives of the program are to preserve, restore, and improve the wetlands of the Nation. • The WBP applies to wetlands on designated farms identified by conservation plans developed in cooperation with Soil and Water Conservation Districts. • Protecting 190,000 ha of natural wetlands and adjacent buffer areas under 10-year rental agreements. Annual payments for 1991 ranged from $7 to $66 per acre. • The agency will cost-share up to 75% of the cost for cover for adjacent land only. These payments may be made to cover the costs of installing conservation practices developed to accomplish one of the following: establish or maintain vegetative cover; control erosion; establish or maintain shallow-water areas and improve habitat; conserve surface water and contribute to flood control and improve subsurface moisture; or provide bottomland hardwood management. • States participating in the 1992 Water Bank Program are Arkansas, California, Louisiana, Minnesota, Mississippi, Montana, Nebraska, North Dakota, Ohio, South Dakota, and Wisconsin.
USDA - ASCS	Wetland Reserve Program	Yes	• The WRP is expected to restore and protect up to 400,000 ha of wetlands in cropland on farms and ranches through easements. California, Iowa, Louisiana, Minnesota, Mississippi, Missouri, New York, North Carolina, and Wisconsin are currently the only States participating in the program although participation by all States is expected by 1993. • The program currently accepts only permanent easements and provides a 75% cost share for such. If in the future less-than-permanent easements are accepted, a 50% cost share would probably be provided.

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Table 7-4. (Continued)

Agency	Type of Program	Cost Share Program	Activities and Funding
USDA - ASCS	Agricultural Conservation Program	Yes	• The ASCS will cost-share with farmers up to 75% of the cost of practices that help control NPS pollution. • Cost share has been provided for the restoration of 225,000 ha of wetlands over the last 30 years for the "Creation of Shallow Water Areas" practice. • Eligible cost share practices include establishment or improvement of permanent vegetative cover; installation of erosion control measures; planting of shrubs and trees for erosion control; and development of new or rehabilitation of existing shallow-water areas to support food, habitat, and cover for wildlife.
USDA - Soil Conservation Service			• The SCS provides technical assistance to private landowners for wetland restoration.

in the Huachuca Mountains. The certificate gives the Arizona Nature Conservancy the legal right to maintain instream flows in the stretch of Ramsey Creek along their property, which in turn preserves instream and riparian habitat and wildlife (Andy Laorenzi, personal communication, 5 October 1992). in turn preserves instream and riparian habitat and wildlife (Andy Laurenzi, personal communication, 5 October 1992).

Zoning and Protective Ordinances. Control activities with a negative impact on these targeted areas through special area zoning and transferable development rights. Identify impediments to wetland protection such as excessive street standards and setback requirements that limit site-planning options and sometimes force development into marginal wetland areas.

Baltimore County, Maryland, has adopted legislation to protect the water quality of streams, wetlands, and floodplains that requires forest buffers for any activity that is causing or contributing to pollution, including NPS pollution, of the waters of the State. Baltimore County has also developed management requirements for the forest buffers, including those located in wetlands and floodplains, that specify limitations on alteration of the natural conditions of these resources. The provisions call for public and private improvements to the forest buffer to abate and prevent water pollution, erosion, and sedimentation of stream channels and degradation of aquatic and riparian habitat.

Water Quality Standards. Almost all wetlands are *waters of the United States*, as defined in the Clean Water Act. Ensure that State water quality standards apply to wetlands. Consider natural water quality functions when specifying designated uses for wetlands, and include biological and hydrologic narrative criteria to protect the full range of wetland functions.

The State of Wisconsin has adopted specific wetlands water quality standards designed to protect the sediment and nutrient filtration or storage function of wetlands. The standards prohibit addition of those substances that would "otherwise adversely impact the quality of other waters of the State" beyond natural conditions of the affected wetland. In addition, the State has adopted criteria protecting the hydrologic conditions in wetlands to prevent significant adverse impacts on water currents, erosion or sedimentation patterns, and the chemical and nutrient regimes of the wetland. Wisconsin has also adopted a sequenced decision-making process for projects potentially

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affecting wetlands that considers the wetland dependency of a project; practicable alternatives; and the direct, indirect, and cumulative impacts of the project.

Regulation and Enforcement. Establish, maintain, and strengthen regulatory and enforcement programs. Where allowed by law, include conditions in permits and licenses under CWA §401, §402, and §404; State regulations; or other regulations to protect wetlands.

Restoration. Programs such as USDA's Conservation Reserve and Wetlands Reserve Program provide opportunities to set aside and restore wetlands and riparian areas. Also, incentives that encourage private restoration of fish and wildlife productivity are more cost-effective than Federal acquisition and can in turn reduce property tax receipts by local government.

Education and Training. Educate farmers, urban dwellers, and Federal agencies on the role of wetlands and riparian areas in protecting water quality and on best management practices (BMPs) for restoring stream edges. Teach courses in simple restoration techniques for landowners.

Comprehensive Watershed Planning. Provide a mechanism for private landowners and agencies in mixed-ownership watersheds to develop, by consensus, goals, management plans, and appropriate practices and to obtain assistance from Federal and State agencies. Establish a framework for multiagency program linkage, and present opportunities to link implementation efforts aimed at protection or restoration of wetlands and riparian areas. EPA's National Estuary Program and the Fish and Wildlife Service's Bay/Estuary Program are excellent examples of this multiagency approach. A number of State and Federal agencies carry out programs with compatible NPS pollution reduction goals in the coastal zone. For example, Maryland's Nontidal Wetlands Protection Act encourages development of comprehensive watershed plans for addressing wetlands protection, mitigation, and restoration issues in conjunction with water supply issues. In addition, the U.S. Army Corps of Engineers (USACE) administers the CWA §404 program; USDA implements the Swampbuster, Conservation Reserve, and Wetlands Reserve Programs; EPA, USACE, and States work together to perform advanced identification of wetlands for special consideration (§404); and States administer both the Coastal Zone Management (CZM) program, which provides opportunity for consistency determinations, and the CWA §401 certification program, which allows for consideration of wetland protection and water quality objectives.

As an example of a linkage to protect NPS pollutant abatement and other benefits of wetlands, a State could determine under CWA §401 a proposed discharge or other activity in a wetland that is inconsistent with State water quality standards. Or, if a proposed permit is allowed contingent upon mitigation by creation of wetlands, such mitigation might be targeted in areas defined in the watershed assessment as needing restoration. Watershed- or site-specific permit conditions may be appropriate (e.g., specific widths for streamside management areas or structures based on adjacent land use activities). Similarly, USDA's Conservation Reserve Program or Wetlands Reserve Program could provide landowner assistance in areas identified by the NPS program as needing particular protection or riparian area reestablishment.

■ *d. Use appropriate pretreatment practices such as vegetated treatment systems or detention or retention basins (Chapter 4) to prevent adverse impacts to wetland functions that affect NPS pollution abatement from hydrologic changes, sedimentation, or contaminants.*

For more information on the technical implementation and effectiveness of this practice, refer to Management Measure C in this chapter and Sections II.A and III.A of Chapter 4.

5. Costs for All Practices

This section describes costs for representative activities that would be undertaken in support of one or more of the practices listed under this management measure. The description of costs is grouped into the following categories:

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(1) For implementation of practice "a": costs for mapping, which aids in locating wetlands and riparian areas in the landscape and determining their relationship to land uses and their potential for NPS pollution abatement.

(2) For implementation of practices "b" and "c": costs for wetland and riparian area protection programs.

(3) For implementation of practice "d": costs for pretreatment such as filter strips, constructed wetlands, and detention or retention basins.

a. Mapping

The identification of wetlands within the watershed landscape, and their NPS pollution abatement potential, involves using maps to determine the characteristics as described in the management measure. These may include vegetation type and extent, soil type, distribution of fully submerged and partially submerged areas within the wetland boundary, and location of the boundary between wetlands and uplands. These types of features can be mapped through a variety of methods.

Lower levels of effort would characteristically involve the acquisition and field-checking of existing maps, such as those available for purchase from the U.S. Fish and Wildlife Service in the National Wetlands Inventory and U.S. Geological Survey (USGS) land use maps (information on these maps is available by calling 1-800-USA-MAPS). An intermediate level of effort would involve the collection and analysis of remote-sensing data, such as aerial photographs or digital satellite imagery. Depending on the size of the study area and the extent of the data to be categorized, the results of photo interpretation or of digital image analysis can be manipulated manually with a computerized database or electronically with a Geographic Information System. The most costly and labor-intensive approach involves plane-table surveys of the areas to be investigated.

Three separate costs are reported below from actual examples of recent projects involving wetland identification and assessment for purposes similar to the goal of the management measure. The examples represent different levels of effort that could be undertaken in support of practice "a" under the management measure.

(1) A project in Clarks Fork, Montana, used remote sensing data for identification of wetlands that were potentially impaired from NPS pollution originating in adjacent portions of the watershed. In addition to identifying the type and extent of wetlands and riparian vegetation along Clarks Fork and the tributary streams, the mapping effort categorized land use in adjoining portions of the landscape. The results were used to identify areas within the watershed that could possibly be contributing NPS pollution in runoff to the wetlands and riparian areas (Lee, 1991).

Total costs for this project were estimated at $0.06 per acre. The items of work include project management, collection of aerial photographs, film processing, and photo interpretation (Lee, 1991).

(2) Remote sensing data have also been used as part of a statewide assessment of wetlands in Wisconsin. The purpose of the project is to determine areas within the landscape where changes are occurring in wetlands. Three or four counties are evaluated each year. The results are used to provide an ongoing update of changes to wetlands characteristics such as hydrology and vegetation (Lee, 1991).

Total costs for this project are approximately $0.07 per acre. The items of work include collection of aerial photography, film processing, photo interpretation, and development and maintenance of a Geographic Information System (Lee, 1991).

(3) The National Wetlands Inventory (NWI) has maps for 74 percent of the conterminous United States, 24 percent of Alaska, and all of Hawaii. Wetlands maps have been updated for wetlands assessment in three areas of the southeastern United States. The purpose of the project is to provide current data on the distribution of wetlands for project reviews, site characterizations, and ecological assessment (Kiraly et al., 1990).

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Total costs reported for this work are listed in Table 7-5. The items of work include staff time, travel expenses, and per diem (Kiraly et al., 1990).

It is important to note that each of these three cases is presented for illustration purposes only. It is not necessary to acquire new data or maps to implement the practices and meet the management measure. Existing maps, surveys, or remotely sensed data (such as aerial photographs) can easily be used. These typically exist in files of State and local governments or educational institutions. Additional data on wetlands functions, locations, or ecological assessments can be culled from existing environmental impact statements, from old permit applications, or from watershed inventories. These sources of information in particular should be evaluated for their usefulness in categorizing historical conditions.

Where the need for new maps is recognized to meet the management measure, several Federal agencies provide mapping products that could be useful. Examples include the following:

- USDA aerial photography. Depending on the locality, this photography is available in black-and-white, color, or color-infrared (color-IR) formats.
- USGS aerial photography. A variety of photo products are available, for example, through the National Aerial Photography Program (NAPP).
- EPA Environmental Monitoring and Assessment Program (EMAP). Some opportunities for cost-shared projects are available to collect and analyze new imagery on the ecosystem or watershed level (Kiraly et al., 1990).

b. Wetland and Riparian Area Protection Programs

Examples of programmatic costs for implementing practices "b" and "c" under this management measure include costs for personnel, the administrative costs of processing applications for permits, and costs for public information brochures and pamphlets. Since some programs may already be in place, the need for apportionment of existing programmatic capabilities to NPS-related issues regarding wetlands and riparian areas will vary widely, depending on the size of the local jurisdiction, the nature and extent of wetland and riparian ecosystems present within the jurisdictional boundaries, and the severity of the NPS problem. Other programs may need to be adapted to include NPS-related issues regarding wetlands.

Six separate examples of costs for existing State wetland programs are shown in Table 7-6 for illustrative purposes. The costs reflect a range of low to high levels of effort, as measured through the assignment of individual full-time

Table 7-5. Total Costs for Wetlands Assessment Project Examples

Location of Project	Cost Item	Cost
Northeast Shark River near Slough, Mississippi	Four weeks of staff time	$2,441
	Travel and per diem	$1,500
	Total	$3,941
West Broward County, Florida	Six weeks of staff time	$3,362
	Travel and per diem	$2,400
	Total	$5,762
Swamp of Toa, Alabama	Eight weeks of staff time	$4,882
	Travel and per diem	$2,000
	Total	$6,882

Table 7-4. Costs for Wetlands Protection Programs*

State	Staffing	Budget
Montana	One FTE	$100,000
South Carolina	Three part-time positions	$80,000
Alaska	Four FTEs	$400,000
Tennessee	Eleven FTEs (Field, clerical, and administrative)	$450,000
Oregon	Fifteen FTEs Five seasonal positions	$300,000
New Hampshire	Fifteen FTEs Five seasonal positions	$500,000

*All levels of staffing and budgeting were reported by States in response to a questionnaire distributed by the Association of State Wetlands Managers (ASWM).

equivalents (FTEs) and the task-specific dedication of discrete levels of clerical and administrative support. A low-level scenario consists of costs for one FTE. A high-level scenario consists of staffing of 10 or more FTEs, including clerical and administrative positions.

If the costs for individual FTEs are estimated at $50,000 each, which includes salary plus fringe benefits, then some of the reported program budgets on the list mentioned above exceed reasonable estimates of salaries. This indicates that additional funding has been allocated for activities ranging from office support to technical assistance in the field.

c. Pretreatment

The use of appropriate pretreatment practices to prevent adverse impacts to wetlands that ultimately affect NPS pollution abatement involves the design and installation of vegetated treatment systems such as vegetated filter strips or constructed wetlands, or the use of structures such as detention or retention basins. These types of systems are discussed individually elsewhere in this guidance document. Refer to Chapter 4 for a discussion of detention and retention basins. See the discussion of Management Measure C later in Chapter 7 for a description of constructed wetlands and filter strips. The purpose of each of these BMPs is to remove, to the extent practicable, excessive levels of NPS pollutants and to minimize impacts of hydrologic changes. Each of these BMPs can function to reduce levels of pollutants in runoff or to attenuate runoff volume before it enters a natural wetland or riparian area.

Whether these BMPs are used individually or in series will depend on several factors, including the quantity and quality of the inflowing runoff, the characteristics of the existing hydrology, and the physical limitations of the area surrounding the wetland or riparian area to be protected.

Costs are reported below for three potential scenarios to implement practice "d" under this management measure.

(1) One filter strip at a cost of $129.00

- Includes design and installation of a grass filter strip 1,000 feet long and 66 feet wide.
- Most effective at trapping sediments and removing phosphorus from surface water runoff.

(2) One constructed wetland at a cost of $5,000.00

- Includes design and installation of a constructed wetland whose surface area is 0.25 acre in size. The constructed wetland is planted with commercially available emergent vegetation.

- Most effective to remove nutrients and decrease the rate of inflow of surface water runoff into the natural wetland located further downstream.

(3) One combined filter strip/constructed wetland $5,129.00

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Promote the restoration of the preexisting functions in damaged and destroyed wetlands and riparian systems in areas where the systems will serve a significant NPS pollution abatement function.

1. Applicability

This management measure is intended to be applied by States to restore the full range of wetlands and riparian functions in areas where the systems have been degraded and destroyed and where they can serve a significant NPS abatement function. Under the Coastal Zone Act Reauthorization Amendments of 1990, States are subject to a number of requirements as they develop coastal NPS programs in conformity with this management measure and will have flexibility in doing so. The application of management measures by States is described more fully in *Coastal Nonpoint Pollution Control Program: Program Development and Approval Guidance*, published jointly by the U.S. Environmental Protection Agency (EPA) and the National Oceanic and Atmospheric Administration (NOAA) of the U.S. Department of Commerce.

2. Description

Restoration of wetlands and riparian areas refers to the recovery of a range of functions that existed previously by reestablishing the hydrology, vegetation, and structure characteristics. A restoration management measure should be used in conjunction with other measures addressing the adjacent land use activities and, in some cases, water activities as well.

The term *NPS pollution abatement function* refers to the ability of a wetland or riparian area to remove NPS pollutants from waters passing through the wetland or riparian area. Acting as a sink for phosphorus and converting nitrate to nitrogen gas through denitrification are two examples of the important NPS pollution abatement functions performed by wetlands and riparian areas.

Restoration of wetlands and riparian areas is a holistic approach to water quality that addresses NPS problems while meeting the goals of the Clean Water Act to protect and restore the chemical, physical, and biological integrity of the Nation's waters. Full restoration of complex wetland and riparian functions may be difficult and expensive, depending on site conditions, the complexity of the system to be restored, the availability of native plants, and other factors. Specific practices for restoration must be tailored to the specific ecosystem type and site conditions.

3. Management Measure Selection

Selection of this management measure was based on:

(1) The localized increase in pollutant loadings that can result from the degradation of wetlands and riparian areas (Reinelt and Horner, 1990; Richardson, 1988);

(2) The nonpoint pollution abatement function of wetlands and riparian areas (Cooper, 1990; Cooper and Gilliam, 1987; Jacobs and Gilliam, 1985; James et al., 1990; Karr and Gorman, 1975; Lowrance et al.,

1983; Lowrance et al., 1984; Peterjohn and Correll, 1984; 9Pinay and Decamps, 1988; Stuart and Greis, 1991); and

(3) The opportunity to gain multiple benefits through the restoration of wetland and riparian area systems, e.g., aquatic and riparian habitat functions for wildlife and NPS pollution reduction benefits (Atcheson et al., 1979; Mitsch and Gosselink, 1986).

Refer to Section II.A.3 of this chapter for additional information regarding the degradation, effectiveness, and multiple benefits of wetlands and riparian areas.

4. Practices

As discussed more fully at the beginning of this chapter and in Chapter 1, the following practices are described for illustrative purposes only. State programs need not require implementation of these practices. However, as a practical matter, EPA anticipates that the management measure set forth above generally will be implemented by applying one or more management practices appropriate to the source, location, and climate. The practices set forth below have been found by EPA to be representative of the types of practices that can be applied successfully to achieve the management measure described above.

■ *a. Provide a hydrologic regime similar to that of the type of wetland or riparian area being restored.*

The following list identifies some important information or considerations to address in a restoration project.

- Site history - Know the past uses of the site, including past functioning as a wetland.
- Topography - Map the surface topography, including slope and relief of the existing land surface, and elevations of levees, drainage channels, ponds, and islands.
- Tide - Determine the mean and maximum tidal range.
- Existing water control structures - Identify the location of culverts, tide gates, pumps, and outlets.
- Hydrology - Investigate the hydrologic conditions affecting the site: wave climate, currents, overland flows, ground-water dynamics, and flood events.
- Sediment budgets - Understand the rates and paths of sediment inflow, outflow, and retention.
- Soil - Describe the existing soils, including their suitability for supporting wetland plants.
- Plants - Identify the existing and, if different, native vegetation.
- Salinity - Measure the existing or planned salt level at the site.
- Consider the timing of the restoration project and the duration of the construction schedule for installation activities.
- Assess potential impacts to the site from adjacent human activities.

Restoration of hydrology, in particular, is a critical factor to gain NPS benefits and to increase the probability of successful restoration.

b. *Restore native plant species through either natural succession or selected planting.*

When consistent with preexisting wetland or riparian area type, plant a diversity of plant types or manage natural succession of diverse plant types rather than planting monocultures. Deeply rooted plants may work better than certain grasses for transforming nitrogen because the roots will reach the water moving below the surface of the soil. For forested systems, a simple approach to successional restoration would be to plant one native tree species, one shrub species, and one ground-cover species and then allow natural succession to add a diversity of native species over time, where appropriate and warranted by target community composition and anticipated successional development. Information on native plant species is available from Federal agencies (e.g., USDA-SCS or USDOI-FWS), or various State or local agencies, such as the local Cooperative Extension Service Office or State departments of agriculture or natural resources. Other factors listed below need to be considered in the implementation of this practice.

Type and Quantity of Pollutant. Sediment, nitrates, phosphates, and thermal pollutants are effectively reduced by riparian areas. Riparian forests can also effectively remove nitrates from ground water. Eroded materials and attached pollutants from upslope areas are trapped on the surface. Suspended sediments and attached pollutants are removed during inundation by floodwaters (Table 7-1).

Slope. Riparian forest water quality functions have primarily been studied on cropland watersheds where slope has not been a factor. While sheet flow is not required for effective removal of NPS pollution from runoff passing through a riparian area, concentrated flows must be dispersed before upland runoff enters the riparian area.

Vegetated Area. Nonleguminous hardwoods are the most effective vegetation for nitrate removal. Where shade is critical, taller conifers may be preferred. The vegetation should be managed to retain larger trees near streams and denser, more vigorous trees on the remainder of the area. Research has also shown that a naturally rough forest floor is effective in trapping sediment (Swift, 1986).

c. *Plan restoration as part of naturally occurring aquatic ecosystems.*

States should factor in ecological principles when selecting sites and designing restoration. For example, seek high aquatic and riparian habitat diversity and high productivity in the river/wetland systems; look for opportunities to maximize connectedness (between different aquatic and riparian habitat types); and provide refuge or migration corridors along rivers between larger patches of uplands (animals are most likely to colonize new areas if they can move upstream and downstream under cover).

Planning to restore wetlands includes:

- Identifying sources of NPS problems;
- Considering the role of site restoration within a broader context, such as on a landscape basis;
- Setting goals for the restoration project based on location and type of NPS problem;
- Replicating multiple functions while still gaining NPS benefits; and
- Locating historic accounts (e.g., maps, descriptions, photographs) to identify sites that were previously wetland or riparian areas. These sites are likely to be more suitable for restoration if the original hydrology has not been permanently altered.

A few examples of wetland restoration are shown in Table 7-7.

Table 7-7. Review of Wetland Restoration Projects

No.	Location	Type of Wetland	Summary of Observations	Source
1	The Kattegat, Swedish west coast	Wetlands restoration Vegetation type not specified	The Kattegat, a semienclosed, shallow, and strongly stratified sea area, has experienced increased effects of eutrophication caused by excessive nitrogen loading. Based on a nitrogen retention model and denitrification studies, the following hypotheses will be tested in the wetland restoration program: • Annual nitrogen retention depends on nitrogen load. • A decrease in the active surface of a wetland causes an increase in the nitrogen load and retention per unit area. • Hydrological loading of a wetland can only be increased to a certain "critical" level. • Nitrogen retention is stabilized as a result of newly established plant communities and sediment formation. • When nitrogen retention is high, denitrification and sedimentation are the predominating mechanisms. • During the winter, high nitrogen load may counteract low-temperature-limited denitrification. • If nitrogen transport in a stream is known, retention in a future restored wetland can be predicted. This 5-year wetland restoration study was just getting under way in 1991.	Fleischer, S., L. Stibe, and L. Leonardson. 1991. Restoration of Wetlands as a Means of Reducing Nitrogen Transport to Coastal Waters. *Ambio: A Journal of the Human Environment*, 20(6):271-272.
2	Ballona Channel Wetlands, Marina Del Rey, Los Angeles, California	Wetlands restoration Vegetation type not specified	This paper discusses the model used to plan stormwater detention for site development, and at the same time to allow wetland restoration. Flood control, restoration of wetland habitat values, and quality control of urban stormwater runoff were some objectives of the project. This paper discusses only the model used to engineer the plan.	Tsihrintzis, V.A., G. Vasarhelyi, W. Trott, and J. Lipa. 1990. Stormwater Management and Wetland Restoration: Ballona Channel Wetlands. In *Hydraulic Engineering: Volume 2, Proceedings of the 1990 National Conference*, pp. 1122-1127.

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Table 7-7. (Continued)

No.	Location	Type of Wetland	Summary of Observations	Source
3	Banana Lake headwater system, Lakeland, Florida	Restored headwaters (including hardwood and herbaceous wetlands)	As compensation for roadway environmental impacts from the development of a belt loop around Lakeland, Florida, the restoration of Banana Lake was initiated in 1983. Development of the project was undertaken by the Polk County Engineering and Water Resources Division, the Florida Department of Transportation, and the City of Lakeland. Objectives of the restoration project include: • Improvement of surface water quality; • Elimination of localized flooding and dangerous roadside ditches; • Restoration of hardwood wetland swamp system; • Restoration of the premining drainage and functions of the headwater system. Postrestoration differences are summarized: • Western basin (average water quality): - All data in mg/L unless otherwise noted. - BDL=Below detection limits. Parameter — Change after restoration Temperature-°C: -0.9 pH-units: +0.3 DO: +1.1 Specific conductance (umhos/cm): -64 Nitrate-Nitrate as N: to BDL N, Ammonia: to BDL N, Total Kjeldahl: -2.98 N, Total: -3.03 Orthophosphate as P: -0.974 Phosphorus, Total: -0.869 Restoration of the western basin was completed in 1985. The following data compare the restored western basin water quality to the existing (1989) water quality in the unrestored eastern ditch. • Roadside ditch quality - Lakeland Highlands Rd.: Parameter — Western Basin (Restored) — Eastern Basin (Unrestored) Temperature (°C): 25.3 — 22.7 pH-units: 7.1 — 7.1 DO: 7.2 — 7.0 Specific conductance (umhos/cm): 217 — 221 Nitrate-Nitrate as N: BDL — 0.016 N, Ammonia: BDL — 0.145 N, Total Kjeldahl: 1.03 — 1.48 N, Total: 1.03 — 1.58 Orthophosphate as P: 0.233 — 0.525 Phosphorus, Total: 0.571 — 1.514	Powers, R.M., and J.F. Spence. 1989. Headwater Restoration: The Key Is Integrated Project Goals. In *Proceedings of the Symposium on Wetlands: Concerns and Successes, Sept. 17-22, Tampa, Florida*, pp. 269-279

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Table 7-7. (Continued)

No.	Location	Type of Wetland	Summary of Observations	Source
4	Creekside Park, Marin County, California	Wetland restoration; Cordgrass and pickleweed planting	In 1972, the U.S. Army Corps of Engineers placed dredged spoils on the Creekside Park site in conjunction with the dredging of Corte Madera Creek. As a result of citizen pressure, a report on the feasibility of creating a salt marsh was prepared in 1973. In 1975, the site was acquired and a committee of local citizens initiated a park plan. • In 1975, the Corps of Engineers issued a permit for a small marsh plant nursery area to provide some initial experience in transplanting cordgrass and pickleweed within the future marsh area. The permit to excavate for the entire marsh restoration project was issued in 1976. • The site plan included removing spoil for channels, grading upland areas for marsh plant colonization, depositing excess material to create islands and upland areas, and creation of public access. • After the first marsh plantings failed to germinate in 1977, a second attempt was made using a number of different species of cordgrass including seeds from Humboldt Bay and Spartina marina from England. • No records were kept of success or establishment of marsh plants. However, in 1979, Royston, Hanamoto, Beck and Abbey, the landscape architect responsible for the project, was given an Award of Excellence by the American Society of Landscape Architects for the restoration plan.	Josselyn, M., and J. Buchholz. 1984. *Marsh Restoration in San Francisco Bay: A Guide to Design & Planning.* Technical Report #3. Tiburon Center for Environmental Studies, San Francisco State University. 104 pp.
5	Coyote Creek and Anza-Borrego Desert State Park, San Diego County, California	Riparian/ creek restoration	Until March 1988, all vehicles were allowed to travel on the 29-kilometer route of Coyote Canyon, including the riverine routes. The jeep trail passed through the three most significant riparian forests of Coyote Creek and by the early 1980s the impacts of approximately 1000 vehicles on the riparian system during busy weekends became too great. An annual seasonal closure of the entire Coyote Canyon watershed to all persons and vehicles was enacted. A bypass route now provides permanent protection to one of the three riparian sections. A ban on all vehicles that are not street legal, including dirt bikes, all-terrain cycles, and many dune buggies, has caused the traffic corridors to become filled in with thick stands of willow and tamarisk, which provide additional avian habitat.	USDA, Forest Service. 1989. *Proceedings of the California Riparian Systems Conference, September 22-24, 1988, Davis, California,* pp. 149-152.

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Table 7-7. (Continued)

No.	Location	Type of Wetland	Summary of Observations	Source
6	Unknown	Wetland	This paper presents economically efficient policy reforms of national wetlands programs that result in enhanced maintenance of wetland stocks and accommodation of development pressures. The authors' suggestions include a fixed wetlands development fee for developers building in unprotected areas. These development tax revenues then would be used to finance a nationwide investment program to aid the replacement and management of wetlands created to offset losses to development. Alternatively, developers may choose to implement their own mitigation plans. According to the authors, this approach would offer more assurance that coastal wetlands damage will be compensated. Included in this paper are tables of summaries of costs for the following conditions: • Wetland creation with dredged material from maintenance of navigation projects; • Wetland creation with proposed 25,000- cfs controlled sediment diversions; and • Wetland creation with uncontrolled sediment diversions.	Shabman, L.A., and S.S. Batie. 1987. Mitigating Damages from Coastal Wetlands Development: Policy, Economics and Financing. *Marine Resource Economics*. 4:227-248.
7	Amana Society Farm, eastern Iowa	Poplar tree buffer strips in riparian zones	This study outlines 2 years of study of Iowa's riparian corridors by the Leopold Center. *Populus* spp. (poplar) were planted in buffer strips along creeks to produce a productive crop and a more stable riparian zone ecosystem. Planting techniques were developed so that roots grew deep enough to intercept the surficial water and dense enough to uptake most available nitrogen before it leached into the stream. During the two growing seasons, the deep-rooted poplar removed soil nitrate and ammonia nitrogen from soil water well below Maximum Contaminant Limits. Tables or graphs for the following data can be found in the paper: • Tree survival and stem and leaf growth; • Total Kjheldahl Nitrogen concentrations; • Nitrate nitrogen concentrations; • Ammonia nitrogen concentrations; and • Total organic carbon concentrations.	Licht, L.A., and J.L. Schnoor. 1990. *Poplar Tree Buffer Strips Grown in Riparian Zones for Non-point Source Pollution Control and Biomass Production.* Leopold Center for Sustainable Agriculture.

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Table 7-7. (Continued)

No.	Location	Type of Wetland	Summary of Observations	Source
8	Sweetwater River Wetlands Complex, San Diego Bay, California	Construction and enhancement of salt marsh	Mitigation for lost wetland habitat is being carried out by the California Department of Transportation. The mitigation marshes include the Connector Marsh, which is a hydrologic link between Paradise Creek and the Sweetwater Marsh, and Marisma de Nacion, a 17-acre marsh excavated from the "D Street fill" in 1990. The assessment study thus far has found that: • Concentrations of free sulfide were greater in the natural marsh compared to only trace amounts in the constructed marsh. • Nitrogen fixation rates were generally twice as high in the natural salt marsh than in the man-made salt marsh. • There were two to four times more individuals in a natural marsh at San Diego Bay than in the 4-year-old man-made marsh. Abundance of species was up to nine times greater in the natural marsh. These samplings were taken at low marsh elevations. At elevations of 0.5 m above mean sea level, the numbers of species and individuals were similar for areas with high cover. • The preliminary conclusion was that the USFWS criteria for fish species and abundance have been met by the constructed marsh. • An overall comparison indicated that the constructed marsh was less than 60% functionally equivalent to the natural reference wetland (Paradise Creek Marsh) when comparing water quality, plant biomass, and number of species and individuals. • The report contains detailed tables that provide the following quantitative data: - Pore water concentrations of free sulfides; - Rates of nitrogen fixation; - Total nitrogen and phosphorus in sediment core samples; - Biomass of cordgrass; - Ammonium levels of pore water samples; - Mean number of individuals per litterbag; - Mean number of species per litterbag; - Number of channel invertebrates found at sampling stations; and - Sightings of water-associated birds.	Pacific Estuarine Research Laboratory. 1990. *A Manual for Assessing Restored and Natural Coastal Wetlands with Examples from Southern California.* California Sea Grant, La Jolla, California, pp. 19-34.

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Table 7-7. (Continued)

No.	Location	Type of Wetland	Summary of Observations	Source
9	Connecticut	Created and natural wetlands	This report compares five 3- to 4-year-old created wetland sites with five nearby natural wetlands of comparable size. Hydrologic, soil, and vegetation data were compiled over a 2-year period (1988-89). Results indicated that: • Only one created site appeared to mimic the hydrology of a natural wetland because of its connection to a natural water source. • Typical wetland soils exhibiting mottling and organic accumulation were lacking in created sites. • Plant cover was higher in the natural sites because of their greater maturity. • The created sites exhibited a slightly higher number of species. This species richness can be attributed to the rapid rate of species establishment on mineral soil substrates. The small sample size also may have contributed to the high number of species in the created site. Egler's Initial Floristic Composition concept, a model of vegetation development, also explains the difference in species numbers. This model assumes a large number of species early in the development process, which may decrease over time as a result of interspecific competition. • Based on observations of bird species diversity and muskrat activity, creation of comparable wildlife habitat was achieved at more than one created site. The authors concluded that the presence of invasive species threatens the future of the created wetlands.	Confer, S., and W.A. Niering. Undated. Comparison of Created Freshwater and Natural Emergent Wetlands in Connecticut. Submitted to *Wetland Ecology and Management.*
10	Wyoming	Riparian zones	Along a degraded cold desert stream in Wyoming, instream flow structures (trash collectors), willow, and beaver are being used to reclaim riparian habitat. Trash collectors are intended to decrease streamflow velocity, causing sediment to be deposited as channel bed material. Willows will be used to stabilize new channel bank deposition. Preliminary results have shown that: • Trash collectors have survived 1 1/2 years and are trapping sediment. • Channel bed material is rising. • Beaver are using trash collectors as support for dams. • Willow plantings have survived 2 years.	Skinner, Q.D., M.A. Smith, J.L. Dodd, and J.D. Rodgers. Undated. *Reversing Desertification of Riparian Zones Along Cold Desert Streams.* pp. 1407-1414.

Table 7-7. (Continued)

No.	Location	Type of Wetland	Summary of Observations	Source
11	California	Riparian	Severe storms of 1978 through 1983 caused considerable damage to streams in California. The Soil Conservation Service used several mechanical and revegetation techniques to stabilize streambanks and reestablish riparian vegetation. Results of evaluations of 29 projects are discussed, and recommendations are made to improve success.	Shultze, R.F., and G.I. Wilcox. 1985. Emergency Measures for Streambank Stabilization: An Evaluation. In *Riparian Ecosystems and Their Management: Reconciling Conflicting Issues.* USDA Forest Service GTR RM-120, pp. 54-58.
12	Rio Grande River, New Mexico	Riparian	Riparian areas continue to be drastically altered, usually by human activities. Managers have generally been unsuccessful in using conventional techniques to replace riparian trees. Experiments with Rio Grande cottonwood, narrowleaf cottonwood, and Gooding willow have shown that a simple and inexpensive method for their reestablishment is now available (i.e., placing large, dormant cuttings into holes predrilled to known depth of the growing season water table).	Swenson, E.A., and C.L.Mullins. 1985. Revegetating Riparian Trees in Southwestern Floodplains. In *Riparian Ecosystems and Their Management: Reconciling Conflicting Issues.* USDA Forest Service GTR RM-120, pp. 135-138.
13	Savannah River, South Carolina	Wetland	Principal factors that affect seedling recruitment in mature cypress-tupelo forests include seed production, microsite availability, and hydrologic regime. Studies on the Savannah River floodplain in South Carolina show that although seed production seems adequate, microsite characteristics and water level changes limit regeneration success. Management of water levels on regulated streams must account for species regeneration requirements to maintain floodplain wetland community structure.	Sharitz, R.R., and L.C. Lee. 1985. Limits onregeneration processes in southeastern riverine wetlands. In *Riparian Ecosystems and Their Management: Reconciling Conflicting Issues.* USDA Forest Service GTR RM-120, pp.139-143.
14	Niger, West Africa	Riparian	A reforestation project in the Majjia Valley, Niger, was undertaken to improve the microclimate, to reduce water and wind erosion, and to produce fuel wood. Windbreaks were planted, wood lots were established, and trees were distributed to the inhabitants. The windbreaks were effective in reducing wind velocities and, at times, retained soil moisture. Water consumption by vegetation in the windbreaks did not affect soil moisture in the agricultural crop rooting zone. Although fuel wood has not been harvested, agricultural crop yields in the windbreaks were 125% of those in the control.	Ffolliott, P.F., and R.L. Jemison. 1985. Land use in Majjia Valley, Niger, West Africa. In *Riparian Ecosystems and Their Management: Reconciling Conflicting Issues.* USDA Forest Service GTR RM-120, pp. 470-474.

5. Costs for All Practices

This section describes costs for representative activities that would be undertaken in support of one or more of the practices listed under this management measure. The description of the costs is grouped into the following two categories:

(1) A wetlands/riparian restoration project involving a low level of effort.

The items of work would include (a) clearing the site of fallen trees and debris; (b) application of seed stock or sprigging of nursery-reared plants; (c) application of fertilizer (most typically for marsh restoration); and (d) a minimal amount of postproject maintenance until the vegetation becomes established.

A low level of effort could also include minor adjustments to the existing hydrology, such as the installation of stop-logs to raise water levels, or improvements to the existing drainage patterns undertaken to lower water levels (e.g., pulling the plug on tile fields).

(2) A wetlands/riparian restoration project involving a high level of effort.

The items of work would include (a) clearing the site of fallen trees and debris; (b) extensive site work requiring heavy construction equipment; (c) application of seed stock or sprigging of nursery-reared plants; (d) application of fertilizer (most typically for marsh restoration); and (e) postproject maintenance and monitoring.

A high level of effort is distinguished from a low level by the amount of site work required. A high level of effort typically will require heavy construction machinery, including graders, bulldozers, and/or dump trucks. These pieces of equipment will be used to accomplish several tasks, such as:

- Adding additional fill material to the site or removing excessive amounts of on-site material;
- Realigning the existing on-site substrate to appropriate lines and grades as shown on the design plan; and
- Realigning existing channels or constructing new channels, diversions, basins, or tidal flats as necessary to restore preexisting surface water flow characteristics.

In addition to the need for heavy construction equipment to perform the work, a restoration project involving a high level of effort typically requires more extensive analysis and evaluation of the site before work is started. Site surveys and preparation of formal design drawings and specifications are frequently necessary prior to starting the work. Periodic site visits are needed to inspect the work in progress. Spot surveys are frequently necessary to check the lines and grades of new channels and wetlands planting areas as they are being formed with the heavy construction machinery. Finally, a high-level restoration frequently requires postproject monitoring and adjustment as water begins to flow through the recreated surface water systems in the restored wetland.

The costs for items of work associated with either a low level or a high level of effort are reported below from actual examples of recent projects involving wetlands and riparian area restoration. The cases cited are representative of the levels of effort that could be undertaken in support of the practices under Management Measure II.B.

Each of the following examples contains a description of costs as they are reported in the source document. For ease of comparison, these costs are converted to 1990 dollars, using conversion factors published in the *Engineering News-Record*. A full explanation of the conversion factors is contained in Table 7-8.

Table 7-8. Construction Cost Index
(Grogan, 1991)

Year	Annual Average	Year	Annual Average
1975	2212	1984	4146
1976	2401	1985	4195
1977	2576	1986	4295
1978	2776	1987	4406
1979	3003	1988	4519
1980	3237	1989	4606
1981	3535	1990	4732
1982	3825	1991	4775
1983	4066	1992	4946

Note: *Engineering News Record (ENR)* builds the index as follows:

200 hours of common labor at the 20-city average of common labor rates, plus 25 cwt of standard structural steel shapes at the mill price, plus 22.56 cwt (1.128 tons) portland cement at the 20-city price, plus 1,088 board-feet of 2X4 lumber at the 20-city price.

Example: To compute a construction cost increase from 1985 to 1990
(a) Divide 1990 index by 1985 index: 4732/4195 = 1.128
(b) Multiply 1985 cost by ratio: 1985 cost X 1.128 = 1990 cost.

a. *Costs for "Low-Level" Restoration Projects*

The two sources of wetland and riparian plants that should be used in restoration projects are seed and nursery-reared plant stock. Transplantation of wetland plant materials from other natural ecosystems is not recommended, but transplantation of young trees and shrubs growing in upland areas for riparian area restoration is acceptable, provided no other suitable source of plant stock is available. Transplantation of wetland plants is not recommended because digging up existing wetlands for removal of plant material can cause serious disturbance and dislocation of healthy systems. In addition, pests, disease, and contaminants can be carried along with the transplants and introduced into the area undergoing restoration. For this reason, even though it is possible to locate citations in the literature for transplantation costs, they are not included in the list below.

(1) Costs for a 1982 tidal wetlands project in Chesapeake Bay, Maryland, included seeding and fertilizing salt marsh cordgrass at $204.85 per acre (Earhart and Garbisch, 1983).

Cost in 1990 dollars $253.42/acre

(2) Costs reported in 1979 for tidal wetlands restoration in coastal California included seeding and fertilizing salt marsh cordgrass at $300 to $500 per acre (Jerome, 1979).

Cost in 1990 dollars .... $470 to 780/acre

(3) Costs reported in 1992 for nontidal wetlands included purchasing and installing nursery-reared plant stock (emergents) at $2,024 to $2,429 per acre (Hammer, 1992).

Cost in 1990 dollars .... $1,936 to 2,323/acre

(4) Costs reported in 1989 for bottomland forest restoration using direct seeding were $40 to $60 per acre (National Research Council, 1991).

Cost in 1990 dollars .... $41.20 to $61.80/acre

(5) Costs reported in 1990 for nursery-reared tree seedlings were $212.50 per acre (Illinois Department of Conservation, 1990).

Cost in 1990 dollars $212.50/acre

As this cost information indicates, nursery-reared plant materials used in nontidal wetland restoration projects are generally more expensive than plants used in restoration of tidal wetlands. This difference seems to be partly due to the greater ease with which tidal wetland plants can be grown in nurseries in sufficient quantities for commercial distribution.

The "law of supply and demand" is another factor influencing the price of these two types of items. Mitigation requirements for tidal wetlands have been imposed in many coastal regions of the United States since the mid-1970s, and the commercial market has responded by developing the methods to produce adequate quantities of nursery stock available at the appropriate planting seasons to meet the demand. The requirements for mitigation of nontidal wetlands have only more recently been enforced. Thus, in certain geographic areas of the United States, the demand for these kinds of plant materials from nurseries probably exceeds the supply, resulting in higher unit costs.

Two other factors that influence the costs of seed or plant stock are (1) using exotic or hybrid varieties or introduced species and (2) purchasing plant stock from properly certified and inspected nurseries. When considering the use of seeds or nursery stock for restoration projects, it is best to consider only strong, nonexotic strains of plant materials. Many nurseries carry exotic strains of common species, introduced species, or hybrid varieties. These types of plant stock are intended for use in the home watergarden or in landscaping projects. Always check the genus and species of the plants found in the natural wetland and riparian systems in the locality and insist on purchasing these same varieties from the nursery. In addition, several States have inspection and certification programs for nursery-reared plant stock. For example, the State of Maryland's Department of Agriculture publishes a *Directory of Certified Nurseries, Licensed Plant Dealers, Licensed Plant Brokers* (Maryland Department of Agriculture, 1990). Likewise, the Association of Florida Native Nurseries (AFNN) publishes an annual *Plant and Service Locator* (AFNN, 1989). In these cases, plants should always be obtained from properly inspected and certified dealers. In some regions of the United States, more stringent rules and regulations apply to plant stock purchased for transport across State lines. Such laws exist in part to minimize the potential for the spread of pests and disease and should be strictly adhered to.

Obtaining strains of plant material identical to those occurring in natural ecosystems, through properly certified and inspected plant dealers, frequently results in a slightly higher product cost. However, increased benefits in environmental protection and project performance will generally justify paying the slightly higher price.

b. Costs for "High-Level" Restoration Projects

Costs for projects involving extensive site work will vary widely based on several factors, including (1) the extent and complexity of the work shown on the design drawing, (2) the local availability of construction equipment, and (3) the degree of difficulty involved in gaining access to the site. In addition, as the examples of restoration projects listed below illustrate, overall project costs can be considerably increased if the land containing the proposed restoration project must be purchased before any work is undertaken.

In compiling the restoration costs for the examples listed below, the reported costs for riparian work were frequently presented in units of linear feet of streambank. For ease of comparison with the other examples, these costs were converted to dollars per acre by assigning a width along the streambank within which work is assumed to have taken place.

(1) Costs reported for the 1980 restoration of diked tidelands at the Elk River in Humboldt Bay, California, ranged from $5,000 to $7,000 per acre. The items of work included breaching of dikes to restore preexisting hydrology, construction of new dikes at a lower elevation, installation of other drainage controls, and restoration of tidal wetland vegetation (Anderson and Rockel, 1991).

Cost in 1990 dollars .... $7,300 to $10,000/acre

(2) Costs reported for the 1986 restoration of tidal wetlands at three California coastal sites averaged $23,700 per acre. The sites included Big Canyon in Upper Newport Bay, Freshwater Slough, and Bracut (both in Humboldt Bay). Existing fill had to be removed from the sites before wetlands restoration could be accomplished (Anderson and Rockel, 1991).

Cost in 1990 dollars $26,070/acre

(3) Costs reported for restoration of riparian areas in Utah between 1985 and 1988 were used to compute an average cost of approximately $2,527 per acre, assuming a streamside width of 100 feet for the work. The items of work included bank grading, installation of riprap and sediment traps in deep gullies, planting of juniper trees and willows, and fencing of the site (Nelson and Williams, 1989).

Cost in 1990 dollars $2,527/acre

[illegible]

Promote the use of engineered vegetated treatment systems such as constructed wetlands or vegetated filter strips where these systems will serve a significant NPS pollution abatement function.

1. Applicability

This management measure is intended to be applied by States in cases where engineered systems of wetlands or vegetated treatment systems can treat NPS pollution. Constructed wetlands and vegetated treatment systems often serve a significant NPS pollution abatement function. Under the Coastal Zone Act Reauthorization Amendments of 1990, States are subject to a number of requirements as they develop coastal NPS programs in conformity with this management measure and will have flexibility in doing so. The application of management measures by States is described more fully in *Coastal Nonpoint Pollution Control Program: Program Development and Approval Guidance*, published jointly by the U.S. Environmental Protection Agency (EPA) and the National Oceanic and Atmospheric Administration (NOAA) of the U.S. Department of Commerce.

2. Description

As discussed in Section I.E of this chapter, vegetated treatment systems (VTS), by definition in this guidance, include vegetated filter strips and constructed wetlands. Although these systems are distinctly different, both are designed to reduce NPS pollution. They need to be properly designed, correctly installed, and diligently maintained in order to function properly.

The term *NPS pollution abatement function* refers to the ability of VTS to remove NPS pollutants. Filtering sediment and sediment-borne nutrients and converting nitrate to nitrogen gas are examples of the important NPS pollution abatement functions performed by vegetated treatment systems.

a. Vegetated Filter Strips

The purpose of vegetated filter strips (VFS) is to remove sediment and other pollutants from runoff and wastewater by filtration, deposition, infiltration, absorption, adsorption, decomposition, and volatilization, thereby reducing the amount of pollution entering surface waters (USDA, 1988). Vegetated filter strips are appropriate for use in areas adjacent to surface water systems that may receive runoff containing sediment, suspended solids, and/or nutrient runoff. Vegetated filter strips can improve water quality by removing nutrients, sediment, suspended solids, and pesticides. However, VFS are most effective in the removal of sediment and other suspended solids.

Vegetated filter strips are designed to be used under conditions in which runoff passes over the vegetation in a uniform sheet flow. Such a flow is critical to the success of the filter strip. If runoff is allowed to concentrate or channelize, the vegetated filter strip is easily inundated and will not perform as it was designed to function.

Vegetated filter strips need the following elements to work properly: (1) a device such as a level spreader that ensures that runoff reaches the vegetated filter strip as a sheet flow (berms can be used for this purpose if they are placed at a perpendicular angle to the vegetated filter strip area to prevent concentrated flows); (2) a dense vegetative cover of erosion-resistant plant species; (3) a gentle slope of no more than 5 percent; and (4) a length at least as long as the adjacent contributing area (Schueler, 1987). If these requirements are met, VFS have been shown to remove a high degree of particulate pollutants. The effectiveness of VFS at removing soluble pollutants is not well documented (Schueler, 1987).

b. Constructed Wetlands

Constructed wetlands are typically engineered complexes of saturated substrates, emergent and submergent vegetation, animal life, and water that simulate wetlands for human use and benefits (Hammer et al., 1989). According to Hammer and others (1989), constructed wetlands typically have four principal components that may assist in pollutant removal:

(1) Substrates with various rates of hydraulic conductivity;
(2) Plants adapted to water-saturated anaerobic substrates;
(3) A water column (water flowing through or above the substrate); and
(4) Aerobic and anaerobic microbial populations.

3. Management Measure Selection

This management measure was selected because vegetated treatment systems have been shown to be effective at NPS pollutant removal. The effectiveness of the two types of VTS is discussed in more detail in separate sections below.

a. Effectiveness of Vegetated Filter Strips

Several studies of VFS (Table 7-9) show that they improve water quality and can be an effective management practice for the control of nonpoint pollution from silvicultural, urban, construction, and agricultural sources of sediment, phosphorus, and pathogenic bacteria. The research results reported in Table 7-9 show that VFS are most effective at sediment removal, with rates generally greater than 70 percent. The published results on the effectiveness of VFS in nutrient removal are more variable, but nitrogen and phosphorus removal rates are typically greater than 50 percent. The following are nonpoint sources for which VFS may provide some nutrient-removal capability:

(1) **Cropland.** The primary function of grass filter strips is to filter sediment from soil erosion and sediment-borne nutrients. However, filter strips should not be relied on as the sole or primary means of preventing nutrient movement from cropland (Lanier, 1990).

(2) **Urban Development.** Vegetated filter strips filter and remove sediment, organic material, and trace metals. According to the Metropolitan Washington Council of Governments, VFS have a low to moderate ability to remove pollutants in urban runoff and have higher efficiency for removal of particulate pollutants than for removal of soluble pollutants (Schueler, 1987).

With proper planning and maintenance, VFS can be a beneficial part of a network of NPS pollution control measures for a particular site. They can help to reduce the polluting effects of agricultural runoff when coupled with either (1) farming practices that reduce nutrient inputs or minimize soil erosion or (2) detention ponds to collect runoff as it leaves a vegetated filter strip. Properly planned VFS can add to urban settings by framing small streams, ponds, or lakes, or by delineating impervious areas. In addition to serving as a pollution control measure, VFS can add positive improvements to the urban environment by increasing wildlife and adding beauty to an area.

b. Effectiveness of Constructed Wetlands

Constructed wetlands have been considered for use in urban and agricultural settings where some sort of engineered system is suitable for NPS pollution reduction.

A few studies have also been conducted to evaluate the effectiveness of artificial wetlands that were designed and constructed specifically to remove pollutants from surface water runoff (Table 7-10). Typical removal rates for

Table 7-9. Effectiveness of Vegetated Filter Strips for Pollutant Removal

Author	Study	VFS Length (m)	Vegetation	Sediment Removal (%)	Total Nitrogen Removal (%)	Total Phosphorus Removal (%)	Other Pollutant Removal (%)
Dillaha et al., 1988	simulated feedlot runoff	4.6	orchard grass	79	64	58	
		9.1		90	74	68	
Dillaha et al., 1989a	simulated cropland runoff	4.6	orchard grass	63	50	57	
		9.1		78	67	74	
Magette et al., 1989	simulated cropland runoff	4.6	orchard grass	72	17	41	
		9.1		86	72	53	
Young et al., 1980	simulated feedlot	36-41	corn	86	92	91	Total Coliform 70
			orchard grass	66	87	88	53
			sorghum	82	84	81	81
			oats	75	73	70	70
			average	79	84	83	NA
Dickey and Vanderholm, 1981	pumped effluent	91	mixed	73	80/86[a]	78	
		61	fescue/alfalfa	63	71/72[a]	NA	
		152-457	foxtail	78	89/85[a]	NA	
Dickey and Vanderholm, 1981	pumped effluent	229	NA	39	50/41[a]	NA	
		305		59	61/63[a]	16	
		381		56	66/64[a]	49	
		533		80	83/83[a]	NA	
Schwer and Clausen, 1989	milkhouse runoff	26	fescue, ryegrass, bluegrass	89	76[b]	78	
Overman and Schanze, 1985			Bermuda grass	81	67	39	

NA = not available.
[a]Total Kjeldahl Nitrogen/ammonia nitrogen.
[b]Total Kjeldahl Nitrogen.

Table 7-10. Effectiveness of Constructed Wetlands for Treatment of Surface Water Runoff

Constituent	Lake Jackson (%)	Orange County (%)	Tampa Office (%)	MWTS (%)
Total Solids				
Suspended	94	83	83	90
Organic	96			89
Nitrogen				
Total	76	30	10	50
Ammonia	37	32	34	
Nitrate	70		75	56
Nitrite	75			
Organic (TKN)		34	-8	48
Phosphorus				
Total	90	37	54	55
Ortho	78	21	63	33
Metals				
Lead		81		75
Iron			33	
Nickel			21	

Sources: Lake Jackson: Tuovila et al. 1987. *An evaluation of the Lake Jackson (Florida) Filter System and Artificial Marsh on Nutrient and Particulate Removal from Stormwater Runoff.*
Orange County: Martin and Smoot. Undated. *Tampa Office Wet Detention Stormwater Treatment.*
Tampa Office: Rushton and Dye 1990. *Water Quality Effectiveness of a Detention/Wetland Treatment System and Its Effect on an Urban Lake.*
MWTS: Oberts and Osgood 1991. *Constituent Load Changes in Urban Stormwater Runoff Routed Through a Detention Pond-Wetland System in Central Florida.*

Notes: Lake Jackson: Constructed wetland system located in Tallahassee, FL. Consists of a detention pond in series with a sand filter and constructed wetland. Analysis done in 1985.
Orange County: Wetland and detention pond system in Orlando, FL. Constructed in 1980.
Tampa Office: Constructed detention pond and wetland system located in Tampa, FL. Analysis done in 1989.
MWTS: Constructed detention pond and wetland system located in Roseville, MN. Consists of a detention pond in series with six wetland cells. Constructed and studied in 1986.

suspended solids were greater than 90 percent (Table 7-10). Removal rates for total phosphorus ranged from 50 percent to 90 percent. Nitrogen removal was highly variable and ranged from 10 percent to 76 percent for total nitrogen.

Like vegetated filter strips, constructed wetlands offer an alternative to other systems that are more structural in design for NPS pollution control. In some cases, constructed wetland systems can provide limited ecological benefits in addition to their NPS control functions. In other cases, constructed wetlands offer few, if any, additional ecological benefits, either because of the type of vegetation installed in the constructed wetland or because of the quantity and type of pollutants received in runoff. In fact, constructed wetlands that receive water containing large amounts of metals or pesticides should be fenced or otherwise barricaded to discourage wildlife use.

4. Practices

As discussed more fully at the beginning of this chapter and in Chapter 1, the following practices are described for illustrative purposes only. State programs need not require implementation of these practices. However, as a practical matter, EPA anticipates that the management measure set forth above generally will be implemented by applying one or more management practices appropriate to the source, location, and climate. The practices set forth below have been found by EPA to be representative of the types of practices that can be applied successfully to achieve the management measure described above.

■ a. *Construct VFS in areas adjacent to waterbodies that may be subject to suspended solids and/or nutrient runoff.*

A survey of the literature on the design, performance, and effectiveness of VFS shows that the following factors need to be considered on a site-specific basis before designing and constructing a vegetated filter strip:

(1) The effectiveness of VFS varies with topography, vegetative cover, implementation, and use with other management practices. In addition, different VFS characteristics such as size and type of vegetation can result in different pollutant loading characteristics, as well as loading reductions. Table 7-9 gives some removal rates for specific NPS pollutants based on VFS size and vegetation.

(2) Several regional differences are important to note when considering the use of VFS. Climate plays an important role in the effectiveness of VFS. The amount and duration of rainfall, the seasonal differences in precipitation patterns, and the type of vegetation suitable for local climatic conditions are examples of regional variables that can affect the performance of VFS. Soil type and land use practices are also regional differences that will affect characteristics of surface water runoff and thus of VFS performance. The sites where published research has been conducted on VFS effectiveness for pollutant removal are overwhelmingly located in the eastern United States. There is a demonstrated need for more studies located in different geographic areas in order to better categorize the effects of regional differences on the effectiveness of VFS.

(3) Vegetated filter strips have been successfully used in a variety of situations where some sort of BMP was needed to treat surface water runoff. Typical locations of VFS have included:

- Below cropland or other fields;
- Above conservation practices such as terraces or diversions;
- Between fields;
- Alternating between wider bands of row crops;
- Adjacent to wetlands, streams, ponds, or lakes;
- Along roadways, parking lots, or other impervious areas;
- In areas requiring filter strips as part of a waste management system; and
- On forested land.

VFS function properly only in situations where they can accept overland sheet flow of runoff and should be designed accordingly. If existing site conditions include concentrated flows, then BMPs other than VFS should be used. Contact time between runoff and the vegetation is a critical variable influencing VFS effectiveness. Pollutant-removal effectiveness increases as the ratio of VFS area to runoff-contributing area increases.

(4) Key elements to be considered in the design of VFS areas follow:

- **Type and Quantity of Pollutant.** Sediment, nitrogen, phosphorus, and toxics are efficiently removed by VFS (see Table 7-9). However, removal rates are much lower for soluble nutrients and toxics.

- **Slope.** VFS function best on slopes of less than 5 percent; slopes greater than 15 percent render them ineffective because surface runoff flow will not be sheet-like and uniform. The effectiveness of VFS is strongly site-dependent. They are ineffective on hilly plots or in terrain that allows concentrated flows.

- **Native/Noninvasive Plants.** The best species for VFS are those which will produce dense growths of grasses and legumes resistant to overland flow. Use native or at least noninvasive plants to avoid negatively impacting adjacent natural areas.

- **Length.** The length of VFS is an important variable influencing VFS effectiveness because contact time between runoff and vegetation in the VFS increases with increasing VFS length. Some sources recommend a minimum length of about 50 feet (Dillaha et al., 1989a; Nieswand et al., 1989; Schueler, 1987). USDA (1988) has prepared design criteria for VFS that take into consideration the nature of the source area for the runoff and the slope of the terrain. Another suggested design criterion that can be found in the literature is for the VFS length to be at least as long as the runoff-contributing area. Unfortunately, there are no clear guidelines available in the literature for calculating VFS lengths for specific site conditions. Accordingly, this guidance does not prescribe either a numeric value for the minimum length for an effective filter strip or a standard method to be used in the design criteria for computing the length of a VFS.

- **Detention Time.** In the design process for a vegetated filter strip, some consideration should be given to increasing the detention time of runoff as it passes over the VFS. One possibility is to design the vegetated filter strip to include small rills that run parallel to the leading edge of the vegetated filter strip. These rills would serve to trap water as runoff passes through the vegetated filter strip. Another possibility is to plant crops upslope of the vegetated filter strip in rows running parallel to the leading edge of the vegetated filter strip. Data from a study by Young and others (1980), in which corn was planted in rows parallel to the leading edge of the filter strip, show an increase in sediment trapping and nutrient removal.

- **Monitoring of Performance.** The design, placement, and maintenance of VFS are all very critical to their effectiveness, and concentrated flows should be prevented. Although intentional planting and naturalization of the vegetation will enhance the effectiveness of a larger filter strip, the strip should be inspected periodically to determine whether concentrated flows are bypassing or overwhelming the BMP, particularly around the perimeter. The vegetated filter strip should also be regularly inspected to determine whether sediment is accumulating within the vegetated filter strip in quantities that would reduce its effectiveness (Magette et al., 1989).

- **Maintenance.** For VFS that are relatively short in length, natural vegetative succession is not intended and the vegetation should be managed like a lawn. It should be mowed two or three times a year, fertilized, and weeded in an attempt to achieve dense, hearty vegetation. The goal is to increase vegetation density for maximum filtration. Accumulated sediment and particulate matter in a VFS should be removed at regular intervals to prevent inundation during runoff events. The frequency at which this type of maintenance will be required will depend on the frequency and volume of runoff flows. Also, if the soil is moderately erodible in the drainage area, additional precautions should be taken to avoid excessive buildup of sediment in the grassed area (NVPDC, 1987). Development of channels and erosion rills within the VFS must be avoided. To ensure effectiveness, sheet flow must be maintained at all times. The maintenance of VFS located adjacent to streams is especially important since sediment bypassing a VFS and entering a coastal waterbody will cause problems for the spawning and early juvenile stages of fish.

Dillaha and others (1989b) showed that many of the VFS installed in Virginia performed poorly because of poor design and maintenance. Consider including one or more of the following items in a VFS maintenance program to make the performance of any VFS more efficient:

- Adding a stone trench to spread water effectively across the surface of the filter;
- Keeping the VFS carefully shaped to ensure sheet flow;
- Inspecting for damage following major storm events; and
- Removing any accumulation of sediment.

b. *Construct properly engineered systems of wetlands for NPS pollution control. Manage these systems to avoid negative impacts on surrounding ecosystems or ground water.*

Several factors must be considered in the design and construction of an artificial wetland to ensure the maximum performance of the facility for pollutant removal:

Hydrology. The most important variable in constructed wetland design is hydrology. If the proper hydrologic conditions are developed, the chemical and biological conditions will, to a degree, respond accordingly (Mitsch and Gosselink, 1986).

Soils. The underlying soils in a wetland vary in their ability to support vegetation, to prevent percolation of surface water into the ground water, and to provide active exchange sites for adsorption of constituents like phosphorus and metals.

Vegetation. The types of vegetation used in constructed wetlands depend on the region and climate of the constructed wetland (Mitsch, 1977). When possible, use native plant species or noninvasive species to avoid negative impacts to nearby natural wetland areas. There are several guides for the selection of wetland plants such as the *Midwestern Guide to Flora* (USDA) or the Florida Department of Environmental Regulation's list of suggested wetland species.

Influent Water Quality. Characterization of influent water quality, such as the types and magnitude of the pollutants, will determine the design characteristics of the constructed wetland.

Geometry. The size and shape of the constructed wetland will influence the detention time of the wetland, the flow rate of surface water runoff moving through the system, and the pollutant removal effectiveness under "typical" conditions.

Pretreatment. Constructed wetlands should contain forebays to trap sediment before runoff enters the vegetated area of the constructed wetland system. Baffles and diversions should be strategically placed to prevent trapped sediment from becoming resuspended during subsequent storm events prior to cleanout.

Maintenance. Constructed wetlands need to be maintained for optimal performance. Since pollutant removal is the primary objective of the constructed wetland, vegetation and sediment removal are two of the more important maintenance considerations. Properly designed constructed wetlands should not need any maintenance of vegetation. Constructed wetlands must be managed to avoid any negative impacts to wildlife and surrounding areas. For example, non-native or undesirable plant species must be kept out of adjacent wetlands or riparian areas. Contamination of sediments due to toxics entering the constructed wetland must also be controlled. The Kesterson National Wildlife Refuge in California is an excellent example of a case in which selenium contamination in wetland sediments was found to cause deaths and deformities in visiting waterfowl (Ohlendorf et al., 1986). Forebays and deep water areas should be inspected periodically, and excess sediment should be removed from the system and disposed of in an appropriate manner. Other routine maintenance requirements include wildlife management, mosquito control, and debris and litter removal (Mitsch, 1990; Schueler, 1987). As debris and litter collect in the detention basins and vegetated areas, they need to be routinely removed to prevent channelization and outflow blockage from occurring. The area around the constructed wetland should be mowed periodically to keep a healthy stand of grass or other desirable vegetation growing. Structural repairs and erosion control should also be done when needed.

Effectiveness of Constructed Wetlands

Table 7-10 summarizes the pollutant-removal effectiveness of constructed wetland systems built for treatment of surface water runoff. In general, constructed wetland systems designed for treatment of NPS pollution in surface water runoff were effective at removing suspended solids and pollutants that attach to solids and soil particles (refer to Table 7-10). The constructed wetland systems were not as effective at removing dissolved pollutants and those pollutants that dissolve under conditions found in the wetland. When the overall effectiveness data are compared among systems, no discernible trends are apparent. Although attempts to correlate removal effectiveness with an area or volume ratio have not shown any significant trends, the constructed wetlands listed in Table 7-10 still served a valuable role in pollutant removal. Total solids removal ranged from 63 percent to 94 percent among the five systems. Nitrogen removal was not as effective, with effectiveness ranging from 10 percent to 76 percent. Phosphorus removal ranged from 37 percent to 90 percent among the constructed wetland systems compared in this document.

Whether constructed wetlands and VFS are used individually or in series will depend on several factors, including the quantity and quality of the inflowing runoff, the characteristics of the existing hydrology, and the physical limitations of the area surrounding the wetland or riparian area to be protected.

A schematic drawing of a system of filter strips and constructed wetland placed in the path of the existing surface water supply to a stream is shown in Figure 7-2.

5. Costs for All Practices

The use of appropriate practices for pretreatment of runoff and prevention of adverse impacts to wetlands and other waterbodies involves the design and installation of vegetated treatment systems such as vegetated filter strips or constructed wetlands, or the use of structures such as detention or retention basins. These types of systems are discussed individually elsewhere in this guidance document. Refer to Chapter 4 for a discussion of the costs and effectiveness of detention and retention basins. The purpose of each of these BMPs is to remove, to the extent practicable, excessive levels of NPS pollutants and to minimize impacts of hydrologic changes. Each of these BMPs can function to reduce levels of pollutants in runoff or attenuate runoff volume before the runoff enters a natural wetland or riparian area or another waterbody.

Several source documents contain information on costs for vegetated treatment systems. Nieswand and others (1989) published costs for vegetated filter strips employed as part of watershed management strategies for New Jersey. Costs varied over a wide range depending on whether the method of installation involved seeding, sodding, or hydroseeding. Another source of cost information on filter strips is EPA's NWQEP 1988 *Annual Report: Status of Agricultural Nonpoint Source Projects* (1988).

The most comprehensive source of cost data for filter strips was obtained from the USDA ASCS, which provides cost share reimbursement each year to individual farmers for a variety of practices contained in the *National Handbook of Conservation Practices* (1988). Information was obtained from USDA on the costs in each State for work performed in accordance with Specification No. 393 (Filter Strips) in the *National Handbook* for the base year of 1990. Based on these data, a total of 914 filter strip projects were installed with cost share assistance in 28 States. The total cost of these projects was $833,871.00. The total combined length of all projects was 6,443,800 linear feet. If an average width of 66 feet is assumed for the filter strip, then an average cost per acre is calculated at $85.41 per acre, in 1990 dollars.

For constructed wetlands, examples of cost data are as follows:

(1) Lake Jackson, Florida: A cost of $80,769 was reported in 1990 for design and construction of a 9.88-acre constructed wetland for treatment of urban nonpoint runoff (Mitsch, 1990).

Cost in 1990 dollars .... $ 8,175.00/acre

(2) Greenwood Urban Wetland, Minnesota: A cost of $20,370 was reported in 1990 for design and construction of a 27.2-acre wetland for treatment of urban nonpoint runoff (Mitsch, 1990).

Cost in 1990 dollars .... $ 748.89/acre

(3) Broward County, Florida: A cost range of $10,000 to $100,000 per acre (1992) was given for constructing surface water runoff wetlands on sites of new developments. The average cost for

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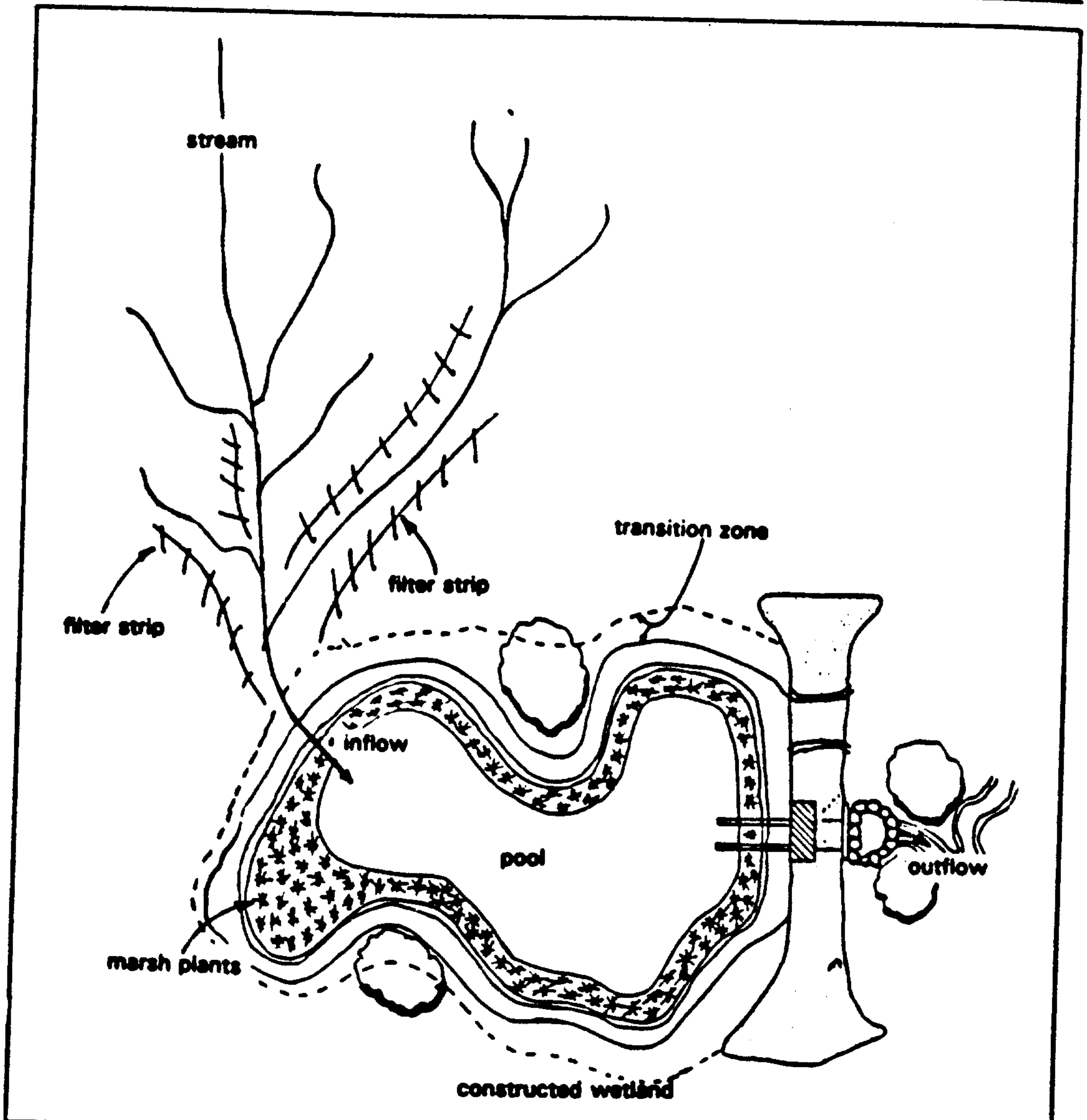

Figure 7-2. Schematic of vegetated treatment system, including a vegetated filter strip and constructed wetland. (After Schueler, 1992).

constructing a wetland was given as $20,000. The costs represent mucking (depositing organic material substrate) and planting emergent wetlands plants. Site monitoring adds $10,000 to $12,000 per year for sites up to 10 acres. (Goldasich, Broward County Office of Natural Resources Protection, personal communication, July 1992).

Cost in 1990 dollars $19,200/acre

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It is important to note that the type of constructed wetland facility described in this guidance is for treatment of urban or agricultural runoff. To avoid confusion, costs of wetlands constructed for other purposes, particularly for municipal wastewater treatment, were not considered.

As illustrated by the three examples cited above, the cost per acre of constructed wetlands facilities will vary from site to site. One reason is that certain items of work have economies of scale that are rather limited. For example, costs for site surveys, design, gaining access to the site, mobilization of equipment, and installation of sediment and surface water runoff controls do not necessarily increase in proportion to the size of the project. Other factors that affect costs are regional variations in suitable plant species, treatment of existing surface water flow patterns, and detention/retention capacity.

Based on the cost data contained in the source documents, costs are reported below for three realistic hypothetical scenarios of systems of constructed wetlands and vegetated filter strips.

(1) One filter strip at a cost of .... $ 129.00

- Includes design and installation of a grass filter strip 1,000 feet long and 66 feet wide.
- Most effective at trapping sediments and removing phosphorus from surface water runoff.

(2) One constructed wetland at a cost of .... $ 5,000.00

- Includes design and installation of a constructed wetland whose surface area is 0.25 acre in size. The constructed wetland is planted with commercially available emergent vegetation.
- Most effective at removing nutrients and at decreasing the rate of inflow of surface water runoff.

(3) One combined filter strip/constructed wetland .... $ 5,129.00

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III. Glossary

Abiotic: Not biological; not involving or produced by organisms (Merriam-Webster, 1991).

Adsorption: The accumulation of substances at the interface between two phases; in water treatment, the interface is between the liquid and solid surfaces that are artificially provided (Peavy et al., 1985).

Biological assimilation: The conversion of nonliving substances into living protoplasm or cells by using energy to build up complex compounds of living matter from the simple nutritive compounds obtained from food (Barnhart, 1986).

Biotic: Caused or produced by living beings (Merriam-Webster, 1991).

Chelation: The process of binding and stabilizing metallic ions by means of an inert complex compound or ion in which a metallic atom or ion is bound at two or more points to a molecule or ion so as to form a ring; the increasing complex stability of coordination compounds caused by an increasing number of attachments (usually to a metal ion) (Barnhart, 1986; Snoeyink and Jenkins, 1980; Merriam-Webster, 1991).

Chemical decomposition: Separation into elements or simpler compounds; chemical breakdown (Merriam-Webster, 1991).

Complexation: The process by which one substance is converted to another substance in which the constituents are more intimately associated than in a simple mixture; chelation is one type of complexation (Merriam-Webster, 1991).

Connectedness: Having the property of being joined or linked together, as in aquatic or riparian habitats.

Constructed wetland: Engineered systems designed to simulate natural wetlands to exploit the water purification functional value for human use and benefits. Constructed wetlands consist of former upland environments that have been modified to create poorly drained soils and wetlands flora and fauna for the primary purpose of contaminant or pollutant removal from wastewaters or runoff. Constructed wetlands are essentially wastewater treatment systems and are designed and operated as such even though many systems do support other functional values (Hammer, 1992).

Denitrification: The biochemical reduction of nitrate or nitrite to gaseous nitrogen, either as molecular nitrogen or as an oxide of nitrogen.

Ecosystem: The complex of a community and its environment functioning as an ecological unit in nature; a basic functional unit of nature comprising both organisms and their nonliving environment, intimately linked by a variety of biological, chemical, and physical processes (Merriam-Webster, 1991; Barnhart, 1986).

Filtration: The process of being passed through a filter (as in the physical removal of impurities from water) or the condition of being filtered (Barnhart, 1986).

Habitat: The place where an organism naturally lives or grows.

Riparian area: Vegetated ecosystems along a waterbody through which energy, materials, and water pass. Riparian areas characteristically have a high water table and are subject to periodic flooding and influence from the adjacent waterbody. These systems encompass wetlands, uplands, or some combination of these two land forms; they do not in all cases have all of the characteristics necessary for them to be classified as wetlands (Mitsch and Gosselink, 1986; Lowrance et al., 1988).

Sedimentation: The formation of earth, stones, and other matter deposited by water, wind, or ice (Barnhart, 1986).

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Species diversity: The variations between groups of related organisms that have certain characteristics in common (Barnhart, 1986; Merriam-Webster, 1991).

Upland: Ground elevated above the lowlands along rivers or between hills (Merriam-Webster, 1991).

Vegetated buffer: Strips of vegetation separating a waterbody from a land use that could act as a nonpoint pollution source. Vegetated buffers (or simply buffers) are variable in width and can range in function from vegetated filter strips to wetlands or riparian areas.

Vegetated filter strip: Created areas of vegetation designed to remove sediment and other pollutants from surface water runoff by filtration, deposition, infiltration, adsorption, decomposition, and volatilization. A vegetated filter strip is an area that maintains soil aeration as opposed to a wetland, which at times exhibits anaerobic soil conditions (Dillaha et al., 1989a).

Vegetated treatment system: A system that consists of a vegetated filter strip, a constructed wetland, or a combination of both.

Wetlands: Those areas that are inundated or saturated by surface water or ground water at a frequency and duration to support, and that under normal circumstances do support, a prevalence of vegetation typically adapted for life in saturated soil conditions; wetlands generally include swamps, marshes, bogs, and similar areas. (This definition is consistent with the Federal definition at 40 CFR 230.3, promulgated December 24, 1980. As amendments are made to the wetland definition, they will be considered applicable to this guidance.)

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CHAPTER 8: Monitoring and Tracking Techniques to Accompany Management Measures

I. INTRODUCTION

Section 6217(g) calls for a description of any necessary monitoring techniques to accompany the management measures to assess over time the success of the measures in reducing pollution loads and improving water quality. This chapter provides:

(1) Guidance for measuring changes in pollution loads and in water quality that may result from the implementation of management measures and

(2) Guidance for ensuring that management measures are implemented, inspected, and maintained properly.

Detailed guidance specific to any particular management measure or practice is contained throughout Chapters 2 through 7 as necessary.

Under section 6217, States will apply management measures to a wide range of sources, including agriculture, forestry, urban activities, marinas and recreational boating, and hydromodification. To monitor at minimum cost the success of these management measures over time, States will need to be creative in the ways that they take advantage of existing monitoring efforts and craft new or expanded monitoring programs.

Nonpoint source monitoring is generally performed by Federal, State, and local agencies. Universities, nonprofit groups, and industry also perform nonpoint source monitoring in a range of circumstances. The landowner, however, rarely performs nonpoint source water quality monitoring.

Section II of this chapter is directed primarily at State agencies, which will be performing or directing the greater share of water quality monitoring under section 6217. This guidance assumes that the reader has a good understanding of basic sample collection and sample analysis methods. Section II is heavily weighted toward discussions of temporal and spatial variability, statistical considerations and techniques, and experimental designs for the purpose of providing the reader with basic information that has been found to be essential in designing and conducting a successful nonpoint source monitoring program. The level of detail in this chapter varies by design to give the reader more or less information on a given subject based on EPA's experience with nonpoint source monitoring efforts over the past 10-15 years. References are provided for those who wish to obtain additional information regarding specific topics.

Section III of this chapter is directed primarily at State and local agencies that are responsible for tracking the implementation, operation, and maintenance of management measures. This section is not intended to provide recommendations regarding the operation and maintenance requirements for any given management measure, but is instead intended to provide "inspectors" with ideas regarding the types of evidence to seek when determining whether implementation or operation and maintenance are being performed adequately.

By tracking management measures and water quality simultaneously, States will be in a position to evaluate the performance of those management measures implemented under section 6217. Management measure tracking will provide the necessary information to determine whether pollution controls have been implemented, operated, and maintained adequately. Without this information, States will not be able to fully interpret their water quality monitoring data. For example, States cannot determine whether the management measures have been effective unless they know the extent to which these controls were implemented, maintained, and operated. Appropriately collected water quality information can be evaluated with trend analysis to determine whether pollutant loads have been

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reduced or whether water quality has improved. Valid statistical associations drawn between implementation and water quality data can be used by States to indicate:

(1) Whether management measures have been successful in improving water quality in the coastal zone and

(2) The need for additional management measures to meet water quality objectives in the coastal zone.

II. TECHNIQUES FOR ASSESSING WATER QUALITY AND FOR ESTIMATING POLLUTION LOADS

Water quality monitoring is the most direct and defensible tool available to evaluate water quality and its response to management and other factors (Coffey and Smolen, 1990). This section describes monitoring methods that can be used to measure changes in pollutant loads and water quality. Due to the wide range of monitoring needs and environmental conditions throughout the coastal zone it is not possible to specify detailed monitoring plans that apply to all areas within the zone. The information in this section is intended merely to guide the development of monitoring efforts at the State and local levels.

This section begins with a brief discussion of the scope and nature of nonpoint source problems, followed by a discussion of monitoring objectives as they relate to section 6217. A lengthy discussion of monitoring approaches is next, with a focus on understanding the watershed to be studied, appropriate experimental designs, sample size and frequency, site locations, parameter selection, sampling methods, and quality assurance and quality control. The intent of this discussion is to provide the reader with basic information essential to the development of effective, tailored monitoring programs that will provide the necessary data for use in statistical tests that are appropriate for evaluating the success of management measures in reducing pollutant loads and improving water quality.

After a brief discussion of data needs, an overview of statistical considerations is presented. Variability and uncertainty are described first, followed by a lengthy overview of sampling and sampling designs. This discussion is at a greater level of detail than others in the section to emphasize the importance of adequate sampling within the framework of a sound experimental design. Hypothesis testing is described next, including some examples of hypotheses that may be appropriate for section 6217 monitoring efforts. An overview of data analysis techniques is given at the end of the section.

A. Nature and Scope of Nonpoint Source Problems

Nonpoint sources may generate both conventional and toxic pollutants, just as point sources do. Although nonpoint sources may contribute many of the same kinds of pollutants, these pollutants are generated in different volumes, combinations, and concentrations. Pollutants from nonpoint sources are mobilized primarily during storm events or snowmelt, but baseflow contributions can be the major source of nonpoint source contaminants in some systems. Thus, knowledge of the hydrology of a system is critical to the design of successful monitoring programs.

Nonpoint source problems are not just reflected in the chemistry of a water resource. Instead, nonpoint source problems are often more acutely manifested in the biology and habitat of the aquatic system. Such impacts include the destruction of spawning areas, impairments to the habitat for shellfish, changes to aquatic community structure, and fish mortality. Thus, any given nonpoint source monitoring program may have to include a combination of chemical, physical, and biological components to be effective.

B. Monitoring Objectives

Monitoring is usually performed in support of larger efforts such as nonpoint source pollution control programs within coastal watersheds. As such, monitoring objectives are generally established in a way that contributes toward achieving the broader program objectives. For example, program objectives may include restoring an impaired use or protecting or improving the ecological condition of a water resource. Supporting monitoring objectives, then, might include assessing trends in use support or in key biological parameters.

The following discussion identifies the overall monitoring objectives of section 6217 and gives some examples of specific objectives that may be developed at the State or local level in support of those overall objectives. Clearly, due to the prohibitive expense of monitoring the effectiveness of every management measure applied in the coastal zone, States will need to develop a strategy for using limited monitoring information to address the broad questions regarding the effectiveness of section 6217 implementation. A combination of watershed monitoring to track the cumulative benefits of systems of management measures and demonstrations of selected management measures of key importance in the State may be one way in which the overall section 6217 monitoring objectives can be met within the constraints imposed by limited State monitoring budgets.

1. Section 6217 Objectives

The overall management objective of section 6217 is to develop and implement management measures for nonpoint source pollution to restore and protect coastal waters. The principal monitoring objective under section 6217(g) is to assess over time the success of the management measures in reducing pollution loads and improving water quality. A careful reading of this monitoring objective reveals that there are two subobjectives: (1) to assess changes in pollution loads over time and (2) to assess changes in water quality over time.

A pollutant load is determined by multiplying the total runoff volume times the average concentration of the pollutant in the runoff. Loads are typically estimated only for chemical and some physical (e.g., total suspended solids) parameters. Water quality, however, is determined on the basis of the chemical, physical, and biological conditions of the water resource. Section 6217(g), therefore, calls for a description of pollutant load estimation techniques for chemical and physical parameters, plus a description of techniques to assess water quality on the basis of chemical, physical, and biological conditions. This section focuses on those needs.

2. Formulating Monitoring Objectives

A monitoring objective should be narrowly and clearly defined to address a specific problem at an appropriate level of detail (Coffey and Smolen, 1990). Ideally, the monitoring objective specifies the primary parameter(s), location of monitoring (and perhaps the timing), the degree of causality or other relationship, and the anticipated result of the management action. The magnitude of the change may also be expressed in the objective. Example monitoring objectives include:

- To determine the change in trends in the total nitrogen concentration in Beautiful Sound due to the implementation of nutrient management on cropland in all tributary watersheds.
- To determine the sediment removal efficiency of an urban detention basin in New City.
- To evaluate the effects of improved marina management on metals loadings from the repair and maintenance areas of Stellar Marina.
- To assess the change in weekly mean total suspended solids concentrations due to forestry harvest activities in Clean River.

C. Monitoring Approaches

1. General

a. Types of Monitoring

The monitoring program design is the framework for sampling, data analysis, and the interpretation of results (Coffey and Smolen, 1990). MacDonald (1991) identifies seven types of monitoring:

(1) Trend monitoring;
(2) Baseline monitoring;
(3) Implementation monitoring;
(4) Effectiveness monitoring;
(5) Project monitoring;

(6) Validation monitoring; and
(7) Compliance monitoring.

Trend, baseline, implementation, effectiveness, and project monitoring all relate to the monitoring objectives of section 6217. These types of monitoring, in fact, are not mutually exclusive. The distinction between effectiveness monitoring and project monitoring, for example, is often simply one of scale, with effectiveness monitoring primarily directed at individual practices and project monitoring directed at entire sets of practices or activities implemented over a larger area. Since one cannot evaluate the effectiveness of a project or management measure (i.e., achievement of the desired effect) without knowing the status of implementation, implementation monitoring is an essential element of both project and effectiveness monitoring. In addition, a test for trend is typically included in the evaluation of projects and management measures, and baseline monitoring is performed prior to the implementation of pollution controls.

Meals (1991a) discussed five major points to consider in developing a monitoring system that would provide a suitable data base for watershed trend detection: (1) understand the system you want to monitor, (2) design the monitoring system to meet objectives, (3) pay attention to details at the beginning, (4) monitor source activities, and (5) build in feedback loops. These five points apply equally to both load estimation and water quality assessment monitoring efforts.

b. Section 6217 Monitoring Needs

The basic monitoring objective for section 6217 is to *assess over time the success of the measures in reducing pollution loads and improving water quality*. This objective would seem to indicate a need for establishing cause-effect relationships between management measure implementation and water quality. Although desirable, monitoring to establish such cause-effect relationships is typically beyond the scope of affordable program monitoring activities.

Mosteller and Tukey (1977) identified four criteria that must be met to show cause and effect: association, consistency, responsiveness, and a mechanism.

- **Association** is shown by demonstrating a relationship between two parameters (e.g., a correlation between the extent of management measure implementation and the level of pollutant loading).
- **Consistency** can be confirmed by observation only and implies that the association holds in different populations (e.g., management measures were implemented in several areas and pollutant loading was reduced, depending on the effect of treatment, in each case).
- **Responsiveness** can be confirmed by an experiment and is shown when the dependent variable (e.g., pollutant loading) changes predictably in response to changes in the independent variable (e.g., extent of management measure implementation).
- A **mechanism** is a plausible step-by-step explanation of the statistical relationship. For example, conservation tillage reduced the edge-of-field losses of sediment, thereby removing a known fraction of pollutant source from the stream or lake. The result was decreased suspended sediment concentration in the water column.

Clearly, the cost of monitoring needed to establish cause-effect relationships throughout the coastal zone far exceeds available resources. It may be suitable, however, to document associations between management measure implementation and trends in pollutant loads or water quality and then account for such associations with a general description of the primary mechanisms that are believed to come into play.

c. Scale, Local Conditions, and Variability

There are several approaches that can be taken to assess the effectiveness of measures in reducing loads and improving water quality. There are also several levels of scale that could be selected: individual practices, individual

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measures, field scale, watershed scale, basin scale, regional scale, etc. With any given monitoring objective, the specific monitoring approach to use at any specific site is a function of the local conditions (e.g., geography, climate, water resource type) and the type of management measures implemented.

The detection and estimation of trends is complicated by problems associated with the characteristics of pollution data (Gilbert, 1987). Physical, chemical, and biological parameters in the receiving water may undergo extreme changes without the influence of human activity. Understanding and monitoring the factors responsible for variability in a local system are essential for detecting the improvements expected from the implementation of management measures.

Simple point estimates taken before and after treatment will not confirm an effect if the natural variability is typically greater than the changes due to treatment (Coffey and Smolen, 1990). Therefore, knowledge of the variability and the distribution of the parameter is important for statistical testing. Greater variability requires a larger change to imply that the observed change is not due solely to random events (Spooner et al., 1987b). Examination of a historical data set can help to identify the magnitude of natural variability and possible sources.

The impact of management actions may not be detectable as a change in a mean value but rather as a change in variability (Coffey and Smolen, 1990). Platts and Nelson (1988) found that a carefully designed study was required to isolate the large natural fluctuations in trout populations to distinguish the effects of land use management. They assumed that normal fluctuation patterns were similar between the control and the treatment area and that treatment-induced effect could be distinguished as a deviation from the historical pattern.

Meals (1991a) calls for the collection and evaluation of existing data as the first step in a monitoring effort, recognizing that additional background data may be needed to identify hot spots or fill information gaps. The results of such initial efforts should include established stage-discharge ratings and an understanding of patterns not associated with the pollution control effort.

2. Understanding the System to Be Monitored

a. The Water Resource

Options for tracking water quality vary with the type of water resource. For example, a monitoring program for ephemeral streams can be different from that for perennial streams or large rivers. Lakes, wetlands, riparian zones, estuaries, and near-shore coastal waters all present different monitoring considerations. Whereas upstream-downstream designs work on rivers and streams, they are generally less effective on natural lakes where linear flow is not so prevalent. Likewise, estuaries present difficulties in monitoring loads because of the shifting flows and changing salinity caused by the tides. A successful monitoring program recognizes the unique features of the water resources involved and is structured to either adapt to those features or avoid them.

Streams. Freshwater streams can be classified on the basis of flow attributes as intermittent or perennial streams. Intermittent streams do not flow at all times and serve as conveyance systems for runoff. Perennial streams always flow and usually have significant inputs from ground water or interflow.

For intermittent streams, seasonal variability is a very significant factor in determining pollutant loads and water quality. During some periods sampling may be impossible due to no flow. Seasonal flow variability in perennial streams can be caused by seasonal patterns in precipitation or snowmelt, reservoir discharges, or irrigation practices.

For many streams the greatest concentrations of suspended sediment and other pollutants occur during spring runoff or snowmelt periods. Concentrations of both particulate and soluble chemical parameters have been shown to vary throughout the course of a rainfall event in many studies across the Nation. This short-term variability should be considered in developing monitoring programs for flowing (lotic) waterbodies.

Spatial variability is largely lateral for both intermittent and perennial streams. Vertical variability does exist, however, and can be very important in both stream types (e.g., during runoff events, in tidal waters, and in deep,

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slow-moving streams). Intake depth is often a key factor in stream sampling. For example, slow-moving, larger streams may show considerable water quality variability with depth, particularly for parameters such as suspended solids, dissolved oxygen, and algal productivity. Suspended sediment samples must be taken with an understanding of the vertical distribution of both sediment concentration and flow velocity (Brakensiek et al., 1979). When sampling bed sediment or monitoring biological parameters, it is important to recognize the potential for significant lateral and vertical variation in the toxicity and contaminant levels of bed sediments (USEPA, 1987).

Lakes. Lakes can be categorized in several ways, but a useful grouping for monitoring guidance is related to the extent of vertical and lateral mixing of the waterbody. Therefore, lakes are considered to be either mixed or stratified for the purpose of this guidance. Mixed lakes are those lakes in which water quality (as determined by measurement of the parameters and attributes of interest) is homogenous throughout, and stratified lakes are considered to be those lakes which have lateral or vertical water quality differentials in the lake parameters and attributes of interest. Totally mixed lakes, if they exist, are certainly few in number, but it may be useful to perform monitoring in selected homogenous portions of stratified lakes to simplify data interpretation. Similarly, for lakes that exhibit significant seasonal mixing, it may be beneficial to monitor during a time period in which they are mixed. For some monitoring objectives, however, it may be best to monitor during periods of peak stratification.

Temporal variability concerns are similar for mixed and stratified lakes. Seasonal changes are often obvious, but should not be assumed to be similar for all lakes or even the same for different parts of any individual lake. Due to the importance of factors such as precipitation characteristics, climate, lake basin morphology, and hydraulic retention characteristics, seasonal variability should be at least qualitatively assessed before any lake monitoring program is initiated.

Short-term variability is also an inherent characteristic of most still (lentic) waterbodies. Parameters such as pH, dissolved oxygen, and temperature can vary considerably over the course of a day. Monitoring programs targeted toward biological parameters should be structured to account for this short-term variability. It is often the case that small lakes and reservoirs respond rapidly to runoff events. This factor can be very important in cases where lake water quality will be correlated to land treatment activities or stream water quality.

In stratified lakes spatial variability can be lateral or vertical. The classic stratified lake is one in which there is an epilimnion and a hypolimnion (Wetzel, 1975). Water quality can vary considerably between the two strata, so sampling depth is an important consideration when monitoring vertically stratified lakes.

Lateral variability is probably as common as vertical variability, particularly in lakes and ponds receiving inflow of varying quality. Figure 8-1 illustrates the types of factors that contribute to lateral variability in lake water quality. In reservoir systems, storm plumes can cause significant lateral variability.

Davenport and Kelly (1984) explained the lateral variability in chlorophyll *a* concentrations in an Illinois lake based on water depth and the time period that phytoplankters spend in the photic zone. A horizontal gradient of sediment, nutrient, and chlorophyll *a* concentrations in St. Albans Bay, Vermont, was related to mixing between Lake Champlain and the Bay (Clausen, 1985). It is important to note that there frequently exists significant lateral and vertical variation in the toxicity and contaminant levels of bed sediments (USEPA, 1987).

Despite the distinction made between mixed and stratified lakes, there is considerable gray area between these groups. For example, thermally stratified lakes may be assumed to be mixed during periods of overturn, and laterally stratified lakes can sometimes be treated as if the different lateral segments are sublakes. In any case, it is important that the monitoring team knows what parcel of water is being sampled when the program is implemented. It would be inappropriate, for example, to assign the attributes of a surface sample to the hypolimnion of a stratified lake due to the differences in temperature and other parameters between the upper and lower waters.

Estuaries. Estuaries can be very complex systems, particularly large ones such as the Chesapeake Bay. Estuaries exhibit temporal and spatial variability just as streams and lakes do. Physically, the major differences between estuaries and fresh waterbodies are related to the mixing of fresh water with salt water and the influence of tides. These factors increase the complexity of spatial and temporal variability within an estuary.

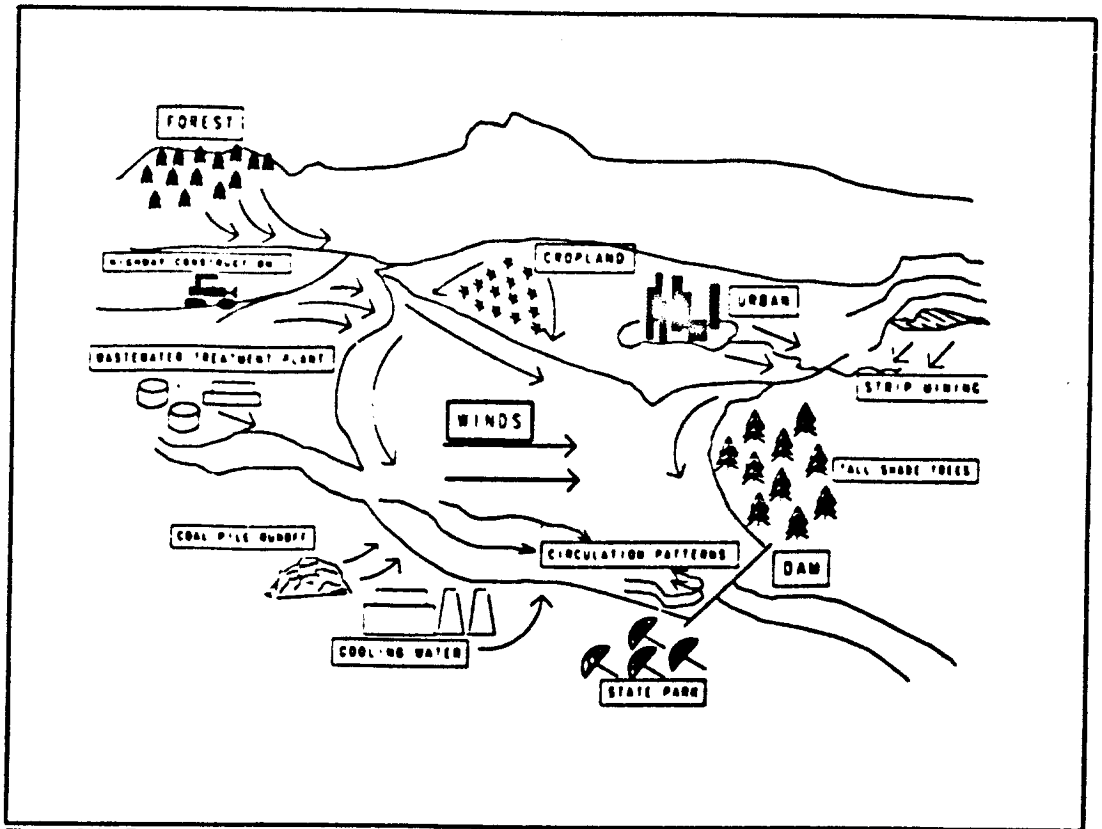

Figure 8-1. Factors contributing to lateral differences in lake quality.

Short-term variability in estuaries is related directly to the tidal cycles, which can have an effect on both the mixing of the fresh and saline waters and the position of the freshwater-saltwater interface (USEPA, 1982a). The same considerations made for lakes regarding short-term variability of parameters such as temperature, dissolved oxygen, and pH should also be made for estuaries.

Temperature profiles such as those found in stratified lakes can also change with season in estuaries. The resulting circulation dynamics must be considered when developing monitoring programs. The effects of season on the quantity of freshwater runoff to an estuary can be profound. In the Chesapeake Bay, for example, salinity is generally lower in the spring and higher in the fall due to the changes in freshwater runoff from such sources as snowmelt runoff and rainfall (USEPA, 1982a).

Spatial variability in estuaries has both significant vertical and lateral components. The vertical variability is related to both temperature and chemical differentials. In the Chesapeake Bay thermal stratification occurs during the summer, and chemical stratification occurs at all times, but in different areas at different times (USEPA, 1982a). Chemical stratification can be the result of the saltwater wedge flowing into and under the freshwater outflow or the accumulation or channeling of freshwater and saltwater flows to opposite shores of the estuary. The latter situation can be caused by a combination of tributary location, the earth's rotation, and the barometric pressure. In addition, lateral variability in salinity can be caused by different levels of mixing between saltwater and freshwater inputs. As noted for streams and lakes, the lateral and vertical variation in the toxicity and contaminant levels of bed sediments should be considered (EPA, 1987).

Coastal Waters. Researchers and government agencies are collectively devoid of significant experience in evaluating the effectiveness of nonpoint source pollution control efforts through the monitoring of near-shore and off-shore coastal waters. Our understanding of the factors to consider when performing such monitoring is therefore very limited.

As for other waterbody types, it is important to understand the hydrology, chemistry, and biology of the system in order to develop an effective monitoring program. Of particular importance is the ability to identify discrete populations to sample from. For trend analysis it is essential that the researcher is able to track over time the conditions of a clearly identifiable segment or unit of coastal water. This may be accomplished by monitoring a semienclosed near-shore embayment or similar system. Knowledge of salinity and circulation patterns should be useful in identifying such areas.

Secondly, monitoring should be focused on those segments or units of coastal water for which there is a reasonable likelihood that changes in water quality will result from the implementation of management measures. Segment size, circulation patterns, and freshwater inflows should be considered when estimating the chances for such water quality improvements.

Near-shore coastal waters may exhibit salinity gradients similar to those of estuaries due to the mixing of fresh water with salt water. Currents and circulation patterns can create temperature gradients as well. Farther from shore, salinity gradients are less likely, but gradients in temperature may occur. In addition, vertical gradients in temperature and light may be significant. These and other biological, chemical, and physical factors should be considered in the development of monitoring programs for coastal waters.

b. The Management Measures to Be Implemented

An integral part of the system to be monitored is the set of management measures to be implemented. Management measures can generally be classified with respect to their modes of control: (1) source reduction, (2) delivery reduction, or (3) the reduction of direct impacts. For example, source-reduction measures may include nutrient management, pesticide management, and marine pump-out facilities. These measures all rely on the prevention of nonpoint source pollution; trapping and treatment mechanisms are not relied upon for control. Delivery-reduction measures include those that rely on detention basins, filter strips, constructed wetlands, and similar practices for trapping or treatment prior to release or discharge to receiving waters. Measures that reduce direct impacts include wetland and riparian area protection, habitat protection, the preservation of natural stream channel characteristics, the provision of fish passage, and the provision of suitable dissolved oxygen levels below dams.

Delivery Reduction. Delivery-reduction measures lend themselves to inflow-outflow, or process, monitoring to estimate the effectiveness in reducing loads. The simple experimental approach is to take samples of inflow and outflow at appropriate time intervals to measure differences in the water quality between the two points. An example is the analysis of totals suspended solids (TSS) concentrations at the inflow and outflow of a sediment retention basin to determine the percentage of TSS removed.

Source Reduction. Source-reduction measures generally cannot be monitored using a process design because there are usually no discrete inflow and outflow points. The effectiveness of these measures will generally be determined by applying approaches such as paired-watershed studies and upstream-downstream studies.

Reduction of Direct Impacts. The effectiveness of measures intended to prevent direct impacts cannot be determined through the monitoring of loads since pollutant loads are not generated. Instead, monitoring might include reference site approaches where the conditions (e.g., habitat or macroinvertebrates) at the affected (or potentially affected) area are compared over time (as management measures are implemented) versus conditions at a representative unimpacted site or sites nearby (Ohio EPA, 1988). This approach can be taken to the point of being a paired-watershed study if the monitoring timing and protocols are the same at the impacted and reference sites.

Combinations of Management Measures. Management measures are systems of practices, technologies, processes, siting criteria, operating methods, or other alternatives. Pollution control programs generally consist of systems of management measures applied over well-defined geographic areas. Combinations of the three types of measures described above are likely to be found in any given area to be monitored. Monitoring programs, therefore, must often be directed at measuring the cumulative effectiveness of a range of different measures applied in different areas at different times within a specified geographic area. Under these conditions, the monitoring approaches for source-reduction and direct-impact-reduction measures are typically used, while process monitoring is not generally used other than to track the effectiveness of specific delivery-reduction measures implemented in the area.

c. Point Sources and Other Significant Activities

There is often a need to isolate the effects of other activities that occur independently of the planned implementation of management measures but that have an effect on the measured parameters. For example, an upgrade from secondary to tertiary treatment at a wastewater treatment plant in a watershed could have a major effect on the measured nitrogen levels. An effective monitoring program would isolate the effects of changes in the point source contributions by measuring the discharge from these sources over time.

3. Experimental Design

a. Types of Experimental Designs

EPA has prescribed monitoring designs for use in watershed projects funded under section 319 of the Clean Water Act (USEPA, 1991b). The objective in promoting these designs is to document changes in water quality that can be related to the implementation of nonpoint source control measures in selected watersheds. The designs recommended by EPA are paired-watershed designs and upstream-downstream designs. Single downstream station designs are not recommended by EPA for section 319 watershed projects (USEPA, 1991b).

Monitoring before implementation is usually required to detect a trend or show causality (Coffey and Smolen, 1990). Two years of pre-implementation monitoring are typically needed to establish an adequate baseline. Less time may be needed for studies at the management measure or edge-of-field scale, when hydrologic variability is known to be less than that of typical agricultural systems, or when a paired-watershed design is used.

Paired-Watershed Design. In the paired-watershed design there is one watershed where the level of implementation (ideally) does not change (the control watershed) and a second watershed where implementation occurs (the study watershed). This design has been shown in agricultural nonpoint source studies to be the most powerful study design for demonstrating the effectiveness of nonpoint source control practice implementation (Spooner et al., 1985). Paired-watershed designs have a long history of application in forest hydrology studies. The paired-watershed design must be implemented properly, however, to generate useful data sets. Some of the considerations to be made in designing and implementing paired-watershed studies are described below.

In selecting watershed pairs, the watersheds should be as similar as possible in size, shape, aspect, slope, elevation, soil type, climate, and vegetative cover (Striffler, 1965). The general procedure for paired-watershed studies is to monitor the watersheds long enough to establish a statistical relationship between them. A correlation should be found between the values of the monitored parameters for the two watersheds. For example, the total nitrogen values in the control watershed should be correlated with the total nitrogen values in the study watershed. A pair of watersheds may be considered sufficiently calibrated when a parameter for the control watershed can be used to predict the corresponding value for the study watershed (or vice versa) within an acceptable margin of error.

It is important to note that the calibration period should cover all or the significant portion of the range of conditions for each of the major water quality determinants in the two watersheds. For example, the full range of hydrologic conditions should be covered (or nearly covered) during the calibration period. This may be problematic in areas where rainfall and snowmelt are highly variable from year to year or in areas subject to extended wet periods or drought. Calibration during a dry year is likely to not be adequate for establishing the relationship between the two watersheds, particularly if subsequent years include both wet and dry periods.

Similarly, some agricultural areas of the country use long-term, multiple-crop rotations. The calibration period should cover not only the range of hydrologic conditions but also the range of cropping patterns that can reasonably be expected to have an influence on the measured water quality parameters. This is not to say that the calibration period should take 5 to 10 years, but rather that States should use careful judgment in determining when the calibration period can be safely ended.

After calibration, the study watershed receives implementation of management measures, and monitoring is continued in both watersheds. The effects of the management measures are evaluated by testing for a change in the relationship between the monitored parameters (i.e., a change in the correlation). If treatment is working, then there should be a greater difference over time between the treated study watershed and the untreated (poorly managed) control watershed. Alternatively, the calibration period could be used to establish statistical relationships between a fully treated watershed (control watershed) and an untreated watershed (study watershed). After calibration under this approach, the study watershed would be treated and monitoring continued. The effects of the management measures would be evaluated, however, by testing for a change in the correlation that would indicate that the two watersheds are more similar than before treatment.

It is important to use small watersheds when performing paired-watershed studies since they are more easily managed and more likely to be uniform (Striffler, 1965). EPA recommends that paired watersheds be no larger than 5,000 acres (USEPA, 1991b).

Upstream-Downstream Studies. In the upstream-downstream design, there is one station at a point directly upstream from the area where implementation of management measures will occur and a second station directly downstream from that area. Upstream-downstream designs are generally more useful for documenting the magnitude of a nonpoint source than for documenting the effectiveness of nonpoint source control measures (Spooner et al., 1985), but they have been used successfully for the latter. This design provides for the opportunity to account for covariates (e.g., an upstream pollutant concentration that is correlated with a downstream concentration of same pollutant) in statistical analyses and is therefore the design that EPA recommends in cases where paired watersheds cannot be established (USEPA, 1991b).

Upstream-downstream designs are needed in cases where project areas are not located in headwaters or where upstream activities that are expected to confound the analysis of downstream data occur. For example, the effects of upstream point source discharges, uncontrolled nonpoint source discharges, and upstream flow regulation can be isolated with upstream-downstream designs.

Inflow-Outflow Design. Inflow-outflow, or process, designs are very similar to upstream-downstream designs. The major differences are scale and the significance of confounding activities. Process designs are generally applied in studies of individual management measures or practices. For example, sediment loading at the inflow and outflow of a detention basin may be measured to determine the pollutant removal efficiency of the basin. In general, no inputs other than the inflow are present, and the only factor affecting outflow is the management measure. As noted above (see The Management Measures to Be Implemented), process monitoring cannot generally be applied to studies of source-reduction management measures or measures that prevent direct impacts, but it can be applied successfully in the evaluation of delivery-reduction management measures.

b. Scale

Management Measure. Monitoring the inflow and outflow of a specific management measure should be the most sensitive scale since the effects of uncontrollable discharges and uncertainties in treatment mechanisms are minimized.

Edge of Field. Monitoring pollutant load from a single-field watershed should be the next most sensitive scale since the direct effects of implementation can be detected without pollutant trapping in a field border or stream channel (Coffey and Smolen, 1990).

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Subwatershed. Monitoring a subwatershed can be useful to monitor the aggregate effect of implementation on a group of fields or smaller areas by taking samples close to the treatment (Coffey and Smolen, 1990). Subwatershed monitoring networks measure the aggregate effects of treatment and nontreatment runoff as it enters an upgradient tributary or the receiving waterbody. Subwatershed monitoring can also be used for targeting critical areas.

Watershed. Monitoring at the watershed scale is appropriate for assessing total project area pollutant load using a single station (Coffey and Smolen, 1990). Depending on station arrangement, both subwatershed and watershed outlet studies are very useful for water and pollutant budget determinations. Monitoring at the watershed outlet is the least sensitive of the spatial scales for detecting treatment effect. Sensitivity of the monitoring program decreases with increased basin size and decreased treatment extent or both (Coffey and Smolen, 1990.

c. Reference Systems and Standards

EPA's rapid bioassessment protocols advocate an integrated assessment, comparing habitat and biological measures with empirically defined reference conditions (Plafkin et al., 1989). Reference conditions are established through systematic monitoring of actual sites that represent the natural range of variation in "least disturbed" water chemistry, habitat, and biological condition. Reference sites can be used in monitoring programs to establish reasonable expectations for biological, chemistry, and habitat conditions. An example application of this concept is the paired-watershed design (Coffey and Smolen, 1990).

EPA's ecoregional framework can be used to establish a logical basis for characterizing ranges of ecosystem conditions or quality that are realistically attainable (Omernik and Gallant, 1986). *Ecoregions* are defined by EPA to be regions of relative homogeneity in ecological systems or in relationships between organisms and their environments. Hughes et al. (1986) have used a relatively small number of minimally impacted regional reference sites to assess feasible but protective biological goals for an entire region.

Water quality standards can be used to identify criteria that serve as reference values for biological, chemical, or habitat parameters, depending on the content of the standard. The frequency distribution of observation values can be tracked against either a water quality standard criterion or a reference value as a method for measuring trends in water quality or loads (USEPA, 1991b).

4. Site Locations

Within any given budget, site location is a function of water resource type (see The Water Resource), monitoring objectives (see Monitoring Objectives), experimental design (see Types of Experimental Designs), the parameters to be monitored (see Parameter Selection), sampling techniques (see Sampling Techniques and Samples and Sampling), and data analysis plans (see Data Analysis). Additional considerations in site selection are accessibility and landowner cooperation.

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It is recommended that monitoring stations be placed near established gaging stations whenever possible due to the extreme importance of obtaining accurate discharge measurements. Where gaging stations are not available but stream discharge measurements are needed, care should be taken to select a suitable site. Brakensiek et al. (1979) provide excellent guidance regarding runoff measurement, including the following selected recommendations regarding site selection:

- Field-calibrated gaging stations should be located in straight, uniform reaches of channel having smooth beds and banks of a permanent nature whenever possible.
- Gaging stations should be located away from sewage outfall, power stations, or other installations causing flow disturbances.
- Consider the geology and contributions of ground-water flow.

- Where ice is a potential problem, locate measuring devices in a protected area that receives sunlight most of the time.

- Daily current-meter measurements may be necessary where sand shifts occur.

5. Sampling Frequency and Interval

a. Sample Size and Frequency

It is important to estimate early in a monitoring effort the number and frequency of samples required to meet the monitoring objectives. Spooner et al. (1991) report that the sampling frequency required at a given monitoring station is a function of the following:

- Monitoring goals;
- Response of the water resource to changes in pollutant sources;
- Magnitude of the minimum amount of change for which detection with trend analyses is desired (i.e., minimum detectable change);
- System variability and accuracy of the sample estimate of reported statistical parameter (e.g., confidence interval width on a mean or trend estimate);
- Satistical power (i.e., probability of detecting a true trend);
- Autocorrelation (i.e., the extent to which data points taken over time are correlated);
- Monitoring record length;
- Number of monitoring stations; and
- Statistical methods used to analyze the data.

The minimum detectable change (MDC) is the minimum change in a water quality parameter over time that is considered statistically significant. Knowledge of the MDC can be very useful in the planning of an effective monitoring program (Coffey and Smolen, 1990). The MDC can be estimated from historical records to aid in determining the required sampling frequency and to evaluate monitoring feasibility (Spooner et al., 1987a). MacDonald (1991) discusses the same concept, referring to it as the minimum detectable effect.

The larger the MDC, the greater the change in water quality that is needed to ensure that the change was not just a random fluctuation. The MDC may be reduced by accounting for covariates, increasing the number of samples per year, and increasing the number of years of monitoring.

Sherwani and Moreau (1975) stated that the desired frequency of sampling is a function of several considerations associated with the system to be studied, including:

- Response time of the system;
- Expected variability of the parameter;
- Half-life and response time of constituents;
- Seasonal fluctuation and random effects;

- Representativeness under different conditions of flow;
- Short-term pollution events;
- Magnitude of response; and
- Variability of the inputs.

Coastal waters, estuaries, ground water, and lakes will typically have longer response times than streams and rivers. Thus, sampling frequency will usually be greater for streams and rivers than for other water resource types. Some parameters such as total suspended solids and fecal coliform bacteria can be highly variable in stream systems dominated by nonpoint sources, while nitrate levels may be less volatile in systems driven by baseflow from ground water. The highly variable parameters would generally require more frequent sampling, but parameter variability should be evaluated on a site-specific basis rather than by rule of thumb.

In cases where pollution events are relatively brief, sampling periods may also be short. For example, to determine pollutant loads it may be necessary to sample frequently during a few major storm events and infrequently during baseflow conditions. Some parameters vary considerably with season, particularly in watersheds impacted primarily by nonpoint sources. Boating is typically a seasonal activity in northern climates, so intensive seasonal monitoring may be needed to evaluate the effectiveness of management measures for marinas.

The water quality response to implementation of management measures will vary considerably across the coastal zone. Pollutant loads from confined livestock operations may decline significantly in response to major improvements in runoff and nutrient management, while sediment delivery from logging areas may decline only a little if the level of pollution control prior to section 6217 implementation was already fairly good. Fewer samples will usually be needed to document water quality improvement in watersheds that are more responsive to pollution control efforts.

Sherwani and Moreau (1975) state that for a given confidence level and margin of error, the necessary sample size, and hence sampling frequency, is proportional to the variance. Since the variance of water quality parameters may differ considerably over time, the frequency requirements of a monitoring program may vary depending on the time of the year. Sampling frequency will need to be greater during periods of greater variance.

There are statistical methods for estimating the number of samples required to achieve a desired level of precision in random sampling (Cochran, 1963), stratified random sampling (Reckhow, 1979), cluster sampling (Cochran, 1977), multistage sampling (Gilbert, 1987), double sampling (Gilbert, 1987), and systematic sampling (Gilbert, 1987). For a more detailed discussion of sampling theory and statistics, see Samples and Sampling.

b. Sampling Interval

A method for estimating sampling interval is provided by Sherwani and Moreau (1975). They note that the least favorable sampling interval for parameters that exhibit a periodic structure is equal to the period or an integral multiple of the period. Such sampling would introduce statistical bias. Reckhow (1979) points out that, for both random and stratified random sampling, systematic sampling is acceptable only if "there is no bias introduced by incomplete design, and if there is no periodic variation in the characteristic measured." Gaugush (1986) states that monthly sampling is usually adequate to detect the annual pattern of changes with time.

c. Some Recommendations

It is generally recommended that the sampling of plankton, fish, and benthic organisms in estuaries should be seasonal, with the same season sampled in multiyear studies (USEPA, 1991a). The aerial coverage and bed density for submerged aquatic vegetation (SAV) vary from year to year due to catastrophic storms, exceptionally high precipitation and turbidity, and other poorly understood natural phenomena (USEPA, 1991a). For this reason, short-term SAV monitoring may be more reflective of infrequent impacts and may not be useful for trend assessment.

In addition, incremental losses in wetland acreage are now within the margin of error for current detection limits. It is recommended that SAV and wetland sampling be conducted during the period of peak biomass (USEPA, 1991a).

The frequency of sediment sampling in estuaries should be related to the expected rate of change in sediment contaminant concentrations (USEPA, 1991a). Because tidal and seasonal variability in the distribution and magnitude of several water column physical characteristics in estuaries is typically observed, these influences should be accounted for in the development of sampling strategies (USEPA, 1991a).

For monitoring the state of biological variables, the length of the life cycle may determine the sampling interval (Coffey and Smolen, 1990). EPA (1991b) recommends a minimum of 20 evenly spaced (e.g., weekly) samples per year to document trends in chemical constituents in watershed studies lasting 5 to 10 years. The 20 samples should be taken during the time period (e.g., season) when the benefits of implemented pollution control measures are most likely to be observed. For benthic macroinvertebrates and fish, EPA recommends at least one sample per year.

6. Load Versus Water Quality Status Monitoring

The choice between monitoring either (a) the status or condition of the water resource or (b) the pollutant load to the water resource should be made carefully (Coffey and Smolen, 1990). Loading is the rate of pollutant transport to the managed resource via overland, tributary, or ground-water flow. Load monitoring may be used to assess the change in magnitude of major pollutant sources or to assess the change in pollutant export at a fixed station. Monitoring water quality status includes measuring a physical attribute, chemical concentration, or biological condition, and may be used to assess baseline conditions, trends, or the impact of treatment on the managed resource.

Monitoring water quality status may be the most direct route to an answer on the effect of management measure implementation on designated use, but sensitivity may be low (Coffey and Smolen, 1990). When the likelihood of detecting a trend in water quality status is low, load monitoring near the source may be necessary. For example, measuring the effectiveness of nutrient management in one tributary to a large coastal embayment may require monitoring nitrogen load, since bay monitoring is unlikely to measure the change in the mean nitrogen concentration or trophic state measures for the bay.

When the basis for a choice between load or water quality status is less obvious (i.e., it is not clear whether abatement can be detected in the receiving resource), a pollutant budget may help to make the decision (Coffey and Smolen, 1990). The budget should account for mass balance of pollutant input by source, including ground-water and atmospheric deposition, all output, and changes in storage. The budget may show the magnitude and relative importance of controlled and uncontrolled sources (e.g., atmospheric deposition, resuspension from sediments, streambank erosion). Sources of error in the budget should also be evaluated. Where treatment is not likely to produce measurable change in the waterbody, load monitoring may be required.

a. Pollutant Load Monitoring

Load monitoring requires a complex, and typically expensive, sampling protocol to measure water discharge and pollutant concentration (Coffey and Smolen, 1990). Both discharge and concentration data are needed to calculate pollutant loading.

Given the variability of discharge and pollutant concentrations in watersheds impacted by nonpoint sources, the consequences of not collecting data from all storm events and baseflow over a range of conditions (e.g., season, land cover) can be major. For example, equipment failure during a single storm event can result in considerable error in estimating annual pollutant load. It is typical that data gaps will occur, requiring the application of mathematical techniques to estimate the discharge and pollutant concentrations for missed events.

Brakensiek et al. (1979) provide a detailed description of methods and equipment needed for discharge monitoring. Techniques are described for both field and watershed studies.

b. Water Quality Status Monitoring

Water quality status can be evaluated in a number of ways, including:

- Evaluating designated use attainment;
- Evaluating standards violations;
- Assessing ecological integrity; or
- Monitoring an indicator parameter.

Monitoring for designated use attainment should focus on those parameters or criteria specified in State water quality standards. Where such parameters or criteria are not specified, critical variables related to use support should be monitored. If the monitoring objective includes relating water quality improvement to the pollution control activities, then it is important that monitored parameters can be related to the management measures implemented. For example, it may be appropriate to monitor nitrogen concentrations if septic system improvements are implemented.

For violations of standards, the choice of variable is specified by the State water quality standard (Coffey and Smolen, 1990). To assess ecological integrity, the selection of parameters should be based on criteria used to evaluate such status. For trend detection the indicator parameter must be carefully selected to account for changes in treatment and system variability (Coffey and Smolen, 1990). Additional information regarding appropriate parameters to monitor can be found under Parameter Selection below.

7. Parameter Selection

Monitoring parameters should be related directly to the identified problems caused by the nonpoint sources that will be controlled, and to those principal pollutants that will be controlled through the implementation of management measures. For example, if metal loads are to be determined to be the primary pollutant of concern from marinas, then appropriate monitoring parameters will include flow and the metals of concern. If the effectiveness of improved management of repair and maintenance areas is to be determined, then implementation should be tracked as well. There should also be a mechanism for relating the management measure to the specific pollutants monitored. For example, it should be clear that improved management of repair and maintenance areas of a marina will have an effect on metals loads if such loads are monitored.

a. Relationship to Sources

MacDonald (1991) evaluates the sensitivity of various monitoring parameters to a range of management activities in forested areas in the Pacific Northwest and Alaska. Table 8-1 provides examples of parameters that could be monitored to determine the effectiveness of management measures. Some of the listed parameters (e.g., benthic macroinvertebrates) can be sampled only in waterbodies, while others (e.g., total suspended solids) can be sampled at the source or in waterbodies. This table is provided for illustrative purposes only.

b. Implementation Tracking

Land treatment and land use monitoring should relate directly to the pollutants or impacts monitored at the water quality station (Coffey and Smolen, 1990). Land use monitoring should also reflect historical impacts as well as activities during the project. Since the impact of management measures on water quality may not be immediate or implementation may not be sustained, information on relevant watershed activities will be essential for the final analysis.

EPA recommends that the reporting units used to track implementation should be reliable indicators of the extent to which the pollutant source will be controlled (USEPA, 1991b). For example, the tons of animal waste managed may be a much more useful parameter to track than the number of confined animal facilities constructed.

Table 8-1. Examples of Monitoring Parameters to Assess Impacts from Selected Sources

Source	Chemical and Physical	Biological	Habitat
Cropland	Sediment, nutrients, pesticides, temperature	Benthic macroinvertebrates	Sediment deposition, cover
Grazing Land	Nutrients, sediment, temperature	Macroinvertebrates, fish, fecal coliform	Streambank stability, spawning bed condition, cover
Urban Construction Sites	Total suspended solids, temperature	Benthic macroinvertebrates	Streambank stability, channel characteristics, cover
Highways	Metals, toxics, flow, temperature	Benthic macroinvertebrates	Channel characteristics, cover
Forestry Harvest	Sediment, temperature	Benthic macroinvertebrates	Large woody debris, cover
Forestry Road Building and Maintenance	Sediment, intergravel dissolved oxygen, temperature	Fish, benthic macroinvertebrates	Channel characteristics, embeddedness, streambank stability, cover
Marinas	Metals, dissolved oxygen, temperature	Fecal coliform	Marsh vegetation, substrate composition, cover
Channelization	Flows, temperature, sediment	Fish, benthic macroinvertebrates	Aquatic vegetation, channel sediment type, cover

c. Explanatory Variables

An effective nonpoint source monitoring program accounts for as many sources of variability as possible to increase the likelihood that the effects of the management measures can be separated from the other sources of variability. Some of this other variability can be accounted for by tracking the parameters (e.g., precipitation, flow, pH, salinity) most likely to affect the values of the principal monitored parameters (Coffey and Smolen, 1990). These explanatory variables are treated as covariates in statistical analyses that isolate the effect of the management measures from the variability, or noise, in the data caused by natural factors. In paired-watershed and upstream-downstream studies, EPA recommends that the complete set of parameters (including explanatory variables) are monitored at each monitoring site, following the same monitoring schedule and protocol (USEPA, 1991b).

8. Sampling Techniques

a. Automated Sampling to Estimate Pollutant Loads

Typical methods for estimating pollutant loads include continuous flow measurements and some form of automated sampling that is either timed or triggered by some feature of the runoff hydrograph. For example, in the Santa Clara watershed of San Francisco Bay, flow was continuously monitored at hourly intervals, wet-weather monitoring included collection of flow-composite samples taken with automatic samplers, and dry-weather monitoring was conducted by obtaining quarterly grab samples (Mumley, 1991). Data were used to estimate annual, wet-weather, and dry-weather copper loads.

In St. Albans Bay, Vermont, continuous flow and composite samples were used to estimate nutrient loads for trend analysis (Vermont RCWP, 1984). In the Nationwide Urban Runoff Program (NURP) project in Bellevue, Washington, catchment area monitoring included continuous gaging and automatic sampling that occurred at a preset time interval (5 to 50 minutes) once the stage exceeded a preset threshold (USEPA, 1982b).

b. Grab Sampling for Pollutant Loads

Grab sampling with continuous discharge gaging can be used to estimate load in some cases. Grab sampling is usually much less expensive than automated sampling methods and is typically much simpler to manage. These significant factors of cost and ease make grab sampling an attractive alternative to automated sampling and therefore worthy of consideration even for monitoring programs with the objective of estimating pollutant loads.

Grab sampling should be carefully evaluated to determine its applicability for each monitoring situation (Coffey and Smolen, 1990). Nonpoint source pollutant concentrations generally increase with discharge. For a system with potentially lower variability in discharge, such as irrigation, grab sampling may be a suitable sampling method for estimating loads (Coffey and Smolen, 1990). Grab sampling may also be appropriate for systems in which the distribution of annual loading occurs over an extended period of several months, rather than a few events. In addition, grab sampling may be used to monitor low flows and background concentrations.

For systems exhibiting high variability in discharge or where the majority of the pollutant load is transported by a few events (such as snowmelt in some northern temperate regions), however, grab sampling is not recommended.

c. Habitat Sampling

EPA recommends a procedure for assessing habitat quality where all of the habitat parameters are related to overall aquatic life use support and are a potential source of limitation to the aquatic biota (Plafkin et al., 1989). In this procedure, EPA begins with a survey of physical characteristics and water quality at the site. Such physical factors as land use, erosion, potential nonpoint sources, stream width, stream depth, stream velocity, channelization, and canopy cover are addressed. In addition, water quality parameters such as temperature, dissolved oxygen, pH, conductivity, stream type, odors, and turbidity are observed.

Then, EPA follows with the habitat assessment, which includes a range of parameters that are weighted to emphasize the most biologically significant parameters (Plafkin et al., 1989). The procedure includes three levels of habitat parameters. The primary parameters are those that characterize the stream "microscale" habitat and have the greatest direct influence on the structure of the indigenous communities. These parameters include characterization of the bottom substrate and available cover, estimation of embeddedness, and estimation of the flow or velocity and depth regime. Secondary parameters measure the "macroscale" and include such parameters as channel alteration, bottom scouring and deposition, and stream sinuosity. Tertiary parameters include bank stability, bank vegetation, and streamside cover.

MacDonald (1991) discusses a wide range of channel characteristics and riparian parameters that can be monitored to evaluate the effects of forestry activities on streams in the Pacific Northwest and Alaska. MacDonald states that "stream channel characteristics may be advantageous for monitoring because their temporal variability is relatively low, and direct links can be made between observed changes and some key designated uses such as coldwater fisheries." He notes, however, that "general recommendations are difficult because relatively few studies have used channel characteristics as the primary parameters for monitoring management impacts on streams."

On the other hand, MacDonald concludes that the documented effects of management activities on the stability and vegetation of riparian zones, and the established linkages between the riparian zone and various designated uses, provide the rationale for including the width of riparian canopy opening and riparian vegetation as recommended monitoring parameters. Riparian canopy opening is measured and tracked through a historical sequence of aerial photographs (MacDonald, 1991). Riparian vegetation is measured using a range of methods, including qualitative measures of vegetation type, visual estimations of vegetation cover, quantitative estimations of vegetation cover using point- or line-intercept methods, light intensity measurements to estimate forest cover density, stream shading estimates using a spherical densiometer, and estimates of vegetation density based on plot measurements.

Habitat variables to monitor grazing impacts include areas covered with vegetation and bare soil, stream width, stream channel and streambank stability, and width and area of the riparian zone (Platts et al., 1987). Ray and Megahan (1978) developed a procedure for measuring streambank morphology, erosion, and deposition. Detailed streambank inventories may be recorded and mapped to monitor present conditions or changes in morphology through time.

To assess the effect of land use changes on streambank stability, Platts et al. (1987) provide methods for evaluating and rating streambank soil alteration. Their rating system can be used to determine the conditions of streambank stability that could affect fish. Other measurements that could be important for fisheries habitat evaluations include streambank undercut, stream shore water depth, and stream channel bank angle.

d. Benthic Organism Sampling

Benthic communities in estuaries are sampled through field surveys, which are typically time-consuming and expensive (USEPA, 1991a). Sampling devices include trawls, dredges, grabs, and box corers. For more specific benthic sampling guidance, see Klemm et al. (1990).

e. Fish Sampling

For estuaries and coastal waters, a survey vessel manned by an experienced crew and specially equipped with gear to collect organisms is required (USEPA, 1991a). Several types of devices and methods can be used to collect fish samples, including traps and cages, passive nets, trawls (active nets), and photographic surveys. Since many of these devices selectively sample specific types of fish, it is not recommended that comparisons be made among data collected using different devices (USEPA, 1991a).

f. Shellfish Sampling

Pathobiological methods provide information concerning damage to organ systems of fish and shellfish through an evaluation of their altered structure, activity, and function (USEPA, 1991a). A field survey is required to collect target organisms, and numerous tissue samples may be required for pathobiological methods. In general, pathobiological methods are labor-intensive and expensive (USEPA, 1991a).

g. Plankton Sampling

Phytoplankton sampling in coastal waters is frequently accomplished with water bottles placed at a variety of depths throughout the water column, some above and some below the pycnocline (USEPA, 1991a). A minimum of four depths should be sampled. Zooplankton sampling methods vary depending on the size of the organisms. Devices used include water bottles, small mesh nets, and pumps (USEPA, 1991a).

h. Aquatic Vegetation Sampling

Attributes of emergent wetland vegetation can be monitored at regular intervals along a transect (USEPA, 1991a). Measurements include plant and mulch biomass, and foliar and basal cover. Losses of aquatic vegetation can be tracked through aerial photography and mapping.

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i. Water Column Sampling

In estuaries and coastal waters, chemical samples are frequently collected using water bottles and should be taken at a minimum of four depths in the vertical profile (USEPA, 1991a). Caged organisms have also been used to monitor the bioaccumulation of toxic chemicals.

Physical sampling of the water column at selected depths in estuaries is done with bottles for temperature, salinity, and turbidity, or with probes for temperature and salinity (USEPA, 1991a). Current meters are used to characterize circulation patterns.

j. Sediment Sampling

Several types of devices can be used to collect sediment samples, including dredges, grabs, and box corers (USEPA, 1991a). Sampling depth may vary depending on the monitoring objective, but it is recommended that penetration be well below the desired sampling depth to prevent sample disturbance as the device closes (USEPA, 1991a). EPA also recommends the selection of sediment samplers that also sample benthic organisms to cut sampling costs and to permit better statistical analyses relating sediment quality to benthic organism parameters.

k. Bacterial and Viral Pathogen Sampling

For estuaries and coastal waters it is recommended that samples be taken of both the underlying waters and the thin microlayer on the surface of the water (USEPA, 1991a). This is recommended, despite the fact that standardized methods for sampling the microlayer have not been established, because research has shown bacterial levels several orders of magnitude greater in the microlayer. In no case should a composite sample be collected for bacteriological examination (USEPA, 1978).

Water samples for bacterial analyses are frequently collected using sterilized plastic bags or screw-cap, wide-mouthed bottles (USEPA, 1991a). Several depths may be sampled during one cast, or replicate samples may be collected at a particular depth by using a Kemmerer or Niskin sampler (USEPA, 1978). Any device that collects water samples in unsterilized tubes should not be used for collecting bacteriological samples without first obtaining data that support its use (USEPA, 1991a). Pumps may be used to sample large volumes of the water column (USEPA, 1978).

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9. Quality Assurance and Quality Control

Effective quality assurance and quality control (QA/QC) procedures and a clear delineation of QA/QC responsibilities are essential to ensure the utility of environmental monitoring data (Plafkin et al., 1989). Quality control refers to the routine application of procedures for obtaining prescribed standards of performance in the monitoring and measurement process. Quality assurance includes the quality control functions and involves a totally integrated program for ensuring the reliability of monitoring and measurement data.

EPA's QA/QC program requires that all EPA National Program Offices, EPA Regional Offices, and EPA laboratories participate in a centrally planned, directed, and coordinated Agency-wide QA/QC program (Brossman, 1988). This requirement also applies to efforts carried out by the States and interstate agencies that are supported by EPA through grants, contracts, or other formalized agreements. The EPA QA program is based on EPA order 5360.1, which describes the policy, objectives, and responsibilities of all EPA Program and Regional Offices (USEPA, 1984).

Each office or laboratory that generates data under EPA's QA/QC program must implement, at a minimum, the prescribed procedures to ensure that precision, accuracy, completeness, comparability, and representativeness of data are known and documented. In addition, EPA QA/QC procedures apply throughout the study design, sample collection, sample custody, laboratory analysis, data review (including data editing and storage), and data analysis and reporting phases.

Specific guidance for QA/QC is provided for EPA's rapid bioassessment protocols (Plafkin et al., 1989) and for EPA's Ocean Data Evaluation System (USEPA, 1991a). Standardized procedures for field sampling and laboratory methods are an essential element of any monitoring program.

D. Data Needs

Data needs are a direct function of monitoring goals and objectives. Thus, data needs cannot be established until specific goals and objectives are defined. Furthermore, data analyses should be planned before data types and data collection protocols are agreed upon. In short, the scientific method, defined as "a method of research in which a problem is identified, relevant data gathered, an hypothesis formulated, and the hypothesis empirically tested" (Stein, 1980), should be applied to determine data needs.

Types of data generally needed for nonpoint source monitoring programs will include chemical, physical, and biological water quality data, precipitation data; topographic and morphologic data; soils data; land use data; and land treatment data. The specific parameters should be determined based on site-specific needs and the monitoring objectives that are established.

Under EPA's quality assurance and quality control (QA/QC) program (see Quality Assurance and Quality Control), a full assessment of the data quality needed to meet the intended use must be made prior to specification of QA/QC controls (Brossman, 1988). The determination of data quality is accomplished through the development of data quality objectives (DQOs), which are qualitative and quantitative statements developed by data users to specify the quality of data needed to support specific decisions or regulatory actions. Establishment of DQOs involves interaction of decision makers and the technical staff. EPA has defined a process for developing DQOs (USEPA, 1986).

E. Statistical Considerations

A significant challenge for those performing monitoring under section 6217 is to isolate the changes in loads and water quality caused by the implementation of management measures from those changes caused by the other sources of variability. In short, the task is to separate the effect, or "signal," from the noise.

Successful monitoring programs typically resemble research, complete with focused objectives, hypotheses to test, statistical analyses, thorough data interpretation, and clear reporting. Statistics are an inherent component of nearly all water quality monitoring programs (MacDonald, 1991). The capability to plan for and use statistical analyses, therefore, is essential to the development and implementation of successful monitoring programs. The following discussion provides some basic information regarding statistics that should be understood by monitoring professionals. A qualified statistician should be consulted to review the proposed monitoring design, the plan for statistical analyses, the application of statistical techniques, and the interpretation of the analytic results.

1. Variability and Uncertainty

Gilbert (1987) identifies five general sources of variability and uncertainty in environmental studies:

(1) Environmental variability;
(2) Measurement bias, precision, and accuracy;
(3) Statistical bias;
(4) Random sampling errors; and
(5) Gross errors and mistakes.

The author describes environmental variability as "the variation in true pollution levels from one population unit to the next." There are multiple sources of environmental variability that could affect pollutant loads and water quality conditions. These sources include variability in weather patterns within and across years, natural variability in water resource conditions, variations in biological communities, variability in loadings from point sources and other sources that may not be addressed under section 6217 programs, and variability in land use. Changing land use brings with it changes in the level of pollution control possible under section 6217. For example, a conversion from well-managed agricultural cropland to well-managed suburban development may cause decreases in nutrient and sediment loads while possibly causing increases in metal loads and changes in hydrology. Gilbert (1987) notes that existing information on environmental variability can be used to "design a plan that will estimate population parameters with greater accuracy and less cost than can otherwise be achieved."

Accuracy is a measure of how close the sample value is to the true population value, whereas precision refers to the repeatability of sample values. Measurement bias occurs when estimates are consistently higher or lower than the true population value (Gilbert, 1987). Random sampling errors (e.g., variability in sample means for different random samples from the same population) are due only to the random selection process and arise from the environmental variability of population units (Gilbert, 1987). By definition, random sampling error is zero if all population units are measured.

Statistical bias is "a discrepancy between the expected value of an estimator and the population parameter being estimated" (Gilbert, 1987). Gilbert (1987) provides examples of estimators that are biased for small sample sizes but less biased or unbiased for larger samples.

Gross mistakes can occur at any point in the process, beginning with sample collection and ending with the reporting of study results (Gilbert, 1987). Adherence to accepted sampling and laboratory protocol, combined with thorough quality control and data screening procedures, will minimize the chances for gross errors.

2. Samples and Sampling

a. Samples

A sample is defined as "a small part of anything or one of a number, intended to show the quality, style, or nature of the whole" (Stein, 1980). Environmental samples are collected for both economic and practical reasons: that is, researchers cannot afford to inspect the *whole* and researchers usually have neither the time and resources nor the capability to even try to inspect the whole. Besides, researchers often find that a sample or collection of samples will provide sufficient information about the whole to allow decisions to be made regarding actions that should or should not be taken.

In a statistical sampling program, the whole is called the *population* or *target population*, and it consists of the set of *population units* about which inferences will be made (Gilbert, 1987). As an example, population units could be defined as macroinvertebrate populations on square-meter sections of river bottom, nitrogen concentrations in 1-liter grab samples, or hourly mean-flow values at a specific gaging station. Gilbert (1987) refers to the *sampled population* as the set of population units directly available for measurement.

b. Sampling Objectives

Gaugush (1986) states that "the major objective in sampling program design is to obtain as accurate or unbiased an estimate as possible, and at the same time to reduce or explain as much of the variability as possible in order to improve the precision of the estimates." According to Cochran (1977), an estimator is unbiased if its mean value, taken over all possible samples, is equal to the population statistic that it estimates.

In the real world it is necessary to design sampling programs that meet accuracy and precision requirements while not placing unreasonable burdens on sampling personnel or sampling budgets. As stated by Gaugush (1986), budget constraints may force the issue of whether sampling results will produce information sufficient to meet the study objectives.

Gaugush (1986) describes in some detail specific points to consider in defining study objectives. He notes that "sampling is facilitated by specifying the narrowest possible set of objectives which will provide the desired

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information." First, he recommends that the target population be defined as a key step in limiting the variability encountered in the sampling program. As an example, in a coastal watershed impacted by nonpoint sources, the target population could be defined as storm-event, total nitrogen concentrations at the outlets of all tributaries to the bay, thus eliminating the need to monitor at upstream and in-bay sites and during baseflow conditions. In this example, the definition of the target population also specifies the water quality parameter of interest (i.e., total nitrogen concentration). Note that both spatial and temporal limits should be established when defining the target population. With respect to the example, then, the researcher may more specifically define the population units as the total nitrogen concentrations in half-hour, composite samples taken during all storms (*storms* as defined by the researcher).

The next step, according to Gaugush (1986), is to decide whether parameter estimation or hypothesis testing is the primary analytic goal. This choice will have an impact on the sampling design. As an example, Gaugush points out that balanced designs are desirable for hypothesis testing (see Estimation and Hypothesis Testing), whereas parameter estimation may require unbalanced sample allocations to account for the spatial variability of parameter levels. Hypothesis testing is likely to be used in program evaluation (e.g., water quality before and after nonpoint source management measures are implemented), whereas parameter estimation can be applied in assessments when determining pollutant loads from various sources.

Finally, Gaugush (1986) recommends that exogenous variables and sampling strata be defined. Exogenous variables are used to explain some of the variability in the measured parameter of interest. As an example, total suspended solids (TSS) is often a covariate of total phosphorus (TP) concentration in watersheds impacted by agricultural runoff. Measurement of TSS may help increase the precision of TP estimates.

c. Sample Type and Sampling Design

The sampling program should provide representative and sufficient data to support planned analyses. Site location and sampling frequency are often considered sufficient to describe the "where" and "when" of sampling programs. While this is certainly true to a large extent, these two factors alone do not describe fully where and when samples are collected. Additional considerations include the depth of sampling and the surface-water or ground-water stratum to which the sampling depth belongs, the origins of the aliquots taken in each sample bottle, and the time frame over which measurements are made (including specific dates). These additional considerations are factors that characterize the *type* of sample collected. Site location and sampling frequency are components of sampling *design*.

In order for the data analyst to interpret sampling results appropriately, the sample type, sampling design, and target population must all be clearly described. It should be clear from these descriptions whether the data collected are representative of the target population.

Examples of sample type classifications include instantaneous and continuous; discrete and composite; surface, soil-profile, and bottom; time-integrated, depth-integrated, and flow-integrated; and biological, physical, and chemical. Specific guidance regarding the collection of these various sample types is not presented in this guidance since there are several existing guidances to address sampling protocols and equipment.

An overview of a range of basic sampling designs is provided below. Users are encouraged to consult basic statistics textbooks (e.g., Cochran, 1977) and books on applied statistics (e.g., Gilbert, 1987) to obtain additional information regarding these designs.

Simple Random Sampling. In simple random sampling, each unit of the target population has an equal chance of being selected. For example, if the target population is the macroinvertebrate population found on 100 square meters of river bottom and the population units are 1-square-meter sections of river bottom, then each unit would have a 1 percent chance of being sampled under a random sampling program.

Gilbert (1987) and Cochran (1977) both address many aspects of simple random sampling. Included in these texts are methods for estimation of the mean and total for sampling with and without replacement, equations for determining the number of samples required for both independent and correlated data, and the impact of measurement errors.

Stratified Random Sampling. In stratified random sampling, the target population is divided into separate groups called *strata* for the purpose of obtaining a better estimate of the mean or total for the entire population (Gilbert, 19987). Simple random sampling is then used within each stratum.

Stratified random sampling could be used, for example, to monitor water quality in streams below irrigation return flows. Based on a knowledge of irrigation and precipitation patterns for the watershed, the researcher could divide the year into two or more homogenous periods. Within each period random samples could be taken to characterize the average concentration of a particular pollutant. These random samples could take the form of daily, flow-weighted composite samples, with the sampling dates randomly determined.

Cluster Sampling. In cluster sampling, the total population is divided into a number of relatively small subdivisions, or clusters, and then some of these subdivisions are randomly selected for sampling (Freund, 1973). For one-stage cluster sampling these selected clusters are sampled totally, but in two-stage cluster sampling random sampling is then performed within each cluster (Gaugush, 1986).

Cluster sampling is applied in cases where it is more practical to measure randomly selected groups of individual units than to measure randomly selected individual units (Gilbert, 1987). An example of one-stage cluster sampling is the collection of all macroinvertebrates on randomly selected rocks within a specified sampling area. The stream bottom may contain hundreds of rocks with thousands of organisms attached to them, thus making it difficult to sample the organisms as individual units. However, it may be possible to randomly select rocks and then inspect every organism on each selected rock.

Multi-stage Sampling. Two-stage sampling involves dividing the target population into primary units, randomly selecting a subset of these primary units, and then taking random samples (subunits) within each of the selected subsets (Gilbert, 1987). All of the random samples from the subunits are measured completely. Two-stage cluster sampling, described above, is one form of two-stage sampling. Cochran (1977) describes two-stage sampling in great detail, and both Gilbert (1987) and Cochran (1977) discuss three-stage sampling and compositing.

Double Sampling. Double sampling, or two-phase sampling, involves taking a large preliminary sample to gain information (e.g., population mean or frequency distribution) about an auxiliary variate (x_i) in the context of a larger sampling survey to make estimates for some other variate (y_i) (Cochran, 1977). This technique can be used for stratification, ratio estimates, and regression estimates (Cochran, 1977).

Double sampling for stratification requires a first sample to estimate the strata weights (the proportion of samples to be taken in each stratum) and a second sample to estimate the strata means (Cochran, 1977). Gilbert (1987) discusses a use of double sampling in which two techniques are used in initial sampling and subsequent sampling is performed using only the cheaper or simpler technique. The initial sampling is used to establish a linear regression between the measurements from the two techniques. This regression is then applied to the subsequent measurements made with the cheaper technique to predict the measurement result that would have been obtained with the better, more expensive technique.

Systematic Sampling. A commonly used sampling approach is systematic sampling, which entails taking samples at a preset interval of time or space, using a randomly selected time or location as the first sampling point (Gilbert, 1987). Systematic sampling is used extensively in water quality monitoring programs usually because it is relatively easy to do from a management perspective.

Cochran (1977) points out that the difference between systematic sampling and stratified random sampling with one unit per stratum is that in systematic sampling the sampled unit occurs in the same relative position within each stratum while in stratified random sampling the relative position is selected randomly. Cochran recommends systematic sampling for the following situations:

- When the ordering of the population is essentially random or it contains at most a mild stratification;
- When stratification with numerous strata is employed and an independent systematic sample is drawn from each stratum;
- When subsampling cluster units; and
- When sampling populations with variation of a continuous type, provided that an estimate of the sampling error is not regularly required.

Sampling for Regression Analysis. Regression analysis is used to predict variable values based on a mathematical relationship between a dependent variable and one or more independent variables (Gaugush, 1986). Gaugush points out that regression analysis requires that at least one quantitative independent variable be used, whereas parameter estimation and hypothesis testing can be performed for groups or classes (i.e., only the variable tested needs to be quantitative). For example, one could quantify the relationship between sediment levels and flow rates by regressing the log of total suspended solids (TSS) concentrations (dependent) against flow rates (independent), which would require quantitative measurements of both parameters. Alternatively, one could estimate average TSS levels (parameter estimation) for high, medium, and low flow conditions with quantitative measures of TSS concentrations and qualitative measures of flow (e.g., visual observation).

Gaugush (1986) discusses sampling to support regression analyses in terms of relating variables to either a spatial or a temporal gradient, the latter being for trends over time. Some key points made are explained below.

Spatial Gradient Sampling

- The gradient variable is treated as a covariant to the variable of interest.
- If the relationship is linear, only two points need to be sampled; the extreme points are preferred.
- Whenever the relationship is known, relatively few sampling points are needed along the gradient. More samples may then be used as replicates.
- Whenever the relationship is not known, more sampling points are needed along the gradient. More replicates are also needed to test the proposed model.
- It is usually acceptable to place sampling points equal distances from each other along the gradient. However, the investigator should be careful not to fall in step with some natural phenomenon, which would bias any data collected.

Time Sampling

- Time can be used either as a covariate or as a grouping variable (e.g., season). Grouping by time may be desirable when changes in the variable of interest are either small over time or occur only during short periods with long periods of little or no change.
- Considerations in using time as a covariate are similar to those above for gradients, but (1) time is usually only a surrogate for other variables (e.g., implementation of management measures) that truly affect the variable of interest, and (2) the relationship with time is likely to be complex.
- If time is to be used as a covariate, relatively frequent sampling will be needed, with some replication within sampling periods. Random sampling within the periods is also recommended.

Comparison of Sampling Designs. Both Gilbert (1987) and Cochran (1977) indicate that systematic sampling is generally superior to stratified random sampling in estimating the mean. Cochran (1977), however, found that stratified random sampling provides a better estimate of the mean for a population with a linear trend, followed in order by systematic sampling and simple random sampling. Freund (1973) notes that estimates of the mean that are based on cluster sampling are generally not as good as those based on simple random samples, but they are better per unit cost. Table 8-2 summarizes the conditions under which each of six probabilistic sampling approaches should be used for estimating means and totals (Gilbert, 1987). Cochran (1977) states that "stratification nearly always results in a smaller variance for the estimated mean or total than is given by a comparable simple random sample." Estimates of variance from systematic samples may differ from those determined from random samples, but Cochran (1977) notes that "on average the two variances are equal." Cochran warns, however, that for any finite population for which the number of sampling units is small the variance from systematic sampling is erratic and may be smaller or larger than the variance from simple random sampling.

d. Preliminary Sampling

Preliminary sampling helps to ensure that the population of interest is being sampled and to evaluate its distribution (Coffey and Smolen, 1990). Preliminary sampling or previous testing helps avoid the problem of collecting large sets of useless data because of ineffective gear, or improper sample preparation or preservation. The target population can be easily missed, especially for biological monitoring.

e. Use of Existing Data

Existing data may be used for problem definition, or for a pre-implementation baseline data set if the collection protocol matches the monitoring objective, design, and quality assurance/quality control (QA/QC) required for the post-implementation data collection (Coffey and Smolen, 1990). Existing data may also be used for assessing parameter variability and estimating the number of samples or the time period for the monitoring survey based on the desired level of significance and error.

3. Estimation and Hypothesis Testing

There are two major types of statistical inference: estimation and hypothesis testing (Remington and Schork, 1970). In estimation it is hoped that sample information can be used to make a reasonable conclusion regarding the value of an unknown parameter. For example, the sample mean and standard deviation are used to estimate a range within which it is likely that the population mean falls. This sort of estimation can be useful in developing baseline information, developing or verifying models, estimating the nonpoint source contributions in a watershed, or determining the nitrogen load from a single runoff event.

In hypothesis testing, data are collected for the purpose of accepting or rejecting a statement made about the expected results of a study or effort. Hypothesis testing can be used to help decide whether management measures have reduced pollutant loads or improved water quality. Because of this, hypothesis testing is a recommended element of monitoring programs under section 6217.

The null hypothesis (H_o) is the root of hypothesis testing. Traditionally, null hypotheses are statements of "no change," but Remington and Schork (1970) prefer the term "tested hypothesis" since these hypotheses can take the form of expected changes, effects, or differences. The alternate hypothesis (H_a) is the counter to the null hypothesis, traditionally being a statement of change, effect, or difference. That is, upon rejection of an H_o stating no change one would accept the H_a of change. One could, however, state an H_o of the type "change of at least 10 percent," with an H_a of the type "no change of at least 10 percent." The choice is left to the researcher.

If the monitoring design is sound and statistical testing shows the null hypothesis to be false, then a change can be inferred (Coffey and Smolen, 1990). Otherwise, the monitoring survey should conclude that the objective was not met or that detection of change was overcome by extreme variability. In either case, with a sound objective, well-formulated hypothesis, and careful design, the monitoring survey may be expected to produce valuable information.

Table 8-2. Applications of Six Probability Sampling Designs to Estimate Means and Totals (after Gilbert, 1987)

Sampling Design	Conditions for Application
Simple Random Sampling	Population does not contain major trends, cycles, or patterns of contamination.
Stratified Random Sampling	Useful when a heterogeneous population can be broken down into parts that are internally homogenous.
Multistage Sampling	Needed when measurements are made on subsamples or aliquots of the field sample.
Cluster Sampling	Useful when population units cluster together and every unit in each randomly selected cluster can be measured.
Systematic Sampling	Usually the method of choice when estimating trends or patterns of contamination over space. Also useful for estimating the mean when trends and patterns in concentrations are not present, or they are known *a priori*, or when strictly random methods are impractical.
Double Sampling	Useful when there is a strong linear relationship between the variable of interest and a less expensive or more easily measured variable.

The following are examples of hypotheses that could be developed for section 6217 monitoring programs.

- Implementation of nutrient management on cropland in all tributary watersheds will not reduce mean total nitrogen concentrations in Beautiful Sound by at least 20 percent.
- Urban detention basins in New City will not remove 80 percent of sediment delivered to the basins.
- Improved marina management will not reduce metals loadings from the repair and maintenance areas of Stellar Marina.
- Forestry harvest activities have not increased weekly mean total suspended solids concentrations in Clean River.

F. Data Analysis

A detailed preliminary analysis using scatter plots and statistical tests of assumptions and the properties of the data set such as the distribution, homogeneity in variance, bias, independence, etc. precede formal hypothesis testing and statistical analysis (Coffey and Smolen, 1990). From the objective and the properties of the data set, the appropriate statistical test may be chosen to determine a trend, impact, or causality.

Simple scatter plots can often reveal much about the data set. For example, a scatter plot of nitrate concentrations versus depth collected at 106 monitoring wells in South Dakota (Figure 8-2) clearly shows that (Goodman et al., 1992):

- With few exceptions, nitrate concentrations above 5 parts per million (ppm) were not detected at depths greater than 20 feet below the water table;

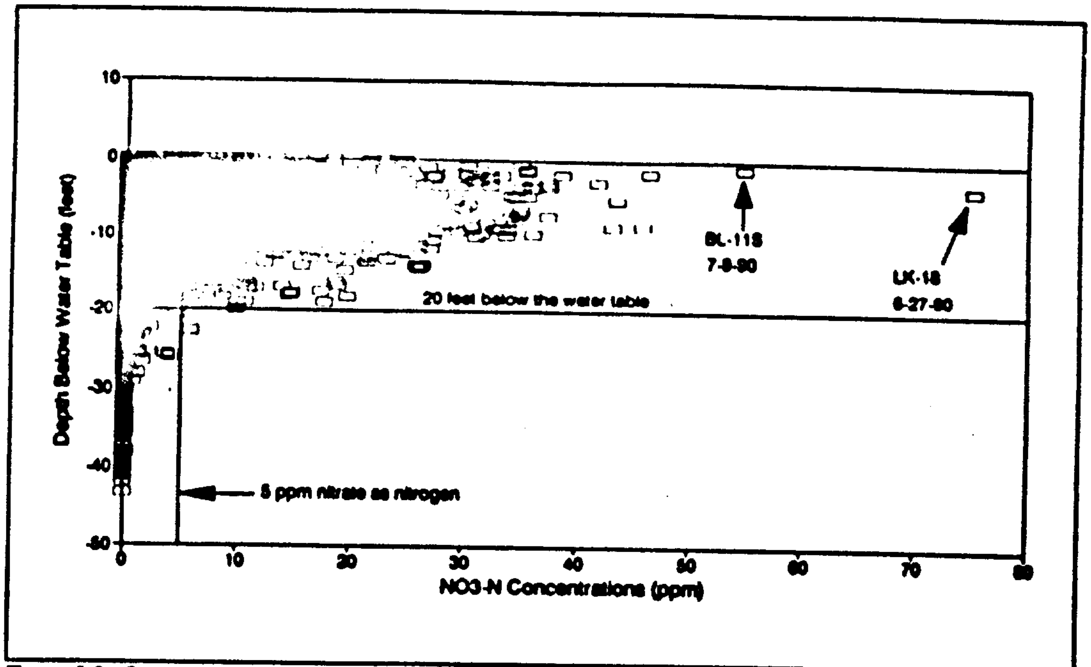

Figure 8-2. Scatter plot of nitrate concentration versus depth below water table (Goodman et al., 1992).

- Nitrate concentrations greater than 0.2 ppm were not observed at depths greater than 30 feet below the water table; and
- Nitrate concentrations exceeded 50 ppm only twice.

For trend detection some of the appropriate tests include Student's t-test, linear regression, time series, and nonparametric trend tests (Coffey and Smolen, 1990). For an assessment of impact and causality, a careful tracking of treatment is required and the two-sample Student's t-test, linear regression, and intervention time series are appropriate statistical tests (Spooner, 1990). Evidence from experimental plot studies, edge-of-field pollutant runoff monitoring, and modeling studies may be used to support the conclusion of causality (Coffey and Smolen, 1990).

A comparison of regression lines for data collected before best management practices (BMPs) were implemented (pre-BMP) and for data collected after BMPs were implemented (post-BMP) can be used to explore the presence of trends in a paired-watershed study. The example in Figure 8-3 (Meals, 1991b) shows a downward shift of the post-BMP regression line, suggesting a significant decrease in total phosphorus (TP) export from the treated (study) watershed (WS 4). In this study, pre-BMP data were collected for 3 years for calibration (see Types of Experimental Designs) of the two watersheds (control and study), followed by a post-BMP monitoring period of 5 years. Meals (1991b) explains the plot by noting that a 5-pound-per-week (lb/wk) export of TP from the control watershed (WS 3) corresponded to an 8.25-lb/wk export from the study watershed (WS 4) before BMP implementation. After BMP implementation, the same 5-lb/wk export from the control watershed corresponded to a 6-lb/wk export from the study watershed.

Lietman (1992) used cluster analysis to establish eight different storm groups based on total storm precipitation, antecedent soil-moisture conditions, precipitation duration, precipitation intensity, and crop cover. The results of analyses performed using the following clusters will be presented:

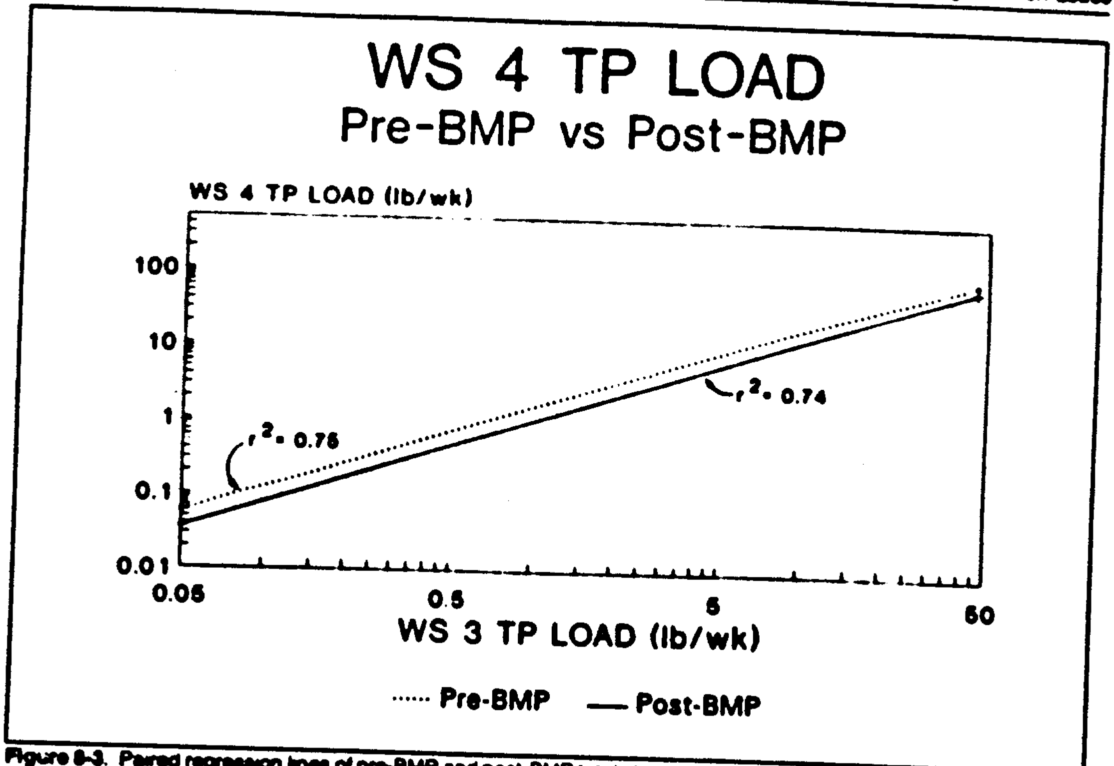

Figure 8-3. Paired regression lines of pre-BMP and post-BMP total phosphorus loads, LaPlatte River, Vermont (Meals, 1991b).

- Cluster 1: Summer showers on moist soil with crop cover.
- Cluster 3: Typical spring and fall all-day storms generally with 0.2 to 0.6 inch of precipitation on soil with little crop coverage.
- Cluster 6: Thunderstorms occurring predominantly in the summer on soil with cover crop.
- Cluster 7: Very small storms throughout the year on dry soil; most storms occurring on soil with little crop cover.
- Cluster 8: Typical spring and fall all-day storms generally with 0.8 to 1.6 inches of precipitation on soil with little crop cover.

These clusters were then used to group data for testing for significant differences between pre-BMP (Period 1, 1983-1984) and post-BMP (Period 3, 1987-1988; after terraces were installed) median runoff volume, mean suspended sediment concentrations, and mean nutrient concentrations at a 22.1-acre field site in Lancaster County, Pennsylvania. Cluster 3 had a very small number of storms producing runoff in Period 3, indicating that terracing increased the threshold at which runoff occurred (Lietman, 1992). Other results, summarized in Figure 8-4 (Lietman, 1992), indicate that terracing caused mean storm suspended sediment concentrations in runoff to decrease for storms in clusters 6, 7, and 8. Terraces also appeared to increase mean nitrate (Clusters 1, 6, 7, and 8) and mean total nitrogen concentrations (Clusters 1 and 8).

Mann-Whitney test results comparing within clusters total storm runoff and mean storm suspended sediment and nutrient concentrations between Period 1 (1983-84) and Period 3 (1987-88); storms on frozen ground excluded. ↑ = statistically significant increase; ↓ = statistically significant decrease; — = no statistically different change; (90) = significant at the 90 percent confidence interval; (95) = significant at the 95 percent interval; n = number of storms; mg/L = milligrams per liter; ft³/s = cubic foot per second; ft³/acre = cubic foot per acre; and lb/acre = pound per acre.

		CLUSTER 1	CLUSTER 6	CLUSTER 7	CLUSTER 8
		PERIOD 1/PERIOD 3	PERIOD 1/PERIOD 3	PERIOD 1/PERIOD 3	PERIOD 1/PERIOD 3
ALL STORMS[1]					
Total storm runoff (ft³/acre)	Change	↓(90)	—	↓(95)	—
	median	86/0	84/400	0/0	208/280
	n	31/21	18/10	67/73	18/12
STORMS THAT PRODUCED RUNOFF					
Total storm runoff (ft³/acre)	Change	↑(90)	—	—	—
	median	120/240	102/740	24/80	280/280
	n	21/7	13/9	26/10	13/12
Mean suspended sediment concentrations (mg/L)	Change	—	↓(95)	↓(95)	↓(95)
	median	2,870/2,030	9,040/1,880	3,930/728	1,930/470
	n	19/7	9/9	22/6	7/10
Mean total phosphorus concentration (mg/L as P)	Change	—	—	—	—
	median	2.6/2.7	4.1/3.4	3.1/3.4	3.1/4.3
	n	12/7	8/7	17/3	6/7
Mean total nitrogen concentration (mg/L as N)	Change	↑(90)	—	—	↑(90)
	median	3.4/6.1	5.4/6.2	5.2/7.4	4.1/7.2
	n	12/7	6/7	17/3	6/7
Mean ammonia + organic nitrogen concentration (mg/L as N)	Change	—	—	—	—
	median	2.7/4.2	4.8/4.2	4.1/4.2	3.6/4.8
	n	12/7	8/7	17/3	6/7
Mean nitrate + nitrite concentration (mg/L as N)	Change	↑(95)	↑(95)	↑(95)	↓(95)
	median	.86/1.7	.84/1.8	.86/4.1	.43/3.0
	n	12/7	8/7	17/3	8/7

[1]Total and mean discharge set equal to zero if no measurable runoff occurred.

Figure 8-4. Results of analysis of clustered pre-BMP and post-BMP data from Conestoga Headwaters, Pennsylvania (Lietman, 1992).

Failure to observe improvement may mean that the problem is not carefully documented, management action is not directed properly, the strength of the treatment is inadequate, or the monitoring program is not sensitive enough to detect change (Coffey and Smolen, 1990). A mid-course evaluation, if conducted early enough, provides an opportunity for modifications in project goals or monitoring design.

Clear reporting of the results of statistical analyses is essential to effective communication with managers. Graphical techniques and simple narrative interpretations of statistical findings generally help managers obtain the level of detail they need to make decisions regarding subsequent actions. For example, Figure 8-5 illustrates the use of box-and-whisker plots to summarize fecal coliform data at the beach on St. Albans Bay, Vermont (Meals et al., 1991). The graphic clearly shows a general decline in bacteria counts in 1987-1989, as well as the fact that the water quality standard has been met during those same years. A graphic summary of trends is illustrated in Figure 8-6, also taken from the St. Albans Bay project (Meals, 1992). This simple graphic is particularly easy for managers to interpret.

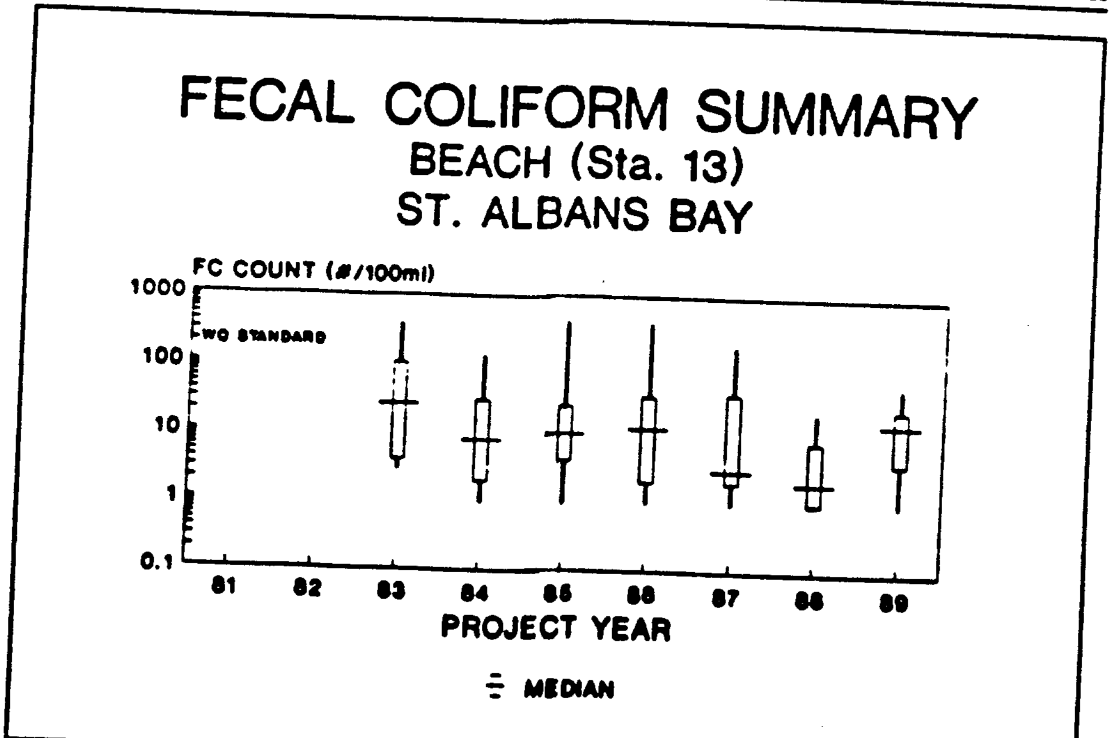

Figure 8-5. Summary of fecal coliform at the beach on St. Albans Bay, Vermont (Meals et al., 1991).

Station	TRB	TSS	VSS	TP	SRP	TKN	NH_3-N	CHL a	S.D.
Off-Bridge (14)	▽	▼	●	▼	▽	●	▽	▲	●
Inner Bay (12)	▽	▽	△	△	●	●	●	▲	▽
Outer Bay (11)	●	●	●	▲	▲	▲	▲	▲	▽

● = No significant trend

△▽ = Increasing or decreasing trend by some but not all statistical tests (P ≤ 0.10)

▲▼ = Increasing or decreasing trend by all statistical tests (P ≤ 0.10)

TRB = turbidity; TSS = total suspended solids; VSS = volatile suspended solids; TP = total phosphorus; SRP = soluble reactive phosphorus; TKN = total Kjeldahl nitrogen; NH_3-N = ammonia nitrogen; CHL a = chlorophyll a; S.D. = Secchi disk.

Figure 8-6. Trends in St. Albans Bay water quality, 1981-1990 (Meals, 1992).

III. TECHNIQUES AND PROCEDURES FOR ASSESSING IMPLEMENTATION, OPERATION, AND MAINTENANCE OF MANAGEMENT MEASURES

A. Overview

As discussed in the introduction to this chapter, States will not be able to fully interpret their water quality monitoring data without information regarding the adequacy of management measure implementation, operation, and maintenance. Section II of this chapter provides an overview of techniques for assessing water quality and estimating pollution loads. The information presented in this section is intended to complement that provided in Section II to give State and local field personnel the basic information they need to develop sound programs for assessing over time the success of management measures in reducing pollution loads and improving water quality.

Successful management measures designed to control nonpoint source pollutants require proper planning, design and implementation, and operation and maintenance. This section presents a general discussion of the procedures involved in ensuring the successful design and implementation of various management measures, but is *not* intended to provide recommendations regarding the operation and maintenance requirements for any given management measure. Instead, this section is intended to provide "inspectors" with ideas regarding the types of evidence to seek when determining whether implementation or operation and maintenance are being performed adequately.

B. Techniques

1. Implementation

Proper planning is an essential step in implementing management measures effectively and developing procedures that ensure that the measures are achieved. During the planning stage, the optimal selection of management practices for a specific discipline, such as forestry, is made following an evaluation of several factors. Some of these factors include site conditions, the water quality goals to be achieved, and the need to meet additional objectives established by the user. In some cases, local and state measures may directly require the use of certain practices or effectively dictate the use of certain practices through the establishment of limits (e.g., application rates for fertilizers and pesticides, annual erosion rates, land use controls, or setback distances from environmentally sensitive areas). The key components of the planning stage include:

- Site investigations by qualified personnel such as soil scientists, biologists, wetlands scientists, hydrologists, and engineers;
- Collection of pertinent data relative to the source category;
- Identification of water quality goals;
- Identification of land user objectives;
- Identification of relevant State and local regulations;
- Coordination with regulatory (and at times funding) agencies as necessary; and
- Identification of an appropriate series of practices that achieve both the stated objectives and the applicable management measures.

Once the appropriate series of practices has been identified for use, it is essential that each practice be properly designed and implemented for the measures to be successful. This requires that design and installation be conducted by qualified and experienced personnel. Design of the management practices should be done in accordance with

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existing design guidelines and standards outlined in technical guides, including those developed by States and the Soil Conservation Service of the U.S. Department of Agriculture. These standards include specific design criteria and specifications that, when followed, will ensure the proper design of a practice. The technical guides also include construction and implementation specifications that provide detailed guidance to the installer. It is always desirable to have a qualified person such as the designer present at certain stages during installation to ensure that the designs are being interpreted correctly and installed as specified.

2. Operation and Maintenance

A critical step in ensuring success of a management measure is proper operation and maintenance (O&M) of each practice. Once a series of practices has been designed and installed, it is crucial that the individual practices be operated and maintained to ensure that they function as intended. During the design process, an operation and maintenance plan that identifies continual procedures, schedules, and responsibility for operating and maintaining the practices should be drafted.

Examples of procedures and techniques to ensure the successful achievement of operation and maintenance are identified in the following subsections. These procedures are generally applied by the landowner or operator responsible for implementing the management measures. The examples provided below are not mandatory but rather are presented as illustrations of effective operation and maintenance practices. States may wish to develop programs that ensure that O&M is performed by the responsible individuals or entities.

a. *Agriculture*

Chapter 2 of this guidance identifies six major categories of agricultural nonpoint pollution sources that affect coastal waters: erosion from cropland, confined animal facilities, application of nutrients to cropland, application of pesticides to cropland, land used for grazing, and irrigation of cropland. Table 8-3 presents examples of general O&M procedures to ensure the performance of these measures.

Table 8-3. Typical Operation and Maintenance Procedures for Agricultural Management Measures

Management Measures	Management Practices	Typical Operation and Maintenance Procedures
Erosion and Sediment Control	<u>Structural and Vegetative Practices</u> Terraces, diversions, sediment basins, drainage structures, vegetative cover establishment and improvement, field borders, filter strips, critical area planting, grassed waterways, tree and shrub planting, and mulching	• Inspections are performed periodically and after large storm events to check for failure and loss of vegetative cover. Revegetation and replacement or repair of structures are performed as needed. Tree and shrub growth is removed from constructed channels and diversions unless needed for maintaining habitat. • Inspections and removal of accumulated sediments are performed periodically and after large storm events. • Vegetative practices are inspected periodically, and mulch and crop residues are applied for vegetation loss, erosion, and channelization resulting from runoff. Eroded channels are regraded, revegetated, and treated with mulch as needed.
	<u>Nonstructural Practices</u> Conservation tillage, conservation cropping sequence, delayed seedbed operation, strip-cropping, and crop rotations	• Practice implemented is compared versus specifications in design standards, and operational procedures are closely followed.

Table 8-3. (Continued)

Management Measures	Management Practices	Typical Operation and Maintenance Procedures
Confined Animal Facility Management	<u>Structural and Vegetative Practices</u> Terraces, diversions, heavy use area protection, drainage structures, dikes, grassed waterways, waste storage ponds and structures, waste treatment lagoons, composting facilities, and vegetative cover establishment	• Inspections are performed periodically and after large storm events to check for failure and loss of vegetative cover. Revegetation and replacement or repair of structures are performed as needed. Tree and shrub growth is removed from constructed channels and diversions unless needed for maintaining habitat. • Waste storage structures are inspected for cracks and leaks after each use cycle. • All drainage structures including downspouts and gutters are annually inspected and repaired as needed. • Established grades for lot surfaces and conveyance channels are maintained at all times. • Holding ponds and lagoons are drawn down to design storm capacity within 14 days of a runoff event. • Solids are removed from the solid separation system after a runoff event to maintain design capacity and prevent solids from entering runoff holding facilities.
	<u>Nonstructural Practices</u> Waste utilization, application of manure and runoff to agricultural land	• Manure transport and application equipment is cleaned with fresh water after each use in an environmentally safe area.

Table 8-3. (Continued)

Management Measures	Management Practices	Typical Operation and Maintenance Procedures
Nutrient Management	Nonstructural Practices Nutrient management plan	• Operational procedures in management plan are adhered to. • Periodic testing of soil and plant tissue is conducted to determine nutrient needs during early growth stages, and manure sludges and irrigation water are tested if used. • The nutrient management plan is updated whenever crop rotation or nutrient source is changed. Nutrient needs and application rates and methods are redetermined if needed. • Records of nutrient use and sources are maintained along with production records for each field. • Application equipment is periodically inspected and calibrated, with repairs made as needed. • The management plan is reviewed at least every 3 years and updated if needed.
	Vegetative Practices Vegetative cover establishment	• Periodically and after large storm events cover crops are inspected for loss of vegetation, erosion, and channelization. Area is regraded and revegetated as needed. A thick, thriving cover crop is maintained.

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Table 8-3. (Continued)

Management Measures	Management Practices	Typical Operation and Maintenance Procedures
Pesticide Management	<u>Nonstructural Practices</u> Pesticide management	• Operational procedures and methods, such as use of proper application methods and rates, are adhered to. • Scouting for pests is conducted periodically, and spot spraying is used when needed. • Pesticide management actions are updated whenever crop rotation is changed or pesticide source is changed. • Application equipment is inspected and calibrated prior to use. • Pesticide use is tracked along with production records for each field. • Pesticide management approach is reviewed each year and updated as needed.

Table 8-3. (Continued)

Management Measures	Management Practices	Typical Operation and Maintenance Procedures
Grazing Management	<u>Structural and Vegetative Practices</u> Pipelines, ponds, tanks and troughs, fencing, wells, pasture and hayland planting, seeding, mulching, and critical area planting	• All structures are periodically inspected, including tanks, pipelines, wells, ponds, and fencing to ensure that they are structurally sound and functioning as designed. Replacement and repair are performed as needed. • Periodically and after large storm events all vegetative and mulching practices are inspected for vegetation loss, erosion, and channelization. Regrading, revegetation, and treatment with mulch are conducted as needed. • Range land is periodically inspected on foot to identify area of erosion, channelization, and loss of vegetation.
	<u>Grazing Management</u> Deferred grazing, planned grazing system, proper grazing use, and livestock exclusion	• Procedures outlined in standards on grazing management practices are adhered to. • Appropriate plant residue or grazing height is maintained to protect grazing soil from erosion. • Livestock herding is provided as needed to protect sensitive areas from excessive use at critical times. • A flexible grazing system is maintained to adjust for unexpected environmental problems.

Table 8-3. (Continued)

Management Measures	Management Practices	Typical Operation and Maintenance Procedures
Irrigation Water Management	Structural and Vegetative Practices All surface and subsurface irrigation systems; irrigation ditches, canal and channel lining, pipelines, water control structures, water meters, irrigation land leveling, and filter strips	• All irrigation system components, such as gate weirs, valves, pipes, meters, and ditches, are annually inspected and maintained to function as designed. • Established grades for lots and conveyance channels are maintained at all times. • Vegetative cover is inspected periodically and after all large rain events for loss of vegetation, erosion, and channelization. Regrading and revegetation are conducted as needed.
	Nonstructural Practices Irrigation water management	• Crop needs and volume of water delivered are measured for each irrigation event, and water is applied uniformly.

b. Forestry

Forestry-related activities such as road construction, timber harvesting, mechanical site preparation, prescribed burning, and fertilizer and pesticide application contribute to nonpoint source pollution. These operations can change water quality characteristics in waterbodies receiving drainage from forest lands. Activities such as timber harvesting, mechanical site preparation, and prescribed burning can accelerate erosion, resulting in increased sediment concentrations.

There are O&M techniques that minimize hydrological impacts, temperature elevations, the amount of sediment production, and the transport of sediment, nutrients, pesticides, and other pollutants from forest lands into waterbodies. These procedures typically involve periodic inspection and repair of the roadways, streamside management areas, and drainage structures (particularly after storm events); containment and proper use of chemicals used during forestry activities; and revegetation of the disturbed areas. A more detailed description of typical O&M procedures to ensure adequate performance of forestry management measures is presented in Table 8-4.

Table 8-4. Typical Operation and Maintenance Procedures for Forestry Management Measures

Management Measure	Management Practices	Typical Operation and Maintenance Procedures
Preharvest Planning	Develop a State process (or use an existing process) that ensures implementation of all forestry management measures. Such a process should include appropriate notification mechanisms for forestry activities with potential NPS impacts.	• Procedures outlined through harvesting planning process are followed. • Preharvest planning process is updated every year based on the results of new studies and Federal and State regulations.
Streamside Management Areas (SMAs)	Establish streamside management zone.	• The SMA width is maintained with respect to each State's special management criteria. • Low-level aerial photos are used to determine whether any changes are occurring in the SMA. • Periodic soil sampling is conducted for the presence of pesticides and fertilizers.
	Maintain necessary canopy species for shade, bank stability, and large woody debris.	• Shade cover is tracked throughout the harvesting activity, and clumping and clustering of leave trees is used if a blowdown threat exists.
Road Construction and Reconstruction	Install proper drainage/erosion control devices. Size to regional flood frequency (e.g., 25- or 50-year storms).	• Roadways are checked for flooding during storms. • Culverts and drainage devices are inspected and cleaned during fall and spring of each year and after major storm events. Drainage devices ar repaired as needed.
	Install appropriate sediment control structures.	• Sediment barriers and hay bales are inspected periodically and after a major storm event. • Erosion, channelization, and any short-circuiting in the filter strips are repaired. • Diversions, terraces, and berms are inspected and repaired.

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Table 8-4. (Continued)

Management Measure	Management Practices	Typical Operation and Maintenance Procedures
Road Construction and Reconstruction (continued)	Stream crossing	• Waterways are kept clear of debris not needed for habitat.
		• Stream crossings are stabilized and maintained.
Road Management	Road maintenance	• Roads are inspected for structural soundness and erosion after extreme weather.
		• Surface condition is inspected.
		• Design grades of roadways are maintained.
		• Roads are regraded and ruts are filled as needed.
		• Turnouts, dips, and waterbars are installed if needed.
		• Drainage structures are inspected, cleared, and repaired as needed.
	Proper closure and maintenance of abandoned roads.	• All restricted access roads are maintained and repaired.
		• Remaining stream-crossing structures are periodically inspected and maintained.
		• Where stream crossings have failed, crossing structures are removed and streambank is returned to grade.
		• Vegetation is established on remaining disturbed areas.
		• Indigenous plant species are selected for replanting.
Timber Harvesting	Landing (Practices have operational and post-operational phases where different O&M procedures may be needed)	• Drainage/erosion control structures are periodically inspected and repaired, and vegetation is established on remaining disturbed areas.

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Table 8-4. (Continued)

Management Measure	Management Practices	Typical Operation and Maintenance Procedures
Timber Harvesting (continued)	Skidding (Practices have operational and post-operational phases where different O&M procedures may be needed)	• Water bar is maintained on skid trails. • Trails and stream channels are revegetated.
	Petroleum management	• Spill prevention and containment procedures are followed. • Petroleum products are stored away from watercourses in sealed containers. • Equipment is serviced away from watercourses. • Waste disposal containers are inspected for leaks.
Site Preparation and Forest Regeneration	Site preparation	• Mechanical site preparation is not applied on slopes greater than 30 percent and is not conducted in SMAs. • Slash is kept from natural drainages. • Windrows and piles are placed away from drainages.
	Regeneration	• Seedlings are distributed evenly across the site. • Planting machines are operated along the contour.
Fire Management	Prescribed fire	• Extensive blading of fire lines by heavy equipment is avoided. • Intense prescribed fire is kept away from SMAs, streamside vegetation for small ephemeral drainages, and very steep slopes with high sedimentation potential.

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Table 8-4. (Continued)

Management Measure	Management Practices	Typical Operation and Maintenance Procedures
Fire Management (continued)	Wildfire suppression and rehabilitation	• Bladed firelines are plowed on contour or stabilized with waterbars and/or other needed techniques to prevent erosion of the fireline.
		• Use of fire-retardant chemicals in SMAs and over watercourses is avoided where possible.
Revegetation of Disturbed Areas	Revegetate disturbed areas, especially high erosion areas	• Growth is inspected until established and replaced as needed.
		• Mulches are inspected periodically and after rainstorms.
		• Vegetation is limed and fertilized if needed.
Forest Chemical Management	Apply fertilizer and pesticides according to label instructions. Use a buffer area for chemical applications.	• Instructions and State regulations for fertilizer and pesticide application are followed.
	Follow spill prevention and containment procedures to prevent products from entering the watercourses.	• In case of spill, spill containment procedures are followed.
	Store the fertilizer and pesticides away from watercourses.	• Fertilizer and pesticide storage containers are inspected for leaks.
	Dispose of wastes properly, with no applications directly to water.	• Waste disposal containers are periodically inspected for leaks.
		• Workers are informed about the correct method of disposal and the harmful effects on the environment if the waste is not disposed of correctly.
	Consider weather and wind conditions before application.	• The National Weather Bureau and local weather information centers are contacted for the weather and wind conditions.

Table 8-4. (Continued)

Management Measure	Management Practices	Typical Operation and Maintenance Procedures
Forest Chemical Management (continued)	Use a licensed applicator with properly calibrated equipment.	• The qualifications of the applicator are checked, and proof of the equipment calibration is inspected.
	Analyze soil and foliage prior to application of fertilizer.	• Samples are collected prior to application.
Wetlands Forest Management	Road design and construction	• Temporary roads are used in forested wetlands unless permanent roads are needed to serve large and frequently used areas.
		• Fill roads are constructed only when absolutely necessary.
		• Adequate cross-drainage is provided to maintain the natural surface and subsurface flow of the wetland.
	Harvesting	• When groundskidding, low-ground-pressure tires or tracked machines are used, and skidding is concentrated along a few primary trails.
		• Groundskidding is suspended when soils become saturated.

c. Urban Sources

Pollutants from urban sources include suspended solids, nutrients, pathogens, metals, petroleum products, and various toxics. Generally, urban nonpoint source control measures consist of nonstructural, and vegetative practices, all of which must be properly maintained to ensure pollutant removal. All of these practices should be periodically inspected. In the case of structural practices and vegetative practices, inspections are conducted to locate any structural defects and to perform cleaning operations. Nonstructural practices should be reviewed periodically as guidelines are updated or to determine the level of compliance with the guidelines. These issues are summarized in Table 8-5.

Table 8-5. Typical Operation and Maintenance Procedures for Urban Management Measures

Management Measure Category	Management Measure	Typical Operation and Maintenance Procedures
New Development, Redevelopment, and New and Relocated Roads, Highways, and Bridges	1. By design or performance: (a) the postdevelopment equivalent of at least 80 percent of the average, annual total suspended solids loading is removed, or (b) postdevelopment loadings of TSS are less than or equal to predevelopment loadings; and 2. To the greatest extent practicable, postdevelopment volume and peak runoff rates are similar to predevelopment levels.	• Selected practices known to achieve 80% TSS removal are designed and installed. • Selected practices are inspected and maintained to ensure operational efficiency. • Structural practices are inspected after major storms.
Watershed Protection for New Development or Redevelopment Including New and Relocated Roads, Highways, and Bridges	Develop a watershed protection program to: 1. Avoid conversion, to the extent practicable, of areas that are particularly susceptible to erosion and sediment loss; 2. Preserve areas that provide water quality benefits and/or are necessary to maintain riparian and aquatic biota; and 3. Site development, including roads, highways, and bridges, to protect, to the extent practicable, the natural integrity of waterbodies and natural drainage systems.	• Legislative authorities establish local planning and zoning controls. • Opportunity for community group and local organization involvement is built into approval mechanisms.

Table 8-5. (Continued)

Management Measure Category	Management Measure	Typical Operation and Maintenance Procedures
Site Development, Including Roads, Highways, and Bridges	Plan, design, and develop sites to: 1. Protect areas that provide important water quality benefits and/or are particularly susceptible to erosion and sediment loss; 2. Limit increases of impervious areas except where necessary; 3. Limit land disturbance activities such as clearing and grading, and cut and fill to reduce erosion and sediment loss; and 4. Limit disturbance of natural drainage features and vegetation.	• Erosion and sediment control plans are reviewed. • Site plans are reviewed for approval to ensure appropriate practices are included.
Construction Site Erosion and Sediment Control	1. Reduce erosion and, to the extent practicable, retain sediment onsite during and after construction and 2. Prior to land disturbance, prepare and implement an approved erosion and sediment control plan or similar administrative document that contains erosion and sediment control provisions.	• Site vegetation and structural practices are periodically inspected. • Area exposed to development is limited and stabilized in a reasonable period of time. • Post-storm inspections are conducted.
Construction Site Chemical Control	1. Limit application, generation, and migration of toxic substances; 2. Ensure the proper storage and disposal of toxic materials; and 3. Apply nutrients at rates necessary to establish and maintain vegetation without causing significant nutrient runoff to surface waters.	• Toxic and nutrient management programs and plans, including spill prevention and control, are developed and implemented. • Proper facilities for storage of construction equipment and machinery are maintained.
Onsite Disposal Systems	New Onsite Disposal Systems	• Postconstruction inspection is performed to ensure proper installation.

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Table 8-5. (Continued)

Management Measure Category	Management Measure	Typical Operation and Maintenance Procedures
Onsite Disposal Systems (continued)	Operating Onsite Disposal Systems	• Failing systems are inspected and repaired or replaced before property is to be sold. • The septic tank is regularly pumped (at least once every 5 years).
Runoff from Existing Development	Develop and implement watershed management programs to reduce runoff pollutant concentrations and volumes from existing development. 1. Identify priority local and/or regional watershed pollutant reduction opportunities, e.g., improvements to existing urban runoff control structures; 2. Contain a schedule for implementing appropriate controls; 3. Limit destruction of natural conveyance systems; and 4. Where appropriate, preserve, enhance, or establish buffers along surface waterbodies and their tributaries.	• Structural practices are inspected and maintained annually or more frequently. Accumulated sediment and debris are removed annually or more often if necessary. • The structural integrity of practices is inspected. • The tops of infiltration facilities are raked or removed and replaced annually or more often if needed to prevent clogging of soil pores. • Vegetative practices are mowed as needed.

Table 8-5. (Continued)

Management Measure Category	Management Measure	Typical Operation and Maintenance Procedures
Pollution Prevention	Implement pollution prevention and education programs to reduce nonpoint source pollutants generated from the following activities, where applicable: 1. Household hazardous waste; 2. Lawn and garden activities; 3. Turf management on golf courses, parks, and recreational areas; 4. Improper operation and maintenance of onsite disposal systems; 5. Discharge of pollutants into storm drains; 6. Commercial areas not under NPDES purview; and 7. Pet waste disposal.	- The success of public education and level of participation are reviewed annually. - Program is improved and expanded into additional areas.
Roads, Highways, and Bridges	Plan, site, and develop roads and highways to: 1. Protect areas that provide important water quality benefits or are particularly susceptible to erosion or sediment loss; 2. Limit land disturbance to reduce erosion and sediment loss; and 3. Limit disturbance of natural drainage features and vegetation.	- Selected practices known to achieve 80% TSS removal are designed and installed at post-development. - Site plans are reviewed to ensure appropriate practices are included. - Erosion and sediment control plan is implemented.
	Site, design, and maintain bridge structures so that sensitive and valuable aquatic ecosystems and areas providing important water quality benefits are protected from adverse effects.	- Drainage systems are inspected to ensure operational efficiency. - Entry of paint chips, abrasives, and solvents to waters during bridge maintenance is minimized.

Table 8-5. (Continued)

Management Measure Category	Management Measure	Typical Operation and Maintenance Procedures
Roads, Highways, and Bridges (continued)	1. Reduce erosion and, to the extent practicable, retain sediment onsite during and after construction; and 2. Prior to land disturbance, prepare and implement an approved erosion control plan or similar administrative document that contains erosion and sediment control provisions.	• Vegetation is inspected regularly and mowed as needed. • Slope cut-and-fill areas are inspected to ensure stability. • Retrofit practices are installed where needed.
	1. Limit the application, generation, and migration of toxic substances; 2. Ensure the proper storage and disposal of toxic materials; and 3. Apply nutrients at rates necessary to establish and maintain vegetation without causing significant nutrient runoff to surface water.	• Instructions and State regulations for fertilizer and pesticide application are followed. • Spill prevention, containment, and cleanup plans are implemented for toxics and hazardous substances. • Workers are informed of the correct methods of storage and disposal and of the harmful effects to the environment if storage and disposal are not done correctly.
	Incorporate pollution prevention procedures into the operation and maintenance of roads, highways, and bridges to reduce pollutant loadings to surface waters.	• Road, highway, and bridge operation and maintenance guidelines are reviewed. • An inspection program is implemented to ensure that operation and maintenance guidelines are fully implemented.

Table 8-5. (Continued)

Management Measure Category	Management Measure	Typical Operation and Maintenance Procedures
Roads, Highways, and Bridges (continued)	Develop and implement runoff management systems for existing roads, highways, and bridges to reduce runoff pollutant concentrations and volumes entering surface waters. 1. Identify priority and watershed pollutant reduction opportunities (e.g., improvements to existing urban runoff control structures) and 2. Establish schedules for implementing appropriate controls.	• Structural practices are inspected and accumulated sediment and debris are removed annually or more often if necessary. • Structural integrity of practices is inspected. • Infiltration facilities are inspected and cleaned annually to prevent clogging of soil pores. • Vegetative practices are mowed as needed, but not within 50-100 feet of waterways with steep banks.

d. Marinas and Recreational Boating

Potential adverse effects of recreational boating include degradation of water quality, degradation of sediment quality, destruction of habitat, increased turbidity, and shoreline and shallow area erosion. Proper design and operation of marinas can result in reductions in these adverse impacts to the environment. However, poorly designed or managed marinas can pose additional environmental hazards including dissolved oxygen deficiencies; concentration of pollutants from boat maintenance, operation, and repair; transport of runoff from impervious surfaces into coastal waters; and destruction of coastal habitat areas.

Management practices typically used to ensure proper operation and maintenance of marinas and boats include both the development of regular schedules for inspecting, cleaning, and repairing facilities and the implementation of education programs for boaters and marina owners and operators. Examples of O&M procedures and techniques for marinas and recreational boating management measures are presented in Table 8-6.

Table 8-6. Typical Operation and Maintenance Procedures for Marinas and Recreational Boating Management Measures

Management Measure	Management Practice	Typical Operation and Maintenance Procedures
Shoreline Stabilization	Structural practices	• Structures are periodically inspected, and repaired or replaced as necessary.
	Vegetative practices	• Growth is inspected periodically and after major storm events, with replanting as needed.
Decrease Turbidity and Physical Destruction of Shallow-Water Habitat Resulting from Boating Activities	Exclude motorized vessels from areas that contain important shallow-water habitat.	• Condition of signs to advise boaters against damaging habitat is inspected periodically during boating season.
	Establish and enforce no-wake zones to decrease turbidity.	• Location of speed zone signs are reviewed for potential to prevent damage to habitat.
Storm Water Runoff	Treat runoff from hull maintenance areas to remove at least 80 percent of the average annual total suspended solids. Sand filters and wet ponds are among the practice options.	• Practices are inspected frequently and appropriate maintenance is provided.
	Prevent generation of pollutants from hull maintenance areas through use of sanders with vacuum attachments, use of tarpaulins, and other practices.	• Hull maintenance areas are inspected regularly and swept/vacuumed as required.
	Prevent organic compounds from boats from entering coastal waters.	• Boats with inboard engines have oil absorbing materials placed in bilge areas. These materials are examined for replacement at least once per year. Used-pad containers are checked for presence of used pads.

Table 8-6. (Continued)

Management Measure	Management Practice	Typical Operation and Maintenance Procedures
Storm Water Runoff (continued)	Minimize boat cleaners, solvents, and paint from entering the coastal waters.	• In-water hull cleaning and the use of cleaners and solvents on boats in the water are minimized. Water only or phosphate-free detergents are used to clean boats. Use of detergents containing ammonia, sodium hypochlorite, chlorinated solvents, petroleum distillates, or lye is discouraged.
	Institute public education, outreach, and training programs for boaters and marina owners and operators on proper disposal methods.	• Promotional material and instructional signs are used to spread messages. Presentations, workshops, and seminars on pollution prevention are provided at local marinas.
Sewage Facility for New and Expanding Marinas	Pumpout facilities, dump stations for portable stations, and restroom facilities	• Pumpout facilities, dump stations, and restrooms are inspected, serviced, and maintained on a regular schedule. Repairs are made as needed.
		• Dye tablets can be placed in holding tanks to discourage illegal disposal.
Solid Waste from the Operation, Cleaning, Maintenance, and Repair of Boats	Waste disposal facilities for marina customers	• Waste disposal facilities are inspected and maintained routinely.
		• Hazardous waste containers are inspected periodically for leaks.
	Provide facilities for recycling.	• Use of recycling facilities is routinely inspected for appropriate separation of materials.
		• Receipts from pickup of materials are retained for inspection.

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Table 8-6. (Continued)

Management Measure	Management Practice	Typical Operation and Maintenance Procedures
Liquid Material	Marinas should provide appropriate facilities for the storage, transfer, containment, and disposal of liquid by-products from maintenance, repair, and operation of boats.	• Containers are checked to see whether they are clearly marked and available for customer use at all times.
		• Separate containers for waste oil, waste gasoline, used antifreeze (where recycling is available), and other chemicals are provided.
	Encourage recycling.	• Marina educational materials are reviewed for information regarding recycling.
		• Site is inspected for the availability of recycling facilities.

e. Hydromodification

Operation and maintenance procedures for hydromodification management measures typically involve periodic inspection of structures and features (particularly after storm events), clearing of debris not needed for habitat, and repair or replacement of structures and features as required. Examples of procedures to ensure adequate operation and maintenance of management measures during hydromodification are presented in Table 8-7.

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Table 8-7. Typical Operation and Maintenance Procedures for Hydromodification Management Measures

Management Measure	Management Practice	Typical Operation and Maintenance Procedures
Instream and Riparian Habitat Restoration for Channelization and Channel Modification	Use models/methodologies to evaluate the effects of proposed channelization and channel modification projects on habitat.	• Model limitations, applicability, and accuracy and precision are reviewed prior to use. Model inputs are developed and modeling is performed under an approved quality assurance/quality control program.
	Identify and evaluate appropriate BMPs for use in the design of proposed channelization or channel modification projects or in the operation and maintenance program of existing projects.	• BMP systems are developed that include an appropriate mix of streambank protection, levee protection, channel stabilization and flow restrictors, check dam systems, grade control structures, vegetative cover, instream sediment load control, noneroding roadways, setback levees, and flood walls. Cumulative beneficial impacts of the BMPs are evaluated.
Physical and Chemical Characteristics of Surface Waters (Channelization and Channel Modification)	Use models/methodologies to evaluate the effects of proposed channelization and channel modification projects.	• Model limitations, applicability, and accuracy and precision are reviewed prior to use. Model inputs are developed and modeling is performed under an approved quality assurance/quality control program.
	Identify and evaluate appropriate BMPs for use in the design of proposed channelization or channel modification projects or in the operation and maintenance programs of existing projects.	• BMP systems are developed that include an appropriate mix of streambank protection, levee protection, channel stabilization and flow restrictors, check dam systems, grade control structures, vegetative cover, instream sediment load control, noneroding roadways, setback levees, and flood walls. Cumulative beneficial impacts of the BMPs are evaluated.

f. Dams

Examples of typical O&M procedures for ensuring adequate performance of management measures for dams are presented in Table 8-8.

Table 8-8. Typical Operation and Maintenance Procedures for Management Measures for Dams

Management Measure	Management Practice	Typical Operation and Maintenance Procedures
Erosion and Sediment Control During and After Construction	Soil bioengineering, grading and sediment control practices, streambank and streambed erosion controls	• Periodic inspections are performed to determine whether disturbed areas are stabilized. • Features are repaired and replaced as needed. • Grassed waterways are mowed as needed. • Waterways are cleared of debris not needed for habitat. • Fertilizer and lime are applied only as needed.
	Prior to land disturbance, prepare and implement an approved erosion and sediment control plan or similar administrative document.	• Plan is reviewed for inclusion of provisions to preserve existing vegetation where possible and control sediment in runoff from the construction area.
Protection of Surface Water Quality and Instream and Riparian Habitat During Dam Operation	Turbine venting, surface water pumps, high purity oxygen injection, diffused aeration, and/or oxygenation to aerate reservoir waters and releases	• Back-up power supply is provided and periodically tested. • Oxygen tanks are replaced as needed. • Optimal location(s) of aeration or oxygenation are determined based on water quality monitoring.
	Re-regulation weir, small turbines, frequent pulsing, sluice modification, spillway modification to improve oxygen levels in tailwaters	• Site-specific O&M procedures are followed and adjusted as needed. • Debris not needed for habitat are cleared. • Periodic inspections are performed.

Table 8-8. (Continued)

Management Measure	Management Practice	Typical Operation and Maintenance Procedures
Protection of Surface Water Quality and Instream and Riparian Habitat During Dam Operation (continued)	Selective withdrawal	• Release water temperature is monitored to determine effectiveness of selective withdrawal.
	Watershed protection	• Watershed modeling is conducted.
		• Periodic inspections of watershed land use and management practices are performed. Adjustments to control practices are made on a site-specific basis as needed.
	Flow augmentation	• Minimum flows are maintained to support downstream habitat.
		• Gates and channels are cleared of debris not needed for habitat.
	Reduce flow fluctuations	• Flow fluctuations are evaluated and adjusted as needed.
	Fish ladders, screens and barriers to prevent fish from entering water pumps and turbines	• Gates, channels, and weirs are cleared of debris not needed for habitat.
Chemical/Pollutant Control During and After Construction	Spill containment procedures	• An emergency spill containment plan is prepared and evaluated.
		• Periodic inspections are conducted to see whether items necessary for spill containment are on-hand.
	Treatment or detention of concrete washout	• Treatment or detention facilities are periodically inspected and maintained.

g. Shoreline Erosion

In shoreline and streambank areas requiring erosion protection from water flow and wave action, shoreline structures such as breakwaters, jetties, groins, bulkheads, and revetments are often constructed. In addition, nonstructural measures (e.g., marsh creation and vegetative bank stabilization) are often used in protecting shorelines and streambanks from erosive forces. Typical O&M procedures for ensuring adequate performance of these measures against erosion include monitoring for erosion, making structural or nonstructural modifications as needed, performing periodic inspection of the erosion control systems, and performing repair and replacement as required. Table 8-9 presents examples of typical O&M procedures for shoreline erosion management measures.

h. Protection of Existing Wetlands and Riparian Zones

Wetlands provide many beneficial uses including habitat, flood attenuation, water quality improvement, shoreline stabilization, and ground-water recharge. Wetlands can play a critical role in reducing nonpoint source pollution problems in open bodies of water by trapping or transforming pollutants before releasing them to adjacent waters. Their role in water quality includes processing, removing, transforming, and storing such pollutants as sediment, nitrogen, phosphorus, pesticides, and certain heavy metals.

The loss of wetland and riparian areas as buffers between uplands and the parent waterbody allows for more direct contribution of nonpoint source pollutants to the aquatic ecosystem. Often, loss of these areas occurs at the same time as the alteration of land features, which increases the amount of surface water runoff. As a result, excessive fresh water, nutrients, sediments, pesticides, oils, greases, and heavy metals from nearby land use activities may be carried in runoff from storm events and discharged to surface and ground water. Without wetlands these nonpoint source pollutants travel downstream to coastal waters without the benefits of filtration and attenuation that would normally occur in the wetland or riparian area.

Wetland and riparian areas also provide important habitat functions. Protection of wetlands and riparian zones provides both nonpoint source control and other corollary benefits of these natural aquatic systems although adverse impacts on wetlands from nonpoint source pollutants can occur. Such impacts can be minimized through pretreatment with stormwater management practices. Land managers should, therefore, use proper management techniques to protect and restore the multiple benefits of these systems. Examples of typical O&M procedures for ensuring adequate performance of measures to protect existing wetlands and riparian areas are provided in Table 8-10.

i. Restoration of Wetland and Riparian Areas

Restoration of wetlands refers to reestablishing a wetland and its range of functions where one previously existed by reestablishing the hydrology, vegetation, and other habitat characteristics. Restoration of wetlands and riparian areas in the watershed have been shown to result in nonpoint source control benefits.

A combination of practices may be implemented to restore preexisting functions in damaged and destroyed wetlands and riparian systems in areas where they could serve a nonpoint source control function. Examples of typical O&M procedures for ensuring adequate performance of measures to restore wetlands and riparian areas are provided in Table 8-11.

Table 8-8. Typical Operation and Maintenance Procedures for Shoreline Erosion Management Measures

Management Measure	Management Practice	Typical Operation and Maintenance Procedures
Management Measure for Eroding Streambanks (Coastal Rivers and Creeks) and Shorelines (Coastal Bays)	Protect naturally occurring features.	• Changes in natural conditions resulting from installed shoreline structures are regularly evaluated. • Structures and operations are modified as necessary if detrimental changes to naturally occurring features are found.
	Biostabilization and marsh creation to restore habitat	• Vegetation is limed and fertilized only as needed. • Growth is inspected periodically and after major storm events, with replanting as needed.
	Shore revetment or bulkheads	• Structures are periodically inspected and repaired or replaced as needed.
	Minimize or prevent transfer of erosion energy.	• Changes in natural conditions resulting from installed shoreline structures are regularly evaluated. • Structures and operations are modified as necessary if detrimental changes to naturally occurring features are found. • Energy-dissipating structures are inspected and repaired or replaced as needed
	Return walls for bulkheads or revetments	• The structural integrity of tie-backs is periodically inspected. Repairs as needed.
	Minimize erosion from boat wakes.	• Erosion is monitored and boating speed zone designations are revised as needed.

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Table 8-10. Typical Operation and Maintenance Procedures for Management Measure for Protection of Existing Wetlands and Riparian Areas

Management Measure	Management Practice	Typical Operation and Maintenance Procedures
Protect from adverse effects wetlands and riparian areas that are serving a significant NPS abatement function and maintain this function while protecting the other existing functions of these wetlands and riparian areas.	Identify existing functions of those wetlands and riparian areas with NPS control potential when implementing NPS management practices. Do not alter these systems to improve their water quality function at the expense of other functions as U.S. waters.	• Existing functions of wetland are maintained by limiting activities in and around wetland and riparian areas. • Periodic assessments of the wetland are conducted to document any changes in function.
	Conduct permitting, licensing, certification, and nonregulatory NPS activities to protect existing beneficial uses and meet water quality standards.	Not available.

Table 8-11. Typical Operation and Maintenance Procedures for Management Measure for Restoration of Wetlands and Riparian Areas

Management Measure	Management Practice	Typical Operation and Maintenance Procedures
Promote restoration of preexisting functions in damaged and destroyed wetlands and riparian systems in areas where they will serve a significant NPS pollution abatement function.	Provide a hydrologic regime similar to that of the type of wetland or riparian area being restored. Restore native plant species through either natural succession or selective planting.	• The maintenance or restoration of NPS function and beneficial uses is assessed by monitoring such factors as water quality, vegetative cover, and structural changes.
	When possible, plan restoration of wetlands and riparian areas as part of naturally occurring aquatic ecosystems. Factor in ecological principles such as seeking high habitat diversity and high productivity. Maximize connectedness between different habitat types. Provide refuge or migration corridors.	• The effectiveness of restoration is monitored by assessing the ecological health of the community and the habitat use by wildlife species.

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J. Vegetated Treatment Systems

Runoff water quality management methods, referred to as biofiltration methods, have been shown to provide significant reductions in pollutant delivery. These include vegetated filter strips, grassed swales or vegetated channels, and created wetlands. When properly installed and maintained, biofiltration methods have been shown to effectively prevent the entry of sediment and sediment-bound pollutants, nutrients, and oxygen-consuming substances into waterbodies.

A combination of practices can be used to manage vegetated treatment systems. Examples of typical O&M procedures for ensuring adequate performance of these systems are provided in Table 8-12.

Table 8-12. Typical Operation and Maintenance Procedures for Management Measure for Vegetated Treatment Systems

Management Measure	Management Practice	Typical Operation and Maintenance Procedures
Promote the use of engineered vegetated treatment systems such as constructed wetlands or vegetated filter strips where these systems will serve a significant NPS pollution. abatement function.	Construct properly engineered systems of wetlands for NPS pollution control. Manage these systems to avoid negative impacts on surrounding ecosystems or ground water.	• Vegetation is harvested periodically and disposed of properly; forbays and deep water are inspected to determine sediment loading rate; and if sediment levels exceed design limits, excess sediment is removed from the system and disposed of appropriately. Other maintenance includes wildlife management, mosquito control, and litter and debris removal.
	Construct vegetated filter strips in areas adjacent to waterbodies that may be subject to sediment, suspended solids, and/or nutrient runoff.	• Vegetation is mowed periodically and residue harvested; filter strips are inspected periodically to determine whether concentrated flows are bypassing or overwhelming the device; accumulated sediment and particulate matter are removed at regular intervals to prevent inundation; and all traffic is limited.

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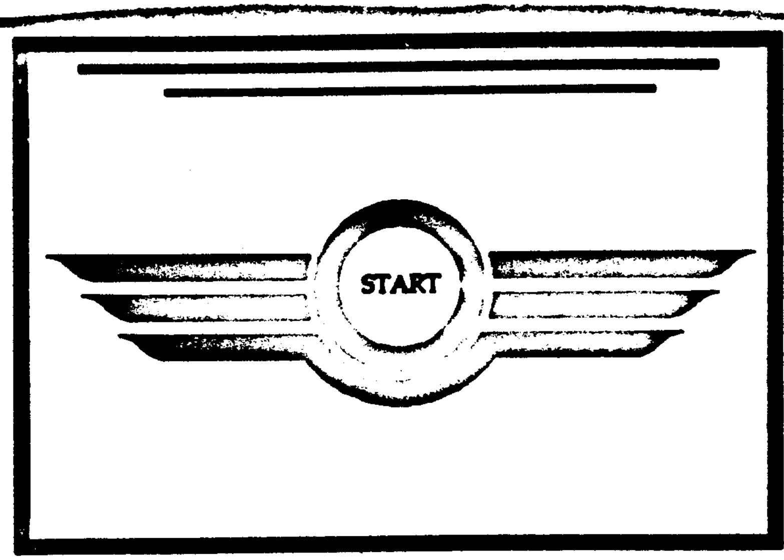

Urban stormwater toxic pollutants: assessment, sources, and treatability

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ABSTRACT: This paper summarizes an investigation to characterize and treat selected stormwater contaminants that are listed as toxic pollutants (termed toxicants in this paper) in the Clean Water Act, Section 307 (Arbuckle *et al.*, 1991). The first project phase investigated typical toxicant concentrations in stormwater, the origins of these toxicants, and storm and land-use factors that influenced these toxicant concentrations. Of the 87 stormwater source area samples analyzed, 9% were considered extremely toxic (using the Microtox® toxicity-screening procedure). Moderate toxicity was exhibited in 32% of the samples, whereas 59% of the samples had no evidence of toxicity. Only a small fraction of the organic toxicants analyzed were frequently detected, with 1,3-dichlorobenzene and fluoranthene the most commonly detected organics investigated (present in 23% of the samples). Vehicle service and parking area runoff samples had many of the highest observed concentrations of organic toxicants. All metallic toxicants analyzed were commonly found in all samples analyzed.

The second project phase investigated the control of stormwater toxicants using a variety of bench-scale conventional treatment processes. Toxicity changes were monitored using the Microtox® bioassay test. The most beneficial treatment tests included settling for at least 24 hours (up to 90% reductions), screening and filtering through at least 40-μm screens (up to 70% reductions), and aeration and/or photodegradation for at least 24 hours (up to 80+% reductions). Because many samples exhibited uneven toxicity reductions for the different treatment tests, a treatment train approach was selected for the current project phase. This current phase includes testing of a prototype treatment device that would be useful for controlling runoff from critical source areas (e.g., automobile service facilities). *Water Environ. Res.*, 67, 260 (1995).

KEYWORDS: metals, organics, sources, stormwater, toxicity, treatability.

Past studies have identified urban runoff as a major contributor to the degradation of many urban streams and rivers (Field and Turkeltaub, 1981; Pitt and Bozeman, 1982; Pitt and Bissonnette 1984; Pitt, 1994, which includes an extensive literature review). Previous studies also found organic and metallic toxicants in urban storm-induced discharges (EPA 1983a; Hoffman *et al.*, 1984; Fram *et al.*, 1987) that can contribute to receiving water degradation.

The Nationwide Urban Runoff Program (NURP) monitored stormwater toxicant discharges from 28 cities and concluded that urban areas were responsible for substantial toxicant discharges (EPA, 1983a). The NURP data were collected mostly from residential areas and did not consider snowmelt. Furthermore, only a few commercial and light industrial areas were represented. The NURP did not identify any significant regional differences in toxicants found or their concentrations. However, other information indicates that industrial stormwater, snowmelt runoff, and dry weather discharges (including illegal discharges into storm drainage) can all contribute significant amounts of toxicants to receiving waters (Pitt and McLean, 1986).

The objective of this research was to further characterize stormwater toxicants, confirm the source areas of concern, and investigate the effectiveness of various conventional treatment processes to control the toxicants. A parallel EPA sponsored research project recently resulted in a user's guide for the investigation of inappropriate discharges into storm drainage systems (Pitt *et al.*, 1993). Clearly, an effective urban runoff control program must consider all seasonal flow phases and sources of critical pollutants. If warm weather stormwater runoff was the only source considered, storm drainage control programs in many areas would be disappointingly deficient. A complete control program must consider snowmelt in northern areas and dry weather flows, in addition to stormwater runoff. The results of the research reported here is only one component of this complete control program approach.

Phase 1: Sources of Stormwater Toxicants

The first project phase included the collection and analysis of 87 urban stormwater runoff samples from a variety of source areas under different rain conditions (Table 1). All of the samples were analyzed in filtered (0.45-μm filter) and nonfiltered forms to enable partitioning of the toxicants into particulate and filterable forms.

Phase 1: analyses and sampling. The samples reported in this paper were all obtained from the Birmingham, Ala., area. Samples were obtained from shallow flows originating from homogeneous source areas by using several manual grab sampling procedures. For deep flows, samples were collected directly into the sample bottles. For shallow flows, a peristaltic hand-operated vacuum pump created a small vacuum in the sample bottle which then gently drew the sample directly into the container through a Teflon® tube. Approximately 1 L of sample was needed, divided into two containers: one 500-mL glass bottle with Teflon®-lined lid was used for the organic and toxicity analyses, and another 500-mL polyethylene bottle was used for the metal and other analyses. Bannerman *et al.* (1993) have recently described a semiautomatic method for collecting source area samples.

An important aspect of the first phase of this research was to evaluate the effects of different land uses and source areas, plus the effects of rain characteristics, on sample toxicant concentrations. Therefore, careful records were obtained of the amount of rain and the rain intensity that occurred before the samples were obtained. Antecedent dry period data were also obtained to compare with the chemical data in a series of statistical tests.

All samples were handled, preserved, and analyzed according to accepted protocols (EPA, 1982 and 1983b). The organic pollutants were analyzed using two gas chromatographs, one with a mass selective detector (GC/MSD) and another with an electron capture detector (GC/ECD). The pesticides were analyzed ac-

Table 1—Numbers of Birmingham, Ala. samples for each area.

Local Source Areas	Residential	Commercial/ institutional	Industrial
Roofs	5	3	4
Parking areas	2	11	3
Storage areas	0	2	6
Streets	1	1	4
Loading docks	0	0	3
Vehicle service area	0	5	0
Landscaped areas	2	2	2
Urban creeks	19		
Detention ponds	12		

cording to EPA method 505, whereas the base neutral compounds were analyzed according to EPA method 625 (but only using 100-mL samples). The pesticides were analyzed on a Perkin Elmer Sigma 300 GC/ECD using a J&W DB-1 capillary column (30 m × 0.32 mm ID with a 1-μm film thickness). The base neutrals were analyzed on a Hewlett Packard 5 890 GC with a 5 970 MSD using a Supelco DB-5 capillary column (30 m × 0.25 mm ID with a 0.2-μm film thickness). Table 2 lists the organic toxicants that were analyzed.

Metallic toxicants, also listed in Table 2, were analyzed using a graphite furnace equipped atomic absorption spectrophotometer. EPA methods 202.2 (Al), 213.2 (cadmium), 218.2 (chromium), 220.2 (copper), 239.2 (lead), 249.2 (nickel), and 289.2 (zinc) were followed in these analyses. A Perkin Elmer 3 030B atomic absorption spectrophotometer was used after nitric acid digestion of the samples. Previous research (Pitt and McLean, 1986; EPA, 1983a) indicated that low-detection limits were necessary to measure the filtered sample concentrations of the metals, which would not be achieved by use of a standard flame atomic absorption spectrophotometer. Low-detection limits would enable partitioning of the metals between the solid and liquid phases to be investigated, an important factor in assessing the fates of the metals in receiving waters and in treatment processes.

The Microtox® 100% sample toxicity screening test by Microbics, Inc. was selected for this research after comparisons with other laboratory bioassay tests. During the first research phase, 20 source area stormwater samples and combined sewer overflow samples were split and sent to four laboratories for analyses using approximately 20 different bioassay tests. Conventional bioassay tests were conducted using freshwater organisms at the EPA's Duluth, Minn., laboratory and using marine organisms at the EPA's Narragansett Bay, R.I., laboratory. In addition, other bacterial tests were also conducted at the Environmental Health Sciences Laboratory at Wright State University, Dayton, Ohio. The Microtox® screening procedure gave similar toxicity rankings for the 20 samples as the conventional bioassay tests. It is also a rapid procedure (requiring approximately 1 hour) and only requires small (approximately 40 mL) sample quantities. The Microtox® toxicity test uses marine bioluminescent bacteria and monitors the light output for different sample concentrations. Approximately one million bacteria organisms are used per sample, resulting in highly repeatable results. The more toxic samples produce greater stress on the bacteria test organisms that results in a greater light attenuation compared with the control sample. It should be emphasized that the Microtox® procedure was not used during this research to determine the absolute toxicities of the samples or to predict the toxic effects of stormwater runoff on receiving waters, but to compare the relative toxicities of different samples that may in-

Table 2—List of selected pollutants analyzed in samples.

Pesticides, DL* = 0.3 μg/L	Phthalate esters, DL = 0.5 μg/L	Polynuclear aromatic hydrocarbons, DL = 0.5 μg/L		Metals, DL = 1 μg/L
BHC (β-Benzene hexachloride)	Bis(2-ethylhexyl) phthalate	Acenaphthene	Fluoranthene	Aluminum
Heptachlor	Butyl benzyl phthalate	Acenaphthylene	Fluorene	Cadmium
Aldrin	Di-n-butyl phthalate	Anthracene	Indeno(1,2,3-cd)pyrene	Chromium
Endosulfan	Diethyl phthalate	Benzo(a)anthracene	Napthalene	Copper
Heptachlor epoxide	Dimethyl phthalate	Benzo(a)pyrene	Phenanthrene	Lead
DDE (dichlorodiphenyl dichloroethylene)	Di-n-octyl phthalate	Benzo(b)fluoranthene	Pyrene	Nickel
DDD (Dichlorodiphenyl dichloroethane)		Benzo(ghi)perylene		Zinc
DDT (Dichlorodiphenyl trichloroethane)		Benzo(k)fluoranthene		
Endrin		Chrysene		
Chlordane		Dibenzo(a,h)anthracene		

* DL, detection limit.

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dicate effective source area treatment locations and to examine changes in toxicity during different treatment procedures.

Phase 1: potential sources. A drainage system captures runoff and pollutants from many source areas, all with individual characteristics influencing the quantity of runoff and pollutant load. Impervious source areas (for example, paved parking lots, streets, driveways, roofs, sidewalks) may contribute most of the runoff during small storm events. Pervious source areas (for example, gardens, bare ground, unpaved parking areas, construction sites, undeveloped areas) can have higher material washoff potentials and become important contributors for larger storm events when their infiltration rate capacity is exceeded. Many other factors also affect the pollutant contributions from source areas, including surface roughness, vegetative cover, gradient, and hydraulic connections to a drainage system; rainfall intensity, duration, and antecedent dry period, and pollutant availability because of direct contamination due to local activities: street cleaning, frequency or efficiency, and natural and regional sources of pollutants. The relative importance of the different source areas is therefore a function of the area characteristics, pollutant washoff potential, and the rainfall characteristics (Pitt 1987).

Important sources of toxicants are often related to the land use (for example high traffic capacity roads, industrial processes, and storage areas, that are unique to specific land uses). Automobile-related sources affect the quality and quantity of road dust particles and pollutant residuals through gasoline and oil drips or spills; deposition of exhaust products; and wear of tire, brake, and pavement materials (Shaheen, 1975). Urban landscaping practices potentially produce vegetation cuttings and fertilizer and pesticide washoff. Miscellaneous sources include holiday firework debris, wildlife, and domestic pet wastes, and possible sanitary wastewater infiltration and illicit connections. In addition, resuspension and deposition of pollutants or particles via the atmosphere can increase or decrease the contribution potential of a source area (Pitt and Bozeman, 1982; Bannerman *et al.* 1993).

Phase 1: results. Table 3 summarizes the source area sample data for the most frequently detected organic toxicants and for all of the metallic toxicants analyzed. The organic toxicants analyzed, but not reported, were generally detected in five or less of the nonfiltered samples and in none of the filtered samples. Table 3 shows the mean, maximum, and minimum concentrations for the detected toxicants. It is important to note that these values are based on the observed concentrations only. They do not consider the nondetectable conditions. Mean values based on total sample numbers for each source area category would therefore result in much lower concentrations. The frequency of detection is an important consideration. High-detection frequencies for the organics may indicate greater potential problems than infrequent high concentrations.

Table 3 also gives the measured pH and suspended solids concentrations. Most pH values were in the range of 7.0 to 8.5 with a low of 4.4 and a high of 11.6 for a roof and concrete plant storage area runoff sample, respectively. This range of pH can have dramatic effects on the speciation of the metals analyzed. The suspended solids concentrations were generally less than 100 mg/L, with impervious area runoff (for example, roofs and parking areas) having much lower suspended solids concentrations and turbidities compared with samples obtained from previous areas (for example, landscaped areas).

Thirteen organic compounds, out of more than 35 targeted compounds analyzed, were detected in more than 10% of all samples, as shown in Table 3. The greatest detection frequencies were for 1,3-dichlorobenzene and fluoranthene which were each detected in 23% of the samples. The organics most frequently found in these source area samples (that is, polycyclic aromatic hydrocarbons (PAHs), especially fluoranthene and pyrene) were similar to the organics most frequently detected at outfalls in prior studies (EPA, 1983a).

Roof runoff, parking area, and vehicle service area samples had the greatest detection frequencies for the organic toxicants. Vehicle service areas and urban creeks had several of the observed maximum organic compound concentrations. Most of the organics were associated with the nonfiltered sample portions, indicating an association with the particulate sample fractions. The compound 1,3-dichlorobenzene was an exception, having a significant dissolved fraction.

In contrast to the organics, the heavy metals analyzed were detected in almost all samples, including the filtered sample portions. The nonfiltered samples generally had much higher concentrations, with the exception of zinc, which was mostly associated with the dissolved sample portion (that is, not associated with the suspended solids). Roof runoff generally had the highest concentrations of zinc, probably from galvanized roof drainage components, as previously reported by Bannerman *et al.* (1983). Parking and storage areas had the highest nickel concentrations, whereas vehicle service areas and street runoff had the highest concentrations of cadmium and lead. Urban creek samples had the highest copper concentrations, which were probably due to illicit connections or nonstormwater discharges.

Table 4 shows that approximately 9% of the nonfiltered samples were considered highly toxic using the Microtox® toxicity-screening procedure. Approximately 32% of the samples were moderately toxic and approximately 59% were considered nontoxic. The greatest percentage of samples considered the most toxic were from industrial storage and parking areas. The Phase 2 study indicated that filtering the samples through a range of fine sieves and finally a 0.45-μm filter consistently reduced sample toxicities. The chemical analyses also generally found much higher toxicant concentrations in the nonfiltered sample portions, compared with the filtered sample portions.

Replicate samples were collected from several source areas at three land uses during four different storm events to statistically examine toxicity and pollutant concentration differences due to storm and site conditions. These data indicated that variations in Microtox® toxicities and organic toxicant concentrations may be better explained by rain characteristics than by differences in sampling locations. As an example, high concentrations of many of the PAHs were more likely associated with long antecedent dry periods and large rains than by any other storm or sampling location parameter.

Phase 2: Laboratory-Scale Toxicant Reduction Tests

Phase 2 examined toxicant treatability for a variety of bench-scale conventional treatment processes. The data from Phase 1 identified the critical source areas (storage or parking and vehicle service areas, which generally had the highest toxicant concentrations) for study during the second research phase.

Phase 2: Analysis and sampling. The objective of the second research phase was to obtain relative measurements of sample toxicity improvements for different stages of each bench-scale treatment method. These data were used to indicate the relative effectiveness of different treatment processes. To meet this objective and resource restraints of cost and time, the Microtox® toxicity-screening test was chosen to indicate relative changes in toxicity.

The efficiency of many pollution control devices is affected by the particle sizes and settling velocity distributions of the pollutants in the wastewater. Therefore, settling column tests were conducted to determine the pollutant-settling velocities. Standard gravimetric solids analyses (EPA, 1983b) were conducted on the settling column samples to calculate the settling velocities and specific gravity. Nephelometric turbidity analyses were also conducted (EPA, 1983b) for all subsamples during the treatability tests.

Samples were collected in the same manner as described in Phase 1, but a larger volume of sample (10 to 20 L) was collected to enable treatability testing from each sampling location.

Phase 2: experimental error. The second phase included intensive analyses of samples from 12 sampling locations in the Birmingham, Ala., area. Table 5 lists the sampling dates, source area categories, and toxicity before treatability testing. These sampled storms represent practically all of the rains that occurred during the field portion of the second project phase (July to November 1990). Independent replicates (obtained during separate analysis runs) were used to determine the measurement errors associated with the Microtox® procedure. The total number of Microtox® analyses that were conducted for all of the treatability tests for each sample are also noted, as are the means, standard deviations, and coefficients of variation (in %) of the replicate toxicity values.

Initial toxicity values (before treatability tests) were plotted on normal probability graphs to indicate their probability distributions. Almost all of the samples had initial toxicity values that were shown to be normally distributed. Therefore, the coefficient of variation (COV = standard deviation/mean) values shown in Table 5 can be used as an indication of the confidence intervals of the Microtox® measurements. The COVs ranged from 2.3% to 9.8%, with an average value of 5.1%. Therefore, the 95% confidence interval (two times the COV values include 95.4% of the data, if normally distributed) for the Microtox® procedure ranged between 5% and 20% of the mean values. These confidence intervals are quite narrow for a bioassay test and indicate the good repeatability of the Microtox® procedure. In all cases, statistical tests were performed on the test results to indicate the significance of the different treatability tests.

Table 5 also shows that samples B and D were initially extremely toxic, whereas the remainder of the samples were moderately toxic. All samples were reduced to nontoxic levels after various treatment processes and degrees of treatment.

Phase 2: treatability tests. The selected source area runoff samples all had elevated toxicant concentrations, compared with other urban source areas, allowing a wide range of laboratory partitioning and treatability analyses to be conducted. The treatability tests conducted were:

- settling column (37 mm × 0.8 m Teflon® column),
- flotation (series of eight glass narrow neck 100-mL volumetric flasks),
- screening and filtering (series of 11 stainless steel sieves from 20 to 106 μm and a 0.45-μm membrane filter),
- photodegradation (2-L glass beaker with a 60-W broadband, incandescent light placed 25 cm above the water, stirred with a magnetic stirrer with water temperature and evaporation rate also monitored),
- aeration (the same beaker arrangement as earlier, without the light, but with filtered compressed air keeping the test solution supersaturated and well mixed),
- photodegradation and aeration combined (the same beaker arrangement as earlier, with compressed air, light, and stirrer),
- undisturbed control sample (a sealed and covered glass jar at room temperature).

Because of the difficulty of obtaining large sample volumes from many of the source areas that were to be examined, these bench-scale tests were all designed to use small sample volumes (approximately 1 L per test). Each test (except for filtration, which was an instantaneous test) was conducted over a 3-day period. Subsamples (40 mL) were obtained for toxicity analyses at 0, 1, 2, 3, 6, 12, 24, 48, and 72 hours. In addition, settling column samples were also obtained several times within the first hour at 1, 3, 5, 10, 15, 25, and 40 minutes.

Phase 2: results. The Microtox® procedure allowed toxicity screening tests to be conducted on each sample partition during the treatment tests. This procedure enabled more than 900 toxicity tests to be made. Turbidity tests were also conducted on all samples.

Figures 1 through 24 are graphic data plots of the toxicity reductions observed during each treatment procedure examined, including the control measurements. These samples are plots of the percentage reductions in toxicity, as indicated using the Microtox® toxicity-screening test, for different levels of treatment compared with initial sample toxicity levels. These are therefore relative changes and are used to indicate the improvements possible using different levels of the different unit treatment processes. Figures 1 through 8 contain the treatment responses for samples from industrial loading and parking areas (samples D, F, G, I, J, and K). Figures 9 through 16 are for the samples from automobile service facilities (samples B, C, E, and H), and Figures 17 through 24 are for samples from automobile salvage yards (samples L and M). Even though the data are separated into these three sampling area groups, very few consistent differences are noted in the way the different samples responded to various treatments. As expected, there are greater apparent differences between the treatment methods than between the sample groupings. Some treatment processes had a much greater effect in reducing toxicities than others. For example, Figures 4, 12, and 20 show dramatic reductions in sample toxicities when the samples are filtered through finer sieves, implying that much of the toxicity, as measured using the Microtox® test, was associated with particulate matter in the samples. Other particulate removal procedures, such as the sedimentation column tests shown in Figures 2, 10, and 18, also indicated reduced sample toxicities because more of the particulates are removed from most samples. Other treatment methods, such as the flotation tests, indicated less consistent benefits.

Table 6 summarizes results from the nonparametric Wilcoxon signed rank test (using SYSTAT: The System for Statistics, Version 5, SYSTAT, Inc., Evanston, Ill.) for different treatment combinations. This statistical test indicates the two-sided probabilities that the sample groups are the same. A probability of 0.05 or less is used to indicate significant differences in the data sets. As an example, Table 6 indicates that there were significant differences (probabilities of 0.02) for all of the treatment tests

Table 3—Stormwater toxicants detected in at least 10% of the source area sheetflow samples (μg/L, unless otherwise noted).

	Roof areas		Parking areas		Storage areas		Street runoff		Loading docks		Vehicle service areas		Landscaped areas		Urban creeks		Detention ponds	
	N.F.[a]	F.[b]	N.F.	F.	N.F.	F.	N.F.	F.	N.F.	F.	N.F.	F.	N.F.	F.	N.F.	F.	N.F.	F.
Total samples	12	12	16	16	8	8	6	6	3	3	5	5	6	6	19	19	12	12
Base neutrals (detection limit = 0.5 μg/L)																		
1,3 Dichlorobenzene detection frequency = 20% N.F. and 13% F.																		
No. detected[c]	3	2	3	2	1	1	1	1			3	2	3	2	2	0	1	1
Mean[d]	52	20	34	13	16	14	5.4	3.3			46	26	29	5.6	93		27	21
Max.	88	23	103	26							72	47	54	7.5	120			
Min.	14	17	3.0	2.0							6.0	4.9	4.5	3.8	65			
Fluoranthene detection frequency = 20% N.F. and 12% F.																		
No. detected	3	2	3	2	1	0	1	1			3	2	3	2	1	0	2	1
Mean	23	9.3	37	2.7	4.5		0.6	0.5			39	3.6	13	1.0	130		10	6.6
Max.	45	14	110	5.4							53	6.8	38	1.3			14	
Min.	7.6	4.8	3.0	2.0							0.4	0.4	0.7	0.7			6.6	
Pyrene detection frequency = 17% N.F. and 7% F.																		
No. detected	1	0	3	2	1	0	1	1			3	2	2	0	1	0	2	1
Mean	28		40	9.8	8		1.0	0.7			44	4.1	5.3		100		31	5.8
Max.			120	20							51	7.4	8.2				57	
Min.			3.0	2.0							0.7	0.7	2.3				6.0	
Benzo(b)fluoranthene detection frequency = 15% N.F. and 0% F.																		
No. detected	4	0	3	0	0	0	1	0			2	0	1	0	2	0	0	0
Mean	76		53				14				98		30		38			
Max.	260		160								110				64			
Min.	6.4		3.0								80				8.0			
Benzo(k)fluoranthene detection frequency = 11% N.F. and 0% F.																		
No. deteted	0	0	3	0	0	0	1	0			2	0	1	0	2	0	0	0
Mean			20				15				59		61		55			
Max.			1								103				78			
Min.			3.0								15				31			
Benzo(a)pyrene detection frequency = 15% N.F. and 0% F.																		
No. detected	4	0	3	0	0	0	1	0			2	0	1	0	2	0	0	0
Mean	99		40				19				90		54		73			
Max.	300		120								120				130			
Min.	34		3.0								60				19			
Bis(2-chloroethyl) ether detection frequency = 12% N.F. and 2% F.																		
No. detected	3	1	2	0	0	0	1	0			1	1	1	0	1	0	1	0
Mean	42	17	20				15				45	23	56		200		15	
Max.	87	2	39															
Min.	20		2.0															
Bis(chloroisopropyl) ether detection frequency = 13% N.F. and 0% F.																		
No. detected	3	0	3	0	0	0	0	0			2	0	1	0	2	0	0	0
Mean	99		130								120		85		59			
Max.	150		400								160				78			
Min.	68		3.0								74				40			
Naphthalene detection frequency = 11% N.F. and 6% F.																		
No. detected	2	0	1	1	0	0	0	0			2	1	1	0	1	1	2	2
Mean	17		72	6.6							70	82	49		300	6.7	43	12
Max.	21										100						68	17
Min.	13										37						18	6.6
Benzo(a)anthracene detection frequency = 10% N.F. and 0% F.																		
No. detected	1	0	3	0	0	0	0	0			2	0	1	0	1	0	0	0
Mean	16		24								35		54		61			
Max.			73								39							
Min.			3.0								31							
Butylbenzyl phthalate detection frequency = 10% N.F. and 4% F.																		
No. detected	1	0	2	1	0	0	0	0			2	2	1	0	1	0	1	0
Mean	100		12	3.3							26	9.8	130		59		13	
Max.			21								46	16						
Min.			3.3								3.8	3.8						

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Table 3—(Continued)

	Roof areas N.F.[a]	Roof areas F.[b]	Parking areas N.F.	Parking areas F.	Storage areas N.F.	Storage areas F.	Street runoff N.F.	Street runoff F.	Loading docks N.F.	Loading docks F.	Vehicle service areas N.F.	Vehicle service areas F.	Landscaped areas N.F.	Landscaped areas F.	Urban creeks N.F.	Urban creeks F.	Detention ponds N.F.	Detention ponds F.
Total samples	12	12	16	16	8	8	6	6	3	3	5	5	6	6	19	19	12	12
Pesticides (detection limit = 0.3 µg/L)																		
Chlordane detection frequency = 11% N.F. and 0% F.																		
No. detected	2	0	2	0	3	0	1	0			1	0	0	0	0	0	0	0
Mean	1.6		1.0		1.7		0.8				0.8							
Max	2.2		1.2		2.9													
Min	0.9		0.8		1.0													
Metals (detection limit = 1 µg/L)																		
Lead detection frequency = 100% N.F. and 54% F.																		
No. detected[c]	12	1	16	8	8	7	6	4	3	1	5	2	6	1	19	15	12	8
Mean[d]	41	1.1	46	2.1	105	2.6	43	2.0	55	2.3	63	2.4	24	1.7	20	1.4	19	10
Max.	170		130	5.2	330	5.7	150	3.9	80		110	3.4	70		100	1.6	56	10
Min	1.3		1.0	1.2	3.6	1.6	1.5	1.1	25		27	1.4	1.4		1.4	<1	1	<1
Zinc detection frequency = 99% N.F. and 98% F.																		
No. detected	12	12	16	16	8	7	6	6	2	2	5	5	6	8	19	19	12	12
Mean	250	220	110	86	1 730	22	68	31	56	33	105	73	230	140	10	10	13	14
Max.	1 580	1 550	650	560	13 100	100	130	76	79	62	230	230	1 160	670	32	23	25	25
Min	11	9	12	6	12	3.0	4.0	4.0	31	4.0	30	11	18	18	<1	<1	<1	<1
Copper detection frequency = 98% N.F. and 78% F.																		
No. detected	11	7	15	13	8	6	6	5	3	2	5	4	6	6	19	17	12	8
Mean	110	2.9	116	11	290	250	280	3.8	22	8.7	135	8.4	81	4.2	50	1.4	43	20
Max	900	6.7	770	61	1 830	1 520	1 250	11	30	15	580	24	300	6.8	440	1.7	210	35
Min	1.5	1.1	10	1.1	10	1.0	10	1.0	15	2.6	1.5	1.1	1.9	0.9	<1	<1	0.2	<1
Aluminum detection frequency = 97% N.F. and 92% F.																		
No. detected	12	12	15	15	7	6	6	6	3	1	5	4	5	5	19	19	12	12
Mean	6 860	230	3 210	430	2 320	180	3 080	860	780	18	700	170	2 310	1 210	620	190	700	210
Max.	71 300	1 560	6 480	2 890	6 990	740	10 040	4 380	930		1 370	410	4 610	1 880	3 250	500	1 570	360
Min.	25	6.4	130	5.0	180	10	70	18	590		93	0.3	180	120	<5	<5	<5	<5
Cadmium detection frequency = 95% N.F. and 69% F.																		
No. detected	11	7	15	9	8	7	8	5	3	3	5	3	4	2	19	15	12	9
Mean	3.4	0.4	6.3	0.8	5.9	2.1	37	0.3	1.4	0.4	9.2	0.3	0.5	0.6	8.3	0.2	2	0.5
Max.	30	0.7	70	1.8	17	10	220	0.8	2.4	0.8	30	0.5	1	1	30	0.3	11	0.7
Min	0.2	0.1	0.1	0.1	0.9	0.3	0.4	0.1	0.7	0.3	1.7	0.2	0.1	0.1	<0.1	<0.1	0.1	0.4
Chromium detection frequency = 91% N.F. and 55% F.																		
No. detected	7	2	15	8	8	5	5	4	3	0	5	1	6	5	19	15	11	8
Mean	85	1.8	56	2.3	75	11	9.9	1.8	17		74	2.5	79	2.0	62	1.8	37	2.0
Max.	510	2.3	310	6.0	340	32	30	2.7	40		320		250	4.1	710	4.3	230	3.0
Min.	5.0	1.4	2.4	1.1	3.7	1.1	2.8	1.3	2.4		2.4		2.2	1.4	<0.1	<0.1	<0.1	<0.1
Nickle detection frequency = 90% N.F. and 37% F.																		
No. detected	10	0	14	4	8	1	5	0	3	1	5	1	4	1	18	16	11	8
Mean	16		45	5.1	55	87	17		6.7	1.3	42	31	53	2.1	29	2.3	24	3.0
Max.	70		130	13	170		70		8.1		70		130		74	3.6	70	6.0
Min	2.6		4.2	1.6	1.9		1.2		4.2		7.9		21		<1	<1	1.5	<1
Other constituents																		
pH																		
Mean	6.9		7.3		8.5		7.6		7.8		7.2		6.7		7.7		8.0	
Max.	8.4		8.7		12		8.4		8.3		8.1		7.2		8.6		9.0	
Min	4.4		5.8		6.5		6.9		7.1		5.3		6.2		6.9		7.0	
Suspended solids																		
Mean	14		110		100		49		40		24		33		26		17	
Max.	92		750		450		110		47		38		81		140		60	
Min.	0.5		9.0		5.0		7.0		34		17		8.0		5.0		3.0	

[a] N.F., nonfiltered sample.
[b] F., filtered sample.
[c] Number detected refers to the number of samples in which the toxicant was detected.
[d] Mean values based only on the number of samples with a definite concentration of toxicant reported (not on the total number of samples analyzed).

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Table 4—Relative toxicities of samples using microtox[a]

Local source areas	Highly toxic, %	Moderately toxic, %	Not toxic, %	No. of samples
Roofs	8	58	33	12
Parking areas	19	31	50	16
Storage areas	25	50	25	8
Streets	0	67	33	6
Loading docks	0	67	33	3
Vehicle service areas	0	40	60	5
Landscaped areas	17	17	66	6
Urban creeks	0	11	89	19
Detention ponds	8	8	84	12
All source areas	9	32	59	87

[a] Microbics suggested toxicity definitions for 35-minute exposures: highly toxic—light decrease > 60%, moderately toxic—light decrease <60% and >20%, not toxic—light decrease <20%.

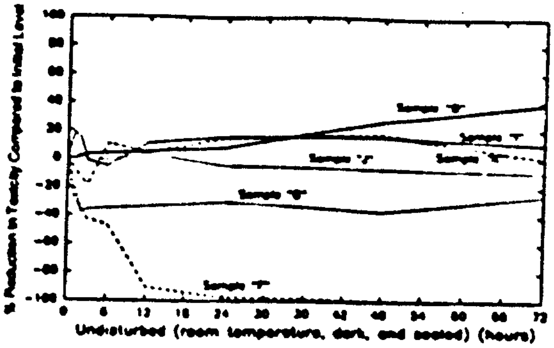

Figure 1—Toxicity changes for control samples.

done on sample D, compared with the undisturbed control sample.

The aeration test provided the most samples that had significant probabilities of being different from the control condition. Settling, photodegradation, and aeration and photodegradation combined were similar in providing the next greatest number of samples that had significant probabilities of being different from the control condition. The flotation test had many samples that had significant differences in toxicity between the top floating layer and the control sample. However, the more important contrast between the middle sample layers (below the top floating layer) and the control sample, which would indicate a reduction in toxicity of posttreated water, had very few samples that were significantly different from the control sample.

The absolute magnitudes of toxicity reductions must also be considered. As an example, it may be significant, but unimportant, if a treatment test provided many (and therefore consistent) samples having statistically significant differences compared with the control sample, if the actual toxicity reductions were very small.

As shown in Figures 1 to 24, important reductions in toxicities were found during many of the treatment tests. The highest toxicant reductions were obtained by settling for at least 24 hours (providing at least 50% reductions for all but two samples), screening through at least a 40-μm screen (20% to 70% reductions), and aeration and/or photodegradation for at least 24 hours (up to 80% reductions). Increased settling, aeration, or photodegradation times and screening through finer meshes all reduced sample toxicities further. The flotation tests produced floating sample layers that generally increased in toxicity with time and lower sample layers that generally decreased in toxicity with time, as expected; however, the benefits were quite small (less than 30% reduction). As shown in Table 6, approximately only 40% of the flotation test toxicity changes were statistically different from the variations found in the control samples.

Table 5—Phase 2 sample descriptions.

Sample source	Date	Initial[a] toxicity, %	No. of analyses	Standard[b] deviation	Coefficient[b] of variation, %
Automobile service area samples					
B	7/10/90	78	28	7.6	9.8
C	7/21/90	34	42	2.9	8.5
E	8/19/90	43	74	1.3	3.0
H	10/17/90	50	88	1.5	3.0
Industrial loading and parking area samples					
D	8/2/90	67	74	2.1	3.1
F	9/12/90	31	88	1.5	4.9
G	10/3/90	53	88	3.0	5.7
I	10/24/90	56	89	1.9	3.4
J	11/5/90	49	89	1.1	2.3
K	11/9/90	28	89	2.2	8.1
Automobile salvage yard samples					
L	11/28/90	26	89	1.4	5.5
M	12/3/90	54	89	1.8	3.4

[a] Toxicity measured as percent light reduction after 35-minute exposure.
[b] Applies to replicate samples only.

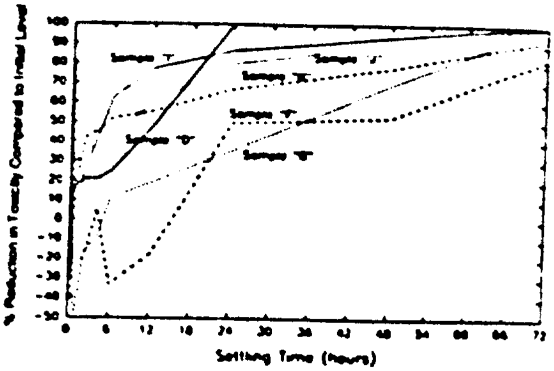

Figure 2—Toxicity reduction from settling treatment of samples from industrial loading and parking areas.

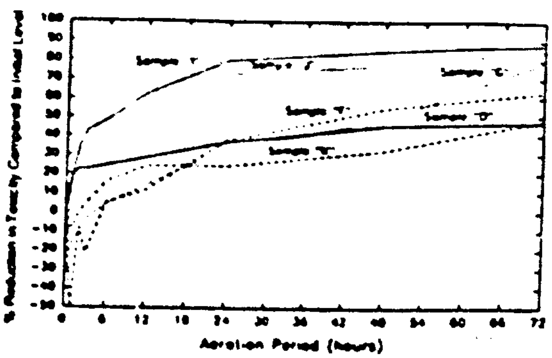

Figure 3—Toxicity reduction from aeration treatment of samples from industrial loading and parking areas.

These tests indicate the wide ranging behavior of these related samples for the different treatment tests. Some samples responded poorly to some tests, whereas other samples responded well to all of the treatment tests. Any practical application of these treatment unit processes would therefore require a treatment train approach, subjecting critical source area runoff to a combination of processes to obtain relatively consistent overall toxicant removal benefits.

Current Phase: Large-Scale Demonstrations of Prototype Critical Source Area Treatment Device

The current research phase includes a large scale test of the most promising treatment processes suitable for small critical source areas. Prototype treatment devices are being installed at a public works garage in Stafford Township, N.J., and in a large parking lot and vehicle maintenance area in Birmingham, Ala., for detailed evaluations. These devices consist of a series of chambers, including an initial grit and aeration chamber, an intermediate tube settler with oil sorbents, and a final mixed sand-peat filter. The design of the device is dependent on the drainage area and its character. Testing is examining various treatment volumes, process combinations, and times. Other source area treatment devices being tested in Stafford include modifications to drainage system inlets. Extensive testing of PAHs, phthalate esters, phenols, pesticides, metals, toxicity screening, chemical oxygen demand, pH, conductivity, turbidity, hardness, sodium adsorption ratio, major ions, particle sizes, solids, and nutrients are being performed on paired filtered and unfiltered samples during 12 rains at the inlets and outlets of these devices.

Future project phases will examine soil, vadose (unsaturated) zone, and groundwater impacts at a long-term stormwater infiltration location. This information will be used to determine needed pretreatment of critical source area runoff before infiltration. An EPA research report was recently published during the current project phase (Pitt *et al.*, 1994) that discusses groundwater impacts associated with intentional and nonintentional stormwater infiltration.

Discussion

The main purpose of treating stormwater is to reduce its adverse impacts on beneficial uses of receiving water. Therefore, it is important in any urban stormwater runoff study to assess the detrimental effects the runoff is actually having on a receiving water. Part of this project involved a literature review to gain a further understanding of the transport, fate, and impacts of pollutants on receiving waters and is briefly summarized here.

In general, previous monitoring of urban stormwater runoff has indicated that the biological beneficial uses of urban receiving waters are most likely affected by habitat destruction and long-term pollutant exposures (especially via contaminated sediment).

Table 6—Two-sided probabilities comparing different treatment tests for industrial loading, parking area, and automobile salvage yard samples.

	Automobile service area				Industrial loading and parking area						Auto salvage	
	B	C	E	H	D	F	G	I	J	K	L	M
Undisturbed versus												
Settling	n/a[a]	0.25	0.02	0.41	0.02	0.12	0.09	0.07	0.01	0.01	0.02	0.02
Aeration	n/a	0.31	0.25	0.07	0.02	0.05	0.06	0.04	0.01	0.01	0.02	0.03
Photodegradation	n/a	0.12	0.06	0.16	0.02	0.04	0.03	0.07	0.01	0.01	0.02	0.16
Aeration and photodegradation	n/a	0.35	0.24	0.06	0.02	0.05	0.03	0.09	0.01	0.01	0.02	0.09
Flotation-top layer	n/a	n/a	0.74	0.02	0.02	0.05	0.13	0.01	0.03	0.21	0.01	0.09
Flotation-middle layer	n/a	n/a	0.31	0.87	0.02	0.78	0.02	0.26	0.16	0.17	0.59	0.89

[a] n/a, not applicable

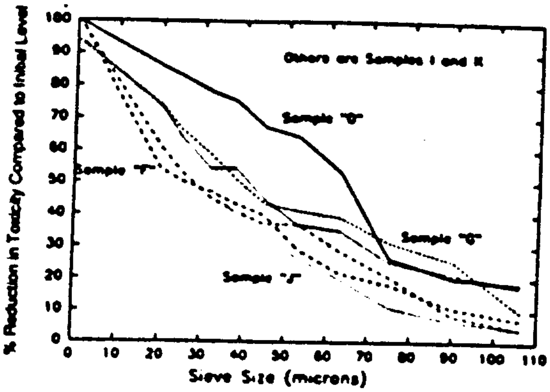

Figure 4—Toxicity reduction from sieve treatment of samples from industrial loading and parking areas.

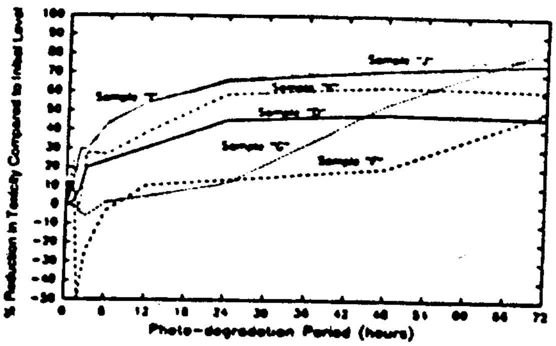

Figure 5—Toxicity reduction from photodegradation of samples from industrial loading and parking areas.

whereas effects associated from acute exposures of toxicants in the water column are rare (Field and Pitt, 1990; Pitt, in press). Receiving water pollutant concentrations resulting from runoff events and typical laboratory bioassay test results have not indicated many significant short-term receiving water problems. As an example, Lee and Jones-Lee (1993) state that exceedences of numeric criteria by short-term discharges does not necessarily imply that a beneficial use impairment exists. However, acute toxicity problems associated with short-term exposures to high toxicant concentrations in stormwater are being reported from careful current studies (Roger Bannerman, Wisconsin Department of Natural Resources, Madison, Wis., personal communication; Allan Burton, Environmental Health Sciences program, Wright State University, Dayton, Ohio, personal communication). A number of comprehensive and long-term studies of biological beneficial uses in areas not affected by conventional point source discharges have typically shown impairments caused by urban runoff. The following paragraphs briefly describe a variety of such studies.

Klein (1979) studied 27 small watersheds having similar physical characteristics, but having varying land uses, in the Piedmont region of Maryland. During an initial phase of the study, they found definite relationships between water quality and land use. Subsequent study phases examined aquatic life relationships in the watersheds. The principal finding was that stream aquatic life problems were first identified with watersheds having imperviousness areas comprising at least 12% of the watershed. Severe problems were noted after the imperviousness quantities reached 30%.

Receiving water impact studies were also conducted in North Carolina (Lenet *et al*., 1979; Lenet and Eagleson, 1981; Lenet *et al*., 1981). The benthic fauna occurred mainly on rocks. As sedimentation increased, the amount of exposed rocks decreased, with a decreasing density of benthic macroinvertebrates. Data from 1978 and 1979 in five cities showed that urban streams were grossly polluted by a combination of toxicants and sediment. Chemical analyses, without biological analyses, would have underestimated the severity of the problems because the water column quality varied rapidly, whereas the major problems were associated with sediment quality and effects on macroinvertebrates. Macroinvertebrate diversities were severely reduced in the urban streams, compared with the control streams. The biotic indexes indicated very poor conditions for all urban streams. Occasionally, high populations of pollutant tolerant organisms were found in the urban streams but would abruptly disappear before subsequent sampling efforts. This was probably

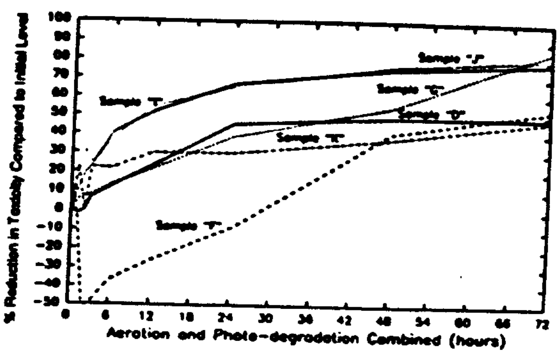

Figure 6—Toxicity reduction from aeration and photodegradation of samples from industrial loading and parking areas.

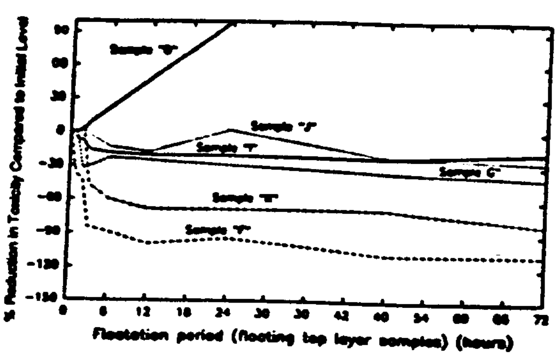

Figure 7—Toxicity reduction from flotation treatment (top layer samples) of samples from industrial loading and parking areas.

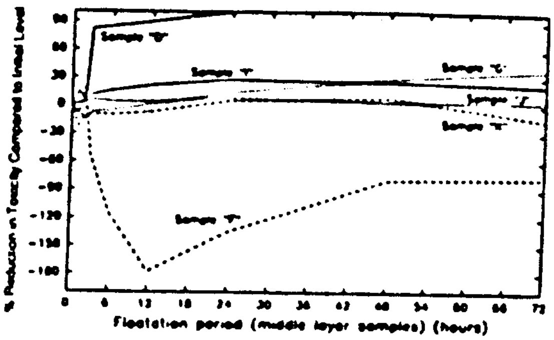

Figure 8—Toxicity reduction from flotation treatment (middle layer samples) of samples from industrial loading and parking areas.

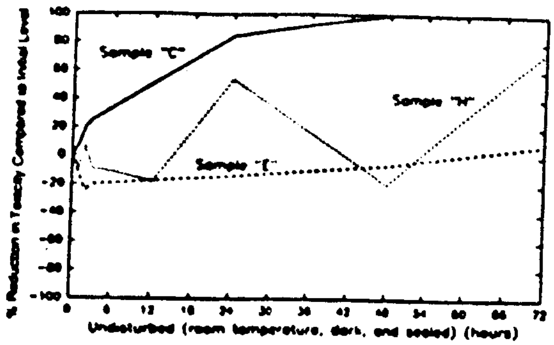

Figure 9—Toxicity changes for control samples from automobile service facilities.

caused by intermittent discharges of spills or illegal dumpings of toxicants. Although the cities studied were located in different geographic areas of North Carolina, the results were remarkably uniform.

During the Coyote Creek, San Jose, Calif., receiving water study, 41 stations were sampled in both urban and nonurban perennial flow stretches of the creek over 3 years. Short- and long-term sampling techniques were used to evaluate the effects of urban runoff on water quality, sediment properties, fish, macroinvertebrates, attached algae, and rooted aquatic vegetation (Pitt and Bozeman, 1982). These investigations found distinct differences in the taxonomic composition and relative abundance of the aquatic biota present. The nonurban sections of the creek supported a comparatively diverse assemblage of aquatic organisms including an abundance of native fishes and numerous benthic macroinvertebrate taxa. In contrast, however, the urban portions of the creek, affected only by urban runoff discharges, comprised an aquatic community generally lacking in diversity and was dominated by pollution-tolerant organisms such as mosquito fish and tubificid worms.

A major nonpoint runoff receiving water impact research program was conducted in Georgia (Cook *et al.*, 1983). Several groups of researchers examined streams in major areas of the state. Benke *et al* (1981) studied 21 stream ecosystems near Atlanta having watersheds of 1 to 3 square miles each and land uses ranging from 0% to 98% urbanization. They measured stream water quality but found little relationship between water quality and degree of urbanization. The water-quality parameters also did not identify a major degree of pollution. In contrast, there were major correlations between urbanization and the number of species found. They had problems applying diversity indexes to their study because the individual organisms varied greatly in size (biomass). The CTA (1983) also examined receiving water aquatic biota impacts associated with urban runoff sources in Georgia. They studied habitat composition, water quality, macroinvertebrates, periphyton, fish, and toxicant concentrations in the water, sediment, and fish. They found that the impacts of land use were the greatest in the urban basins. Beneficial uses were impaired or denied in all three urban basins studied. Fish were absent in two of the basins and severely restricted in the third. The native macroinvertebrates were replaced with pollution-tolerant organisms. The periphytons in the urban streams were very different from those found in the control streams and were dominated by species known to create taste and odor problems.

Pratt *et al.* (1981) used basket artificial substrates to compare benthic population trends along urban and nonurban areas of

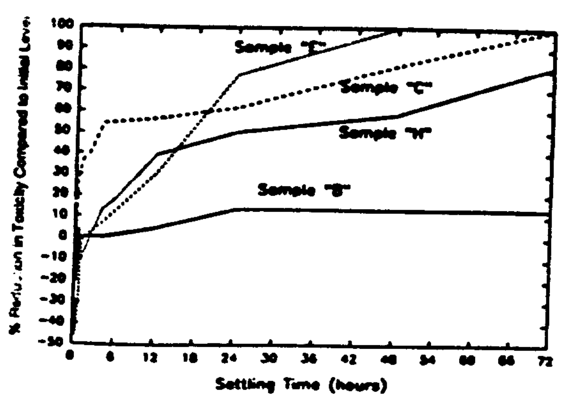

Figure 10—Toxicity reduction from settling of samples from automobile service facilities.

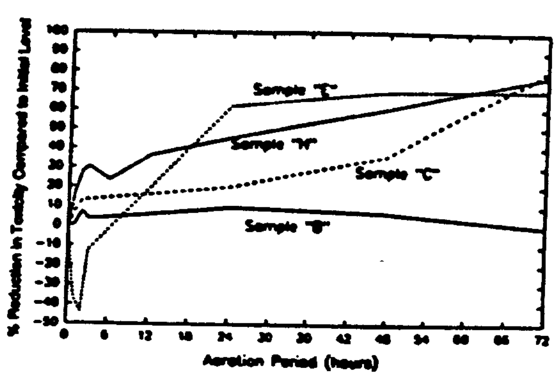

Figure 11—Toxicity reduction from aeration of samples from automobile service facilities.

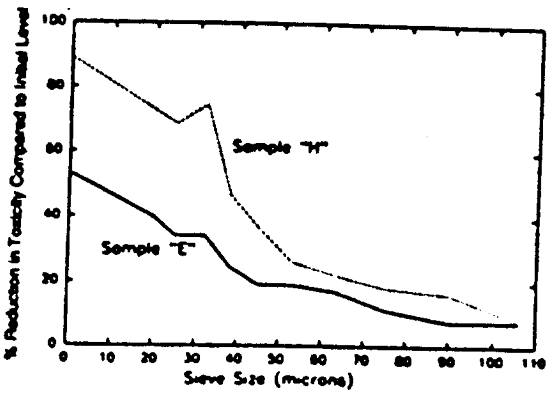

Figure 12—Toxicity reduction from sieve treatment of samples from automobile service facilities.

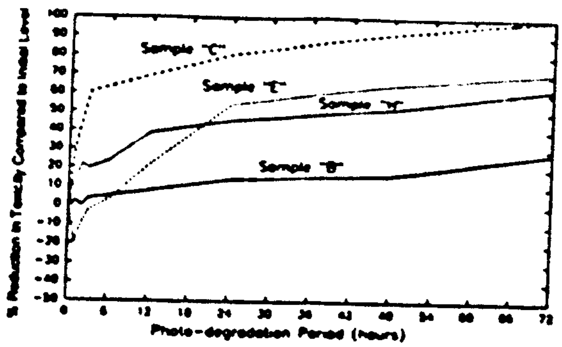

Figure 13—Toxicity reduction from photodegradation of samples from automobile service facilities.

the Green River (Mass.). The benthic community became increasingly disrupted as urbanization increased. The problems were not only associated with times of heavy rain but seemed to be affected at all times. The stress was greatest during summer low-flow periods and was probably localized near the stream bed. They concluded that the high degree of correspondence between the known sources of urban runoff and the observed effects on the benthic community was a forceful argument that urban runoff was the causal agent of the disruption observed.

Cedar swamps in the New Jersey Pine Barrens were studied by Ehrenfeld and Schneider (1983). They examined 19 wetlands subjected to varying amounts of urbanization. Typical plant species were lost and replaced by weeds and exotic plants in urban runoff affected wetlands. Increased uptakes of phosphorus and lead in the plants were found. It was concluded that the presence of stormwater runoff to the cedar swamps caused marked changes in community structure, vegetation dynamics, and plant tissue element concentrations.

Medeiros and Coler (1982) and Medeiros *et al.* (1984) used a combination of laboratory and field studies to investigate the effects of urban runoff on fathead minnows. Hatchability, survival, and growth were assessed in the laboratory in flow through and static bioassay tests. Growth was reduced to one-half of the control growth rates at 60% dilutions of urban runoff. The observed effects were believed to be associated with a combination of toxicants.

The University of Washington (Pedersen, 1981; Richey *et al.*, 1981; Perkins, 1982; Richey, 1982; Scott *et al.*, 1982; Ebbert *et al.*, 1983; Pitt and Bissonnette, 1984; Prych and Ebbert, undated) conducted a series of studies to contrast the biological and chemical conditions in urban Kelsey Creek with rural Bear Creek in Bellevue, Wash. The urban creek was significantly degraded when compared with the rural creek but still supported a productive, but limited and unhealthy salmonid fishery. Many of the fish in the urban creek, however, had respiratory anomalies. The urban creek was not grossly polluted, but flooding from urban developments had increased dramatically in recent years. These increased flows dramatically changed the urban stream's channel by causing unstable conditions with increased stream bed movement and by altering the availability of food for the aquatic organisms. The aquatic organisms were very dependent on the few relatively undisturbed reaches. Dissolved oxygen concentrations in the sediments depressed embryo salmon survival in the urban creek. Various organic and metallic priority pollutants were discharged to the urban creek, but most of them were apparently carried through the creek system by the high storm flows to Lake Washington. The urbanized Kelsey Creek also had higher water temperatures (probably because of reduced

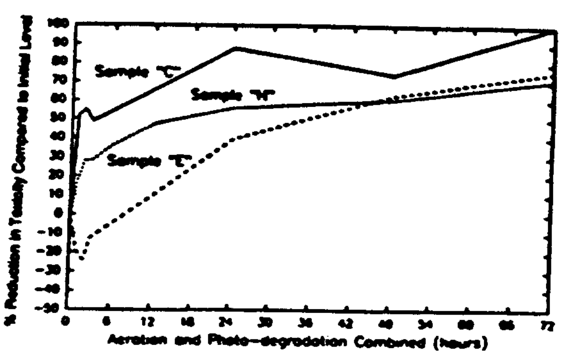

Figure 14—Toxicity reduction from aeration and photodegradation of samples from automobile service facilities.

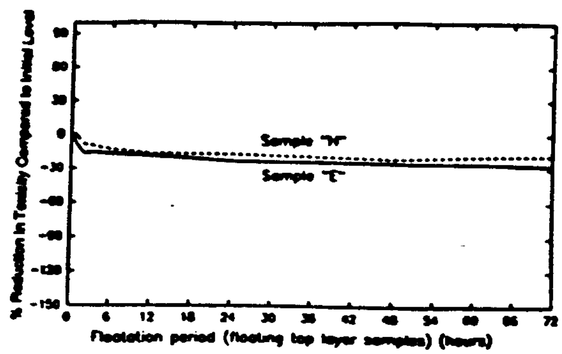

Figure 15—Toxicity reduction from flotation (top layer samples) of samples from automobile service facilities.

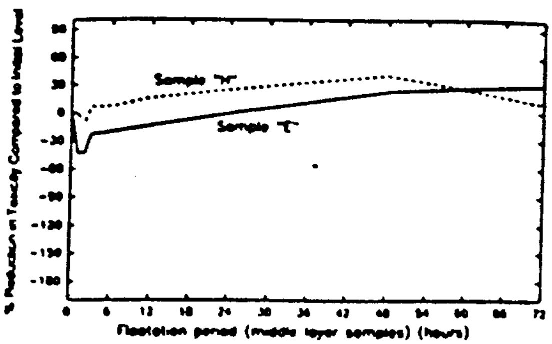

Figure 16—Toxicity reduction from flotation (middle layer samples) of samples from automobile service facilities.

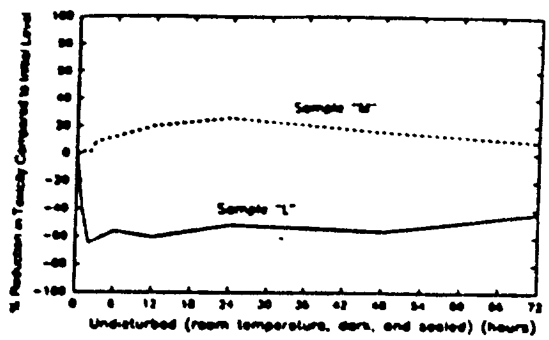

Figure 17—Toxicity changes for control samples from automobile service facilities.

shading) than Bear Creek. This probably caused the faster fish growth in Kelsey Creek.

The fish population in the urbanized Kelsey Creek had adapted to its degrading environment by shifting the species composition from coho salmon to less sensitive cutthroat trout and by making extensive use of less disturbed refuge areas. Studies of damaged gills found that up to three-fourths of the fish in Kelsey Creek were affected with respiratory anomalies, whereas no cutthroat trout and only two of the coho salmon sampled in the forested Bear Creek had damaged gills. Massive fish kills in Kelsey Creek and its tributaries were also observed on several occasions during the project because of the dumping of toxic materials down the storm drains.

There were also significant differences in the numbers and types of benthic organisms found in urban and forested creeks during the Bellevue research. Mayflies, stoneflies, caddisflies, and beetles were rarely observed in the urban Kelsey Creek but were quite abundant in the forested Bear Creek. These organisms are commonly regarded as sensitive indicators of environmental degradation. One example of degraded conditions in Kelsey Creek was shown by a species of clams (*Unionidae*) that was not found in Kelsey Creek but was commonly found in Bear Creek. These clams are very sensitive to heavy siltation and unstable sediments. Empty clam shells, however, were found buried in the Kelsey Creek sediments, indicating their previous presence in the creek and their inability to adjust to the changing conditions. The benthic organism composition in Kelsey Creek varied radically with time and place, whereas the organisms were much more stable in Bear Creek.

Urban runoff impact studies were conducted in the Hillsborough River near Tampa Bay, Fla., as part of U.S. EPA's NURP (Mote Marine Laboratory, 1984). Plants, animals, sediment, and water quality were all studied in the field and supplemented by laboratory bioassay tests. Effects of saltwater intrusion and urban runoff were both measured because of the estuarine environment. During wet weather, freshwater species were found closer to the bay than during dry weather. In coastal areas, these additional natural factors made it even more difficult to identify the cause and effect relationships for aquatic life problems. During another NURP project, Striegl (1985) found that the effects of accumulated pollutants in Lake Ellyn (Glen Ellyn, Ill.) inhibited desirable benthic invertebrates and fish and increased undesirable phytoplankton blooms.

The number of benthic organism taxa in Shabakunk Creek in Mercer County, N.J., declined from 1[illegible] in relatively undeveloped areas to 4 below heavily urbaniz[illegible] areas (Garie and McIntosh, 1986). Periphyton samples were also analyzed for heavy metals with significantly higher metal concentrations found below the heavily urbanized area than above.

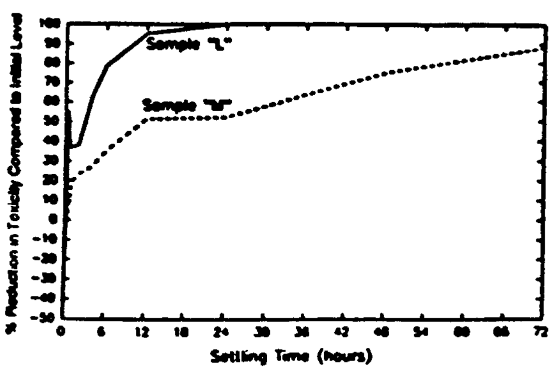

Figure 18—Toxicity reduction from settling of samples from automobile salvage yards.

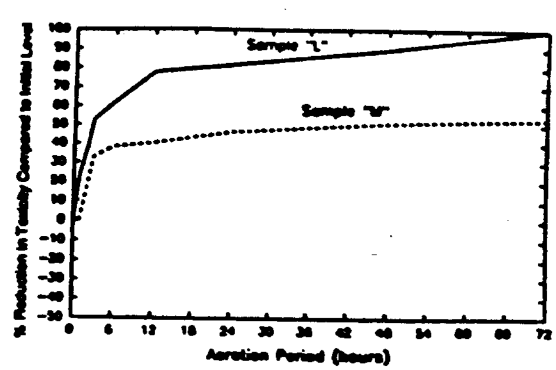

Figure 19—Toxicity reduction from aeration of samples from automobile salvage yards.

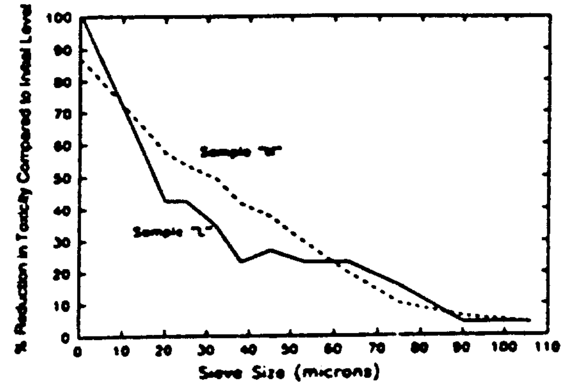

Figure 20—Toxicity reduction from sieve treatment of samples from automobile salvage yards.

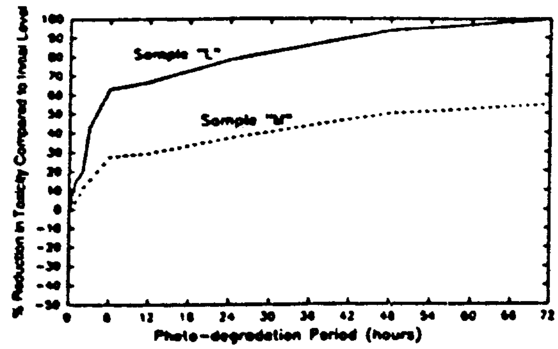

Figure 21—Toxicity reduction from photodegradation of samples from automobile salvage yards.

Many of the earlier noted biological effects associated with urban runoff are likely caused by polluted sediments and benthic organism impacts. Examples of heavy metal and nutrient accumulations in sediments are numerous. In addition to the studies noted earlier, DePinto *et al* (1980) found that the cadmium content of river sediments can be more than 1 000 times greater than the overlying water concentrations, and the accumulation factors in sediments are closely correlated with sediment organic content. Another comprehensive study on polluted sediment was conducted by Wilber and Hunter (1980) along the Saddle River (N.J.) where they found significant increases in sediment contamination with increasing urbanization.

The effects of urban runoff on receiving water aquatic organisms or other beneficial uses is very site-specific. Different land development practices create substantially different runoff flow characteristics. Different rain patterns cause different particulate washoff, transport, and dilution conditions. Local attitudes also define specific beneficial uses and, therefore, current problems. There is also a wide variety of water types receiving urban runoff, and these waters all have watersheds that are urbanized to various degrees. Therefore, it is not surprising that urban runoff effects, though generally dramatic, are also quite variable and site specific.

The literature review of potential transport and fate mechanisms of pollutants in receiving waters identified many processes that likely affect urban runoff pollutants after discharge. Sedimentation in the receiving water is the most common fate mechanism because many of the pollutants investigated are mostly associated with settleable particulate matter and have relatively low-filterable concentration components. Exceptions include zinc and 1,3-dichlorobenzene, which are mostly associated with the filtered sample portions. Particulate removal can occur in many stormwater runoff and combined sewer overflow control facilities, including (but not limited to) catchbasins, swirl concentrators, fine mesh screens, sand or other filters, drainage systems, and detention ponds. These control facilities (with the possible exception of drainage systems) allow removal of the accumulated polluted sediment for final disposal in an appropriate manner. Uncontrolled sedimentation will occur in relatively quiescent receiving waters, such as lakes, reservoirs, or slow moving rivers or streams. In these cases, the wide dispersal of the contaminated sediment is difficult to remove and can cause significant detrimental effects on biological processes.

Biological or chemical degradation of the sediment toxicants may occur in the typically anaerobic environment of the sediment, but the degradation is quite slow for many of the pollutants. Degradation by photochemical reaction and volatilization

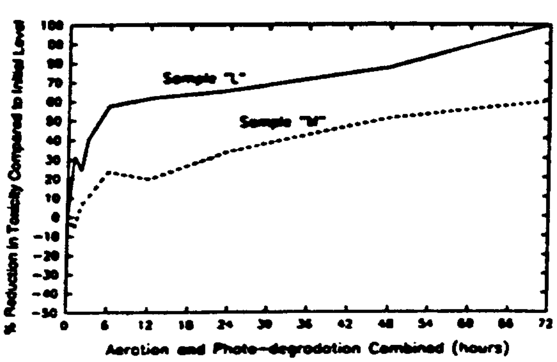

Figure 22—Toxicity reduction from aeration and photodegradation of samples from automobile salvage yards.

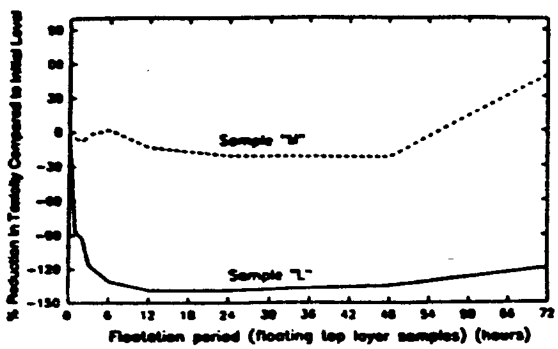

Figure 23—Toxicity reduction from flotation (top layer samples) of samples from automobile salvage yards.

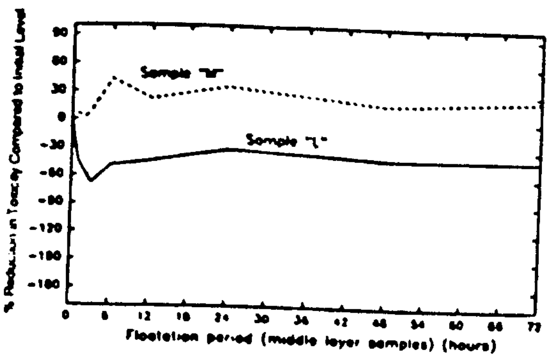

Figure 24—Toxicity reduction from flotation (middle layer samples) of samples from automobile salvage yards.

(evaporation) of the soluble pollutants may also occur, especially when these pollutants are near the surface of aerated waters (Callahan *et al.*, 1979; Parmer, 1993). Increased turbulence and aeration encourages these degradation processes that, in turn, may significantly reduce toxicant concentrations. In contrast, quiescent waters would encourage sedimentation that would also reduce water column toxicant concentrations but increase sediment toxicant concentrations. Metal precipitation and sorption of pollutants onto suspended solids increases the sedimentation and/or flotation potential of the pollutants and also encourages more efficient bonding of the pollutants to soil particles, preventing their leaching to surrounding waters.

Receiving waters have a natural capacity to treat and/or assimilate polluted discharges. This capacity will be exceeded sooner (assuming equal inputs), resulting in more degradation, in smaller urban creeks and streams, than in larger receiving waters. Larger receiving waters may still have ecosystem problems from the long-term buildup of toxicants in the sediment and repeated exposures to high flow rates, but these problems will be harder to identify using chemical analyses of the water alone because of increased dilution (Pitt and Bissonnette, 1984).

In-stream receiving water investigations of urban runoff effects need a multitiered monitoring approach, including habitat evaluations, water- and sediment-quality monitoring, flow monitoring, and biological investigations over long periods of time (Pitt, 1991). In-stream taxonomic (biological community structure) investigations are needed to help identify actual toxicity problems. Laboratory bioassay tests can be useful to determine the major sources of toxicants and to investigate toxicity reduction through treatment, but they are not a substitute for actual in-stream investigations of receiving water effects. To identify the sources and treatability of the problem pollutants, detailed watershed investigations are needed, including both dry and wet weather urban drainage monitoring and source area monitoring.

An estimate of the actual pollutant loads (calculated from the runoff volumes and pollutant concentrations) from different watershed areas is needed for the selection and design of most treatment devices. Several characteristics of a source area are significant influences on the pollutant concentrations and stormwater runoff volumes. The washoff of debris, soil, and pollutants depends on the intensity of the rain, the properties of the material removed, and the surface characteristics where the material resides. The potential mass of pollutants available to be washed off will be directly related to the time interval between runoff events during which the pollutants can accumulate.

A storm event will not cause runoff until the initial runoff losses (for example, initial abstractions, including surface wetting, surface depression storage, interception by overhanging vegetation, and evaporation) and infiltration rates are exceeded. For urban impervious surfaces, these initial abstractions can account for the first 5 to 10 mm of a storm event and would be much greater for pervious areas (Pitt, 1987). The route the runoff flow then takes to the drainage system will also offer further opportunities to increase or decrease the pollutant load and runoff volume.

It is important to note that the design of a drainage system is based on peak flow rates, whereas the total runoff volume is the critical flow parameter for calculating pollutant mass loadings. The receiving water impact of moderate storm events occurring several times a year likely causes more severe long-term problems because of the short recovery time available between events (Pitt and Bozeman, 1982). Large storms can certainly contribute massive pollutant loadings, but when they are averaged over their recurrence intervals, the significance of their annual average pollutant contributions are greatly reduced. The single-shock loadings from a large storm may create significant receiving water-use impairments, and a number of years may be required for recovery. But since these large storms are rare, a long time period is usually available for recovery before another devastating event occurs.

The peak flow rate of concern in drainage design will be associated with a large and infrequent storm event, and the earlier noted abstractions comprise a much smaller fraction of the total rainfall than for smaller rains. However, a large fraction of the annual runoff volume is generally due to small or moderate sized storm events. In many parts of the country, 85% of all the rains are less than 15 mm in depth (and usually only a few hours in duration) and can generate approximately 70% of the total annual runoff. The influence of initial abstractions is great (one-third to two-thirds of the total rainfall) for these small rains for typical urban areas. Therefore, special small storm hydrology procedures that accurately consider the runoff losses for these small events are needed for water-quality investigations, as opposed to conventional large storm hydrology procedures that are used for drainage design (Pitt, 1987).

Conclusions

Previous studies have indicated that urban stormwater runoff contains a variety of conventional and potentially toxic pollutants that can degrade receiving waters and impair beneficial uses. Receiving water impacts are due to many variables, including the magnitude of the dry and wet weather discharges; the transport and fate mechanisms of the toxicants; and effects from other discharges and receiving water conditions. These factors, and the unknown and site-specific relationships between them, make the prediction of receiving water effects difficult, if not impossible, especially if one only relies on water column-quality measurements. *In situ* biological community structure studies can give an indication of the receiving water effects, especially if predevelopment or control conditions are known for comparison purposes. However, it will generally be difficult to relate any identified impacts to any specific pollutant, but an in-stream biological community structure study will indicate whether the receiving water is being adversely effected.

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Phase 1 of this research detected only a small fraction of the organic toxicants analyzed but detected heavy metal concentrations in the majority of samples. The study also confirmed that many toxicants are associated with particulate matter in the runoff. Industrial or commercial areas are likely to be the most significant pollutant source areas, with the highest toxicant concentrations and most frequent occurrences found at vehicle service and parking or storage areas. The duration of the antecedent dry period before a storm and the intensity of the storm event were found to be significant factors influencing the concentrations of most of the toxicants detected. These critical areas were sampled for Phase 2 treatability tests.

The treatability study phase found that settling, screening, and aeration and/or photodegradation treatments showed the greatest potential for toxicant removals, as measured by the reduction in toxicity of the samples, using the Microtox® toxicity-screening procedure. Studies to measure the actual toxicant removals in full-scale applications are needed to confirm the real benefit of the potential treatment processes. The results from the second study phase, in conjunction with results from the first project phase, will enable the modification of treatment devices and system designs (for new installations and for retrofitting existing installations) to optimize toxicant removals from critical stormwater runoff source areas. The current project phase is examining the toxicant removal benefits of several large-scale applications of the most suitable treatment unit processes investigated.

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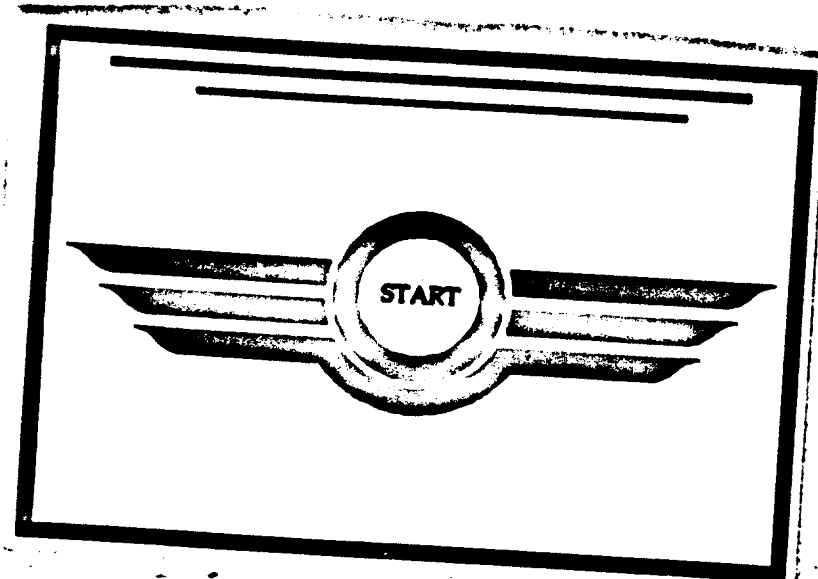

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September 1992

EPA

Storm Water Management For Construction Activities

Developing Pollution Prevention Plans And Best Management Practices

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CHAPTER 1

INTRODUCTION

1.1 PURPOSE OF THIS GUIDANCE MANUAL

The purpose of this guidance manual is to help you develop and implement a Storm Water Pollution Prevention Plan specifically designed for your construction site. With the help of this guidance, you should be able to put together most aspects of the plan using your own construction managers and engineers.

As part of its efforts to expand the use and benefits of pollution prevention practices, the U.S. Environmental Protection Agency (EPA) expects that most National Pollutant Discharge Elimination System (NPDES) storm water permits for construction activities, both individual and general permits, may require this type of plan, including the NPDES General Permit for Storm Water Discharges from Construction Activities That Are Classified As "Associated with Industrial Activity" (referred to as EPA's Baseline Construction General Permit). Although specific components of a Storm Water Pollution Prevention Plan may vary from one storm water permit to another, many of the general concepts described in this manual are common to all plans.

1.2 ORGANIZATION OF THIS GUIDANCE MANUAL

This manual is organized to function as a user's guide to meet Storm Water Pollution Prevention Plan requirements. The step-by-step guidelines and checklists in the following sections walk you through the process of developing a Storm Water Pollution Prevention Plan. The checklists are designed to help you organize the required information. The remainder of this manual is divided into a number of sections: Chapter 2 provides an overview of the process of developing and implementing a Storm Water Pollution Prevention Plan, and Chapters 3-6 are resources for selecting Best Management Practices (BMPs) and controls to use as part of your plan. Using this information, you will develop and implement your plan following the basic phases listed below. Each phase is important and should be completed before moving on to the next one:

- Site Planning and Design Development Phase
- Assessment Phase
- Control Selection/Plan Design Phase
- Notification/Approval Phase
- Implementation/Construction Phase
- Final Stabilization/Termination Phase

Developing a Storm Water Pollution Prevention Plan is, therefore, a six-phase process. Because most aspects of the Storm Water Pollution Prevention Plan take a significant amount of planning, its development must be closely connected to the development of your overall site plan for construction. You must keep storm water considerations in mind as you develop your site plan. The Initial Site Planning/Design Development Phase starts the process. The next phase, the Assessment Phase, involves gathering information about your site, such as determining drainage patterns and runoff coefficients. Then you will enter the Control Selection/Plan Design Phase, using the information collected during the Assessment Phase to select BMPs. Following Control Selection and Plan Design is the Certification/Notification Phase. In this phase the plan is certified by the owner and operator of the construction project and a notice is sent to the government agency which is responsible for NPDES permits in your area. The next stage is the Implementation/Construction Phase, during which you put your Storm Water Pollution Prevention Plan to action and construct your facility. Periodic reviews, inspections, and evaluations will allow you to keep the plan up-to-date and effective. Finally, as construction activities are completed, you reach the Final Stabilization/Termination Phase during which you put into place permanent controls.

Chapter 5 provides recommendations to assist the readers in selecting the most appropriate BMPs. A combination of these types of BMPs may be most appropriate for your site.

In addition, there are a few appendices included in the back of this manual. Appendix A includes checklists relating to specific elements of Storm Water Pollution Prevention Planning. Appendix B provides technical design specifications for the BMPs described in Chapters 3 and 4. Appendix C shows what a model plan should look like. Appendix D lists references and resources. Appendix E contains a glossary of terms. Appendix F contains a list of hazardous substances and reportable quantities. Appendix G lists references for rainfall data. Appendix H lists efficiencies for several types of BMPs.

1.3 DEFINITIONS

Throughout this manual you will see four key words and phrases used over and over. A solid understanding of these concepts is very important in meeting the goals of storm water management discussed above.

The first term of importance is "Storm Water Pollution Prevention Plan (SWPPP)." As mentioned in Section 1.1, this manual is designed to help you to prepare and implement a Storm Water Pollution Prevention Plan. As you will learn in Chapter 2, storm water pollution prevention consists of a series of phases and activities to, first, characterize your site, and then, to select and carry out actions which prevent the pollution of storm water discharges.

The next term is NPDES Storm Water Permit or permit. NPDES is an acronym for National Pollutant Discharge Elimination System. NPDES is the National program for issuing, modifying, revoking, etc., permits under Sections 307, 318, 402, and 405 of the Clean Water Act (CWA). A permit is an authorization issued by EPA or an approved State to discharge under certain specified conditions.

The other term used throughout this manual is "Best Management Practice" or BMP. BMPs are measures or practices used to reduce the amount of pollution entering surface waters, air, land, or ground waters. BMPs may take the form of a process, activity, or physical structure. Some BMPs are simple and can be put into place immediately, while others are more complicated and require extensive planning. They may be inexpensive or costly. This manual describes numerous BMPs which you may use as part of your Storm Water Pollution Prevention Plan.

The final term used frequently in this manual is "operator." The operator of a construction activity is the party or parties that either individually or taken together meet the following two criteria: (1) they have operational control over the site specifications (including the ability to make modifications in specifications); and (2) they have the day-to-day operational control of those activities at the site necessary to ensure compliance with plan requirements and permit conditions (e.g., are authorized to direct workers at the site to carry out activities identified in the plan).

1.4 GOALS OF EROSION AND SEDIMENT CONTROL AND STORM WATER MANAGEMENT

EPA's November 16, 1990, storm water final rule addresses certain types of storm water discharges, including storm water discharges from construction activities. This regulation is based on the results of a number of National studies which pointed to storm water discharges as a significant source of pollutants and cause of water use impairment in receiving streams. Storm water runoff becomes polluted by picking up soil particles and other pollutants (from construction materials) as it flows over surfaces where construction activities are occurring. By requiring certain construction sites to apply for NPDES storm water permits, this regulation provides a way for States and EPA Regions to monitor and manage these discharges, and reduce or ultimately eliminate the amount of pollutants present in them. The basic goal of storm water management, therefore, is simple:

IMPROVE WATER QUALITY BY REDUCING POLLUTANTS IN STORM WATER DISCHARGES

Construction activities produce many different kinds of pollutants which may cause storm water contamination problems. Grading activities remove grass, rocks, pavement and other protective ground covers resulting in the exposure of underlying soil to the elements. Because the soil surface is unprotected, soil and sand particles are easily picked up by wind and/or washed away by rain or snow melt. This process is called erosion. The water carrying these particles eventually reaches a stream, river or a lake where it slows down, allowing the particles to fall onto the bottom of the stream bed or lake. This process is called sedimentation. Gradually, layers of these clays and silt build up in the stream beds choking the river and stream channels and covering the areas where fish spawn and plants grow. These particles also cloud waters causing aquatic respiration problems and can kill fish and plants growing in the river stream.

In addition, the construction of buildings and roads may require the use of toxic or hazardous materials such as petroleum products, pesticides, and herbicides, and building materials such as asphalt, sealants and concrete which may pollute storm water running off of the construction site. These types of pollutants often contain small amounts of metals and other toxic materials which may be harmful to humans, plants, and fish in streams.

Considering the nature of construction activities and the resulting pollutants, and the variable nature of storm events, EPA determined that the best approach to storm water management for these sites is through the use of self-designed Storm Water Pollution Prevention Plans. These plans are based on the use of BMPs. For construction sites, there are three main types of BMPs, those that prevent erosion, others which prevent pollutants from the construction materials from mixing with storm water, and those which trap pollutants before they can be discharged. Although these three types of BMPs have different functions, the basic principle is the same: these BMPs are designed to prevent, or at least control, the pollution of storm water before it has a chance to affect receiving streams. Using BMPs in this way is called storm water management or sediment and erosion control.

1.5 LIMITATIONS OF THIS MANUAL

This manual provides useful information on many sediment and erosion and storm water management controls which you can use to prevent or reduce the discharge of sediment and other pollutants in storm water runoff from your site. This manual describes the practices and controls, tells how, when, and where to use them, and how to maintain them. However, the effectiveness of these controls lies fully in your hands. Although specific recommendations will be offered in the following chapters, keep in mind that careful consideration must be given to selecting the most appropriate control measures based on site-specific features, and on properly installing the controls in a timely manner. Finally, although this manual provides guidelines for maintenance, it is up to you to make sure that your controls are carefully maintained or they will prove to be ineffective.

This manual describes some of the EPA Baseline General Permit requirements for pollution prevention plans. However, requirements may vary from permit to permit. You should read your permit to determine the required components of your pollution prevention plan. This manual does describe "typical" permit requirements. However, do not assume that the typical permit requirements described in this manual are the same as your permit requirements, even if you are included under an NPDES general permit for storm water discharges from construction activities that are classified as "Associated with Industrial Activities." Permit conditions may vary between different permits and/or different versions of the permit.

This manual also does not describe State or local requirements for erosion and sediment control or for storm water management. Although it is expected that, in most cases, plan requirements will be similar, you should contact your State or local authorities to determine what their requirements are.

EPA has issued a number of regulations addressing pollution control practices for different environmental media (i.e., land, water, air, and ground water). However, this manual focuses on identifying pollution prevention measures and BMPs specifically for storm water discharges from construction activities and provides guidance to industrial facilities on how to comply with storm water permits.

Although Storm Water Pollution Prevention Plans primarily focus on storm water, it is important to consider the impacts of selected storm water management measures on other environmental media (i.e., land, air, and ground water). For example, if the water table is unusually high in your area, a retention pond for contaminated storm water may also lead to contamination of a ground water source unless special preventive measures are taken. EPA strongly discourages this transfer of pollution from one environmental medium to another and prohibits the adoption of any storm water management practice that results in a violation of other Federal, State, or local environmental laws.

For instance, under EPA's July 1991 Ground Water Protection Strategy, States are encouraged to develop Comprehensive State Ground Water Protection Programs. Your facility's efforts to control storm water should be compatible with the ground water protection objectives reflected in your State's program.

1.6 ADDITIONAL INFORMATION

Although this manual describes many potential control measures for construction sites, there are additional resources. Some references are listed in Appendix D of this manual. Many State and local sediment and erosion control agencies have published BMP documents specifically for construction activities. A few of these are listed in Appendix D. For other documents, State and local agencies should be contacted directly.

CHAPTER 2

STORM WATER POLLUTION PREVENTION PLAN

The Storm Water Pollution Prevention Plan is the focus of your NPDES storm water permit and is the key to controlling pollutants in storm water discharges. Therefore, proper and careful development and implementation of the plan will maximize the potential benefits of pollution prevention and sediment and erosion control measures. Your permit consists of specific requirements for the plan, including deadlines and certain storm water control measures. This Chapter provides a step-by-step explanation of how to develop and implement your Storm Water Pollution Prevention Plan.

The process of developing and implementing a Storm Water Pollution Prevention Plan for construction activities has been divided into six phases which are indicated in Figure 2.1. These phases are:

1. Site Evaluation and Design Development
2. Assessment
3. Control Selection/Plan Design
4. Certification/Notification
5. Construction/Implementation
6. Final Stabilization/Termination.

The following sections describe the processes involved in each of the phases listed above. The pollution prevention plan is developed during the first three phases listed above.

Your NPDES storm water permit may specify deadlines for plan development and implementation. The sequence in Figure 2.1 assumes that pollution prevention plans will be completed and implemented at the time the project breaks ground and revised (if necessary) as construction proceeds. Your plan should be in place before project initiation because construction operations pose environmental risks as soon as activity begins. The initial rough grading activities may contribute a significant amount of pollutants to storm water runoff. Be sure to read your permit closely to see what dates and deadlines apply to your site.

The planning for pollution prevention measures should be done while you develop the site construction plan. The best Storm Water Pollution Prevention Plans are developed at the same time as the design of the site plan. However, if you have completed your site plan design before you begin to prepare the Storm Water Pollution Prevention Plan it is not necessary to start the process all over again. Much of the information needed for the plan should already be included in your design documents. A Storm Water Pollution Prevention Plan can be prepared for most construction projects by using information from the existing design, and modifying the design to accommodate the controls.

Responsibility for developing a Storm Water Pollution Prevention Plan typically lies with the owner of the property that is being developed, or with the owner and operator (e.g., General Contractor) of the construction project.

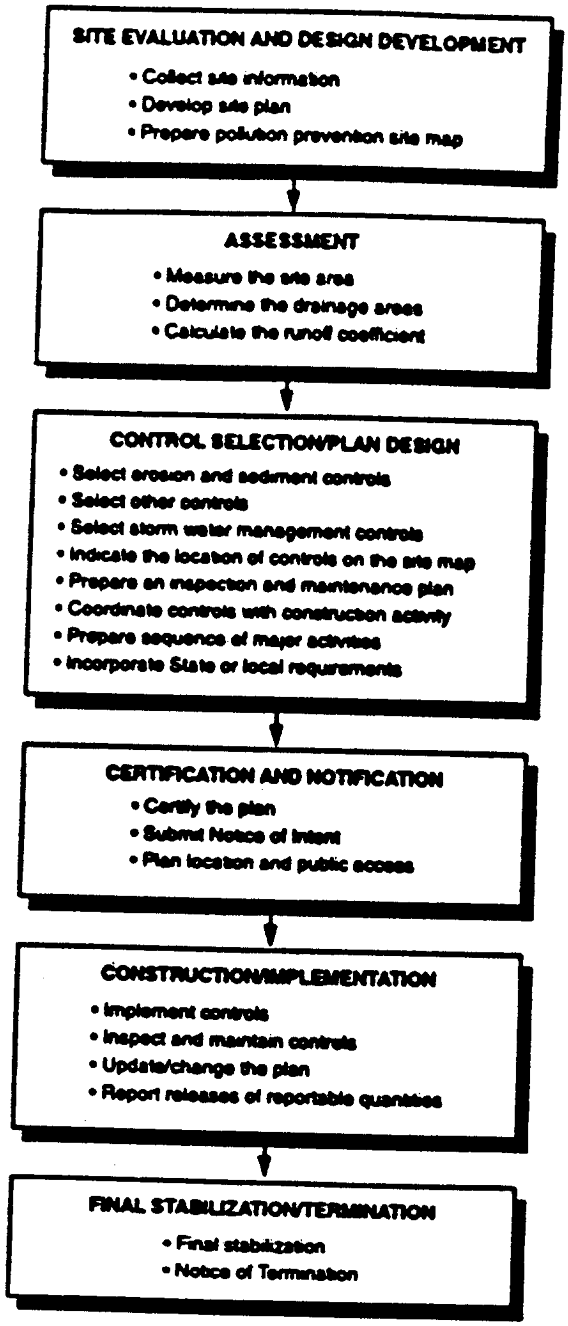

FIGURE 2.1 DEVELOPING AND IMPLEMENTING A STORM WATER POLLUTION PREVENTION PLAN FOR CONSTRUCTION

EPA BASELINE GENERAL PERMIT REQUIREMENTS
Storm Water Pollution Prevention Plan Development Parts IV.A.1, 2, and 3. Storm Water Pollution Prevention Plans should be fully developed and implemented upon submitting the Notice of Intent (NOI) to be covered by the general permit. The operator should comply with the terms and schedule of the plan beginning with the initiation of construction activities or October 1, 1992, whichever is later. This requirement applies to existing construction sites on October 1, 1992, as well as new sites which begin construction after this date.

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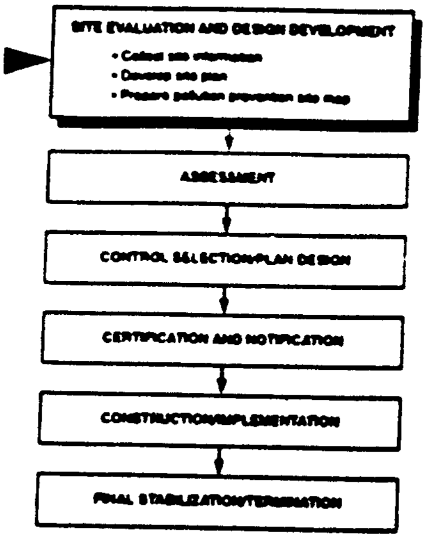

2.1 SITE EVALUATION AND DESIGN DEVELOPMENT

The first phase in a preparing a Storm Water Pollution Prevention Plan for a construction project is to define the characteristics of the site and of the type of construction which will be occurring. This phase is broken down into three tasks: collect site information, develop site plan, and prepare site map. The following subsections describe each of these tasks.

2.1.1 Collect Site Information

The first phase in preparing a pollution prevention plan is to collect information on the site which will be developed. The following items are suggested.

Existing Conditions Site Map

Obtain a map of the existing conditions at the site. This map will be the starting point for the site map required by the pollution prevention plan. The map should be to scale and preferably topographic. The map should indicate the existing land use for the site (i.e., wooded area, open grassed area, pavement, building, etc.) as well as the location of surface waters which are located on or next to the site (Surface waters include wetlands, streams, rivers, lakes, ponds, etc.). The best way to obtain a site map is to have your site surveyed by a professional surveyor (either land based or aerial). If it is not practical to survey the site, then topographic maps may be available from your State or local government. A final alternative is to use the United States Geological Survey (USGS) topographical maps. USGS maps are least desirable for use as a site map for a pollution prevention plan because they are only available in a very large scale (1:24,000) and the features of a construction site would be very difficult to distinguish. The scale of the map should be small enough so that you can easily distinguish important features such as drainage swales and control measures.

Soils Information

Determine the type of soils present on the site. This information should be based upon information from your specific site, not regional characteristics. You may use the Soil Conservation Service's (SCS) Soils Map of your area to determine types of soil on your site. The SCS Soil Surveys are excellent sources of information for surface soils and typically will indicate if a soil is erodible. Even more accurate information may be obtained by performing soil borings at the site; this method is more expensive and is usually only required for some storm water practices such as infiltration. Soil borings may already be required for the design of foundations or other structures.

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Runoff Water Quality

Collect any information on the quality of the runoff from the site which may be available. In many cases, there will be little water quality data from runoff collected specifically from a site, however, if your construction site is located on or next to an existing industrial facility, or if it drains to a municipal separate storm sewer in a city/county with a population greater than 100,000, water quality data may have been collected which indicates the quality of runoff from your site. Contact either the industrial facility or the municipal storm sewer authority which will receive your storm water and ask if they have performed any analysis on storm water from your proposed construction site. You may also be able to obtain runoff water quality information from the U.S. Geological Survey (USGS), the USDA Soil Conservation Service (SCS), State or local watershed protection agencies. Contact these agencies to see if they have collected samples of runoff from your site or from locations down stream of your site.

Name of Receiving Water

Identify the name of the body of water(s) which will receive runoff from the construction site. If the receiving water is a tributary include the name of the ultimate body of water if possible. Receiving waters could include: rivers, lakes, streams, creeks, runs, estuaries, wetlands, bays, ocean, etc. If the site drains into a Municipal Separate Storm Sewer System, identify the system and indicate receiving water to which the system discharges. This information is usually available from county, State, or USGS maps.

Rainfall Data

It is useful to determine the amount of rainfall you will anticipate in your design of storm water management measures. These rainfall amounts are often referred to as "design storms." Design storms are typically described in terms of the average amount of time that passes before that amount of rain falls again and by the duration of the rain (e.g., the 10 year-24 hour storm). Contact your State/local storm water program agency for additional information on the design storm criteria in your project area. Consult Appendix G for sources of design storm data if it is not available from your State/local agency.

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2.1.2 Develop Site Plan

The next step in the process is to develop a preliminary site plan for the facility which is to be constructed. The site plan will be developed primarily based upon the goals and objectives of the proposed facility. However, there are several pollution prevention principals which should be considered when developing the site plan for the project. They are:

- Disturb the smallest vegetated area possible.
- Keep the amount of cut and fill to a minimum.
- Limit impacts to sensitive areas such as:
  - Steep and/or unstable slopes
  - Surface waters, including wetlands
  - Areas with erodible soils
  - Existing drainage channels.

In addition to reducing pollution in storm water runoff from your site, incorporating the above objectives into the site plan for the project can also: reduce construction costs for grading and landscaping, reduce the amount of sediment and storm water management controls, and improve the aesthetics of the completed project.

Once the preliminary design is developed, you should prepare a narrative description of the nature of the construction activity to include in the Storm Water Pollution Prevention Plan. The narrative should provide a brief description of the project including the purpose of the project (the final result); the major soil disturbing activities that will be necessary to complete the project; and the approximate length of time it will take to complete the project.

You might describe the purpose of construction (goal or project result) as one of the following: residential development, commercial, industrial, institutional, office development, highway projects, roads, streets, or parking lots, recreational areas, or underground utility.

When you describe soil disturbing activities you might include one or more of the following: clearing and grubbing, excavation and stockpiling, rough grading, final or finish grading, preparation for seeding or planting, excavation of trenches, demolition, etc.

The description of the construction activity does not need to address indoor construction activities that will not have any affect on the quality of storm water. For example, it is not necessary to describe the construction of indoor wiring for a building in the narrative if the wiring will not be installed until after the building is enclosed.

2.1.3 Prepare Site Map

When the site plan is complete for your construction project, the information should be transferred onto the pollution prevention plan site map (Note: the construction site plan and the Storm Water Pollution Prevention Plan site map can be the same map). At this phase in the Storm Water Pollution Prevention Plan development, there are three things which can be indicated on the site map: the approximate slopes after grading, the drainage pattern, and the areas of disturbance. [Note the surface waters should already be indicated on the map (see Section 2.1.1).] Appendix C includes an example site map for a Storm Water Pollution Prevention Plan. It may be helpful to refer to this while reading this section.

Approximate Slopes after Grading

It is suggested that you indicate the revised grades on the same topographic map as the existing grades. You should use two separate symbols for existing contours and proposed contour (i.e., dashed and solid lines). Topographic maps indicating existing and proposed contours for a site are suggested because it is easy to determine the areas which must be disturbed for regrading.

If you do not prepare a topographic map of the site, then you should examine the proposed plan for the site and indicate on the site map the approximate location, direction and steepness of slopes. The location and direction of the slope may be indicated by arrows (pointing from high to low) and numbers indicating the degree of slope. Slope is usually expressed as a ratio of the length it takes to decrease one foot in height, e.g., 3:1 indicates that the slope takes 3 feet in length to drop one foot in height.

Areas of Soil Disturbance

After indicating the proposed grading on the site map, the next phase is to indicate the entire area which will be disturbed by the construction activity. The suggested method for indicating this area is to draw a "limit of disturbance" line on the site plan. You should draw the limit of disturbance

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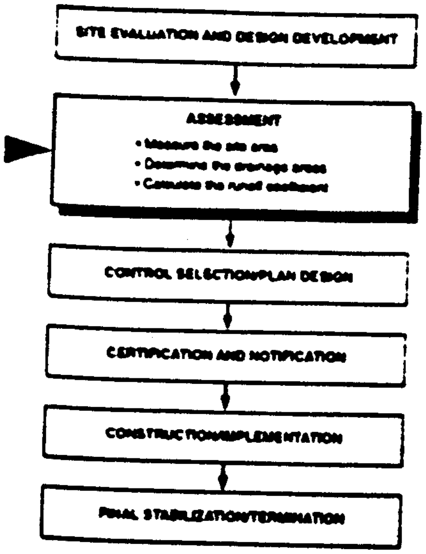
so that any soil disturbing activity such as: clearing, stripping, excavation, backfill, stock piling (topsoil or other fill material), and paving will be inside of the limit. The limit of disturbance should also include roads for construction vehicles unless those roads are paved (or stabilized) and have measures to reduce tracking of sediments. When drawing the line try to leave room for the control structures which may be required (this may be difficult, but you can always redraw the limit of disturbance after you design the control structures). The limit of disturbance should be a closed boundary line around the entire disturbed area. There can be "islands" of undisturbed area inside the limit of disturbance, for example, a tree or group of trees which are to be preserved. These islands should be encircled with a limit of disturbance.

Drainage Patterns

In addition to the slopes anticipated after grading, and areas of soil disturbance your Storm Water Pollution Prevention Plan site map should also indicate the drainage patterns of the site after the major grading activities.

The suggested method for showing this is with a topographic map of the site which indicates drainage basin boundaries and drainage channels or pipes. A drainage basin for the purposes of the Storm Water Pollution Prevention Plan is an area of the site in which water, sediments and dissolved materials drain to a common outlet (such as a swale or storm drain pipe) from the site. There can be one or more drainage basins on a site. Drainage boundaries are closed lines which start and end at the common outlet. Drainage boundaries typically follow the high points on a site including hill tops, ridges, roads, etc. Drainage areas do not overlap. To determine the drainage basin boundaries, ask yourself where will rain falling on this portion flow off of the site. Areas that drain to different points are in different drainage areas. Drainage boundaries can be changed by grading and structural controls. The site map should indicate the drainage boundaries after the major grading has occurred or structural controls installed. It may be necessary to change the drainage boundaries after you select your structural controls. If you do not provide a topographic site map, use arrows to indicate which direction water will flow. Show the areas where there will be overland flow and the location of swales or channels. If there is a new or proposed underground storm drain system on the site then this should be indicated on the Storm Water Pollution Prevention Plan site map as well. It is recommended that the pipe diameter and slope also be included on the site map.

Please note that the Storm Water Pollution Prevention Plan site map is not complete until you have indicated the locations of the major control structures and the areas where stabilization is expected to occur. These items are discussed in Section 3.3.4.



2.2 ASSESSMENT

After the characteristics of the site and the construction have been defined, the next phase in developing a Storm Water Pollution Prevention Plan is to measure the size of the land disturbance and estimate the impact the project will have on storm water runoff from the site from the information developed in phase 1. There are three tasks which should be done to assess the project, they are: measure site area, measure drainage areas, and calculate runoff coefficient.

2.2.1 Measure Site Area

Typically, NPDES storm water permits may require that you indicate in the Storm Water Pollution Prevention Plan estimates of the total site area and the area which will be disturbed. You will need the Storm Water Pollution Prevention Plan site map which clearly shows the site boundary and the limit of disturbance. The area of the site can usually be found on the deed of sale for the property, the record plat, site survey, or the site plan. The amount of area to be disturbed is sometimes noted on a site plan, or grading plan. If the information is not available from one of these sources you may measure using the grid method or by using a planimeter.

The most accurate method to measure area from the site map is with a planimeter. A planimeter is a device which can measure the area on a drawing by tracing its outline. Planimeters are available from Engineering and Surveyor Supply Stores.

If you do not have access to a planimeter and do not wish to buy one, the grid method is an easy method for estimating the size of an area which only requires transparent graph or grid paper. The steps are as follows:

1. Place graph or grid paper over the scale drawing and trace the outline of the entire property.
2. Count the total number of complete squares within the site area, count every two partial squares along the edges of the site as one square.
3. Divide the total number of squares by the number of squares in one square inch of graph/grid paper. This results in an estimate of the number of square inches contained in the outline of the site.
4. Multiply the result of Step 3 by the number of square feet in a one inch square based on the scale of the drawing. This results in an estimate of the number of square feet on the site.

5. The last step is to divide the number of square feet on the site by 43,560 square feet per acre to see how many acres there are. The result is an estimate of the site area in acres. Repeat this method using the outline of the disturbed area to find the estimated acreage of soil disturbing activities.

Example:

The site plan pictured below (Figure 2.2) is drawn to a 1 inch equals 200 feet scale (1":200'). After tracing the boundary and counting the number of squares, the result is 620 1/4-inch squares.

Divide 620 by the number of 1/4-inch squares per square inch, which in this case is 16 (the number of 1/4-inch squares in a square inch is 16). The result is 38.75 one-inch squares.

Multiply 38.75 square inches by the number of square feet per square inch, 40,000 square feet per square inch (based on the scale of this drawing that would be 200' times 200'). The result is 1,550,000 square feet.

The final step is to convert the estimated area from square feet to acres by dividing by 43,560 square feet per acre into the total number of square feet. The final result is 35.6 acres.

The area should be expressed in acres to the nearest tenth of an acre, e.g., 5.5 acres total site area and 3.5 acres disturbed area.

The first measurement which you should make is to determine the total area of the site. The total area of the site should include the area inside the project's property boundaries, easements and/or right-of-ways. The total area includes both the disturbed and undisturbed areas. The second measurement which you should make is the area which will be disturbed by the construction project. This area can be determined by measuring the area enclosed by the limit of disturbance drawn in on the site map (see Section 2.1.2) and subtracting from this value the area of any undisturbed "islands" within the limit of disturbance. The disturbed area should always be less than or equal to the total site area.

2.2.2 Determine the Drainage Areas

The final areas which you should measure are the size of each drainage basins for each point where concentrated flow will leave the site. Although you do not need to put this information into the pollution prevention plan, you will need this data to help you select and design the sediment control and storm water management measures for your project.

For design of the sediment control measures, you will need to know the area of the portion of each drainage basin which will be disturbed. The disturbed areas of the drainage basins should be measured using the methods suggested above to estimate the area enclosed by the limit of disturbance and/or the drainage boundary (whichever boundary gives the smaller area).

For the design of the storm water management controls and for the calculation of the runoff coefficient, you should measure the total area of each drainage basin and the areas of each land use which will occur in the basin after the construction is complete. Be sure to include offsite water draining onto your site when determining the total size of the drainage basin. See Table 2.1 for a listing of different types of land uses. The area of each land use in the drainage basins should be measured using the methods suggested above to estimate the area enclosed by the land use boundary and/or the drainage boundary (whichever boundary gives the smaller area). Topographic maps are helpful tools to use in determining drainage boundaries.

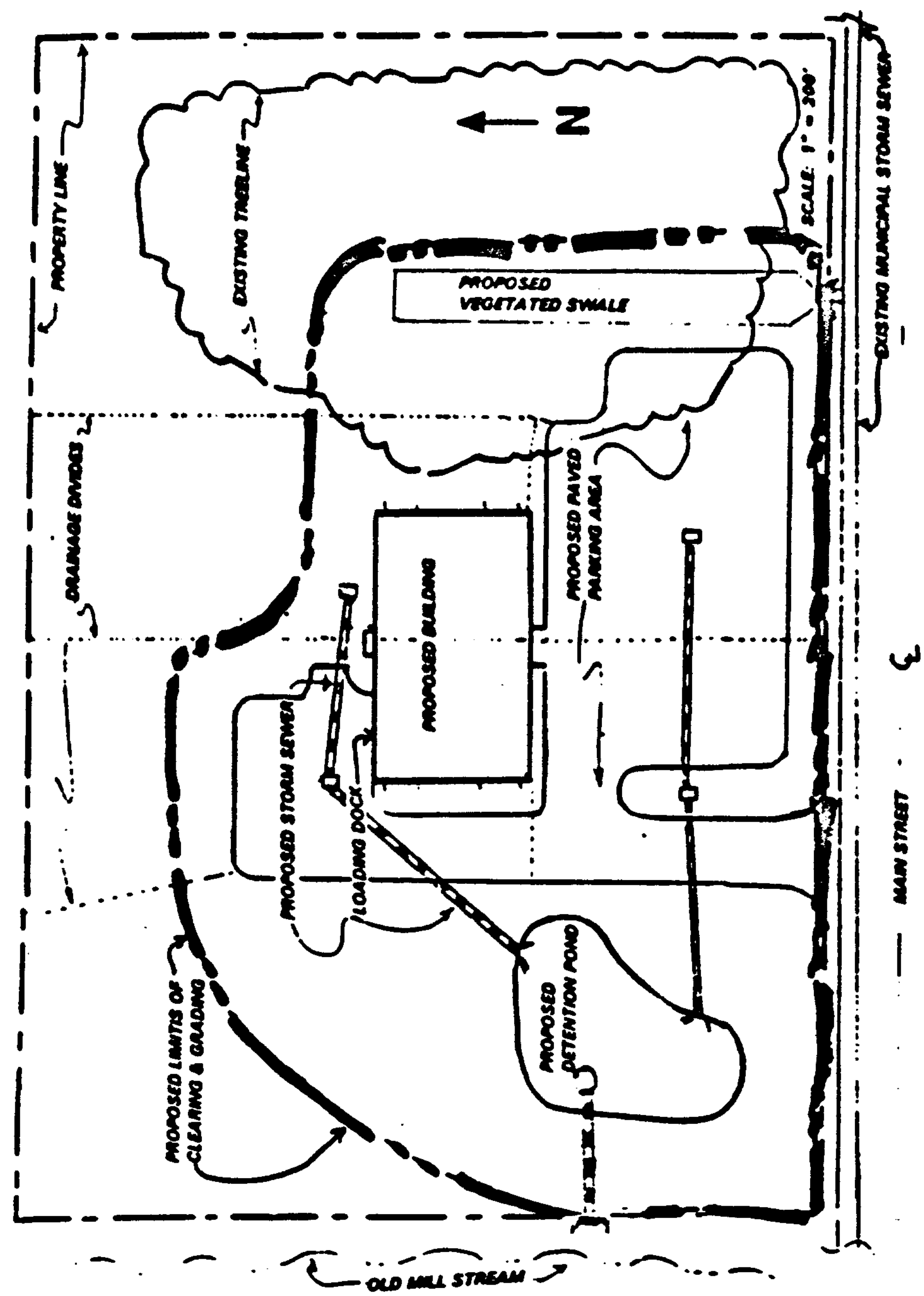


FIGURE 2.2 SAMPLE SITE PLAN

2.2.3 Calculate the Runoff Coefficient

The next step in the assessment phase is to develop an estimate of the development's impact on runoff after construction is complete. This can be done by estimating a runoff coefficient for post construction conditions. The runoff coefficient ("C" value) is the partial amount of the total rainfall which will become runoff. The runoff coefficient is used in the "rational method" which is:

$$Q = CIA,$$

where

Q = the rate of runoff from an area
I = rainfall intensity, and
A = the area of the drainage basin.

There are many methods which can be used to estimate the amount of runoff from a site. You are not required to use the rational method to design storm water conveyances or management measures. Consult your State/local design guides to determine what methods to use for estimating design flow rates from your development.

The less rainfall that is absorbed (infiltrates) into the ground, evaporates, or is otherwise absorbed on site, the higher the "C" value. For example, the "C" value of a lawn area is 0.2, which means that only 20 percent of the rainfall landing on that area will run off, the rest will be absorbed or evaporate. A paved parking area would have a "C" value of 0.9, which means that 90 percent of the rainfall landing on that area will become runoff. The "C" value which you are being asked to calculate is the one that represents the final condition of the site after construction is complete. It is suggested that a runoff coefficient be calculated for each drainage basin on the site. The following is an example of how to calculate the "C" value.

The runoff coefficient or "C" value for a variety of land uses may be found in Table 2.1. These "C" values provide an accurate estimate of anticipated runoff for particular land uses. Most sites have more than one type of land use and therefore more than one "C" value will apply. To have a "C" value that represents your site you will need to calculate a "weighted C value."

Calculating a "Weighted C"

When a drainage area contains more than one type of surface materials with more than one runoff coefficient a "weighted C" must be calculated. This "weighted C" will take into account the amount of runoff from all the various parts of the site. A formula used to determine the "weighted C" is as follows:

$$C = \frac{A_1 C_1 + A_2 C_2 ... A_x C_x}{\Sigma \text{ of } A}$$

where *A* = acres and *C* = coefficient.

Therefore, if a drainage area has 15 acres (ac.) with 5 paved acres (C = .9), 5 grassed acres (C = .2), and 5 acres in natural vegetation (C = .1), a "weighted "C" would be calculated as follows:

TABLE 2.1 TYPICAL "C" VALUES (ASCE 1960)

Description of Area	Runoff Coefficients
Business	
Downtown Areas	0.70-0.95
Neighborhood Areas	0.50-0.70
Residential	
Single-family areas	0.30-0.50
Multiunits, detached	0.40-0.60
Multiunits, attached	0.60-0.75
Residential (suburban)	0.25-0.40
Apartment dwelling areas	0.50-0.70
Industrial	
Light Areas	0.50-0.80
Heavy areas	0.60-0.90
Parks, cemeteries	0.10-0.25
Playgrounds	0.20-0.35
Railroad yard areas	0.20-0.40
Unimproved areas	0.10-0.30
Streets	
Asphalt	0.70-0.95
Concrete	0.80-0.95
Brick	0.70-0.85
Drives and walks	0.75-0.85
Roofs	0.75-0.95
Lawns - course textured soil (greater than 85% sand)	
Slope: Flat, 2%	0.05-0.10
Average, 2-7%	0.10-0.15
Steep, 7%	0.15-0.20
Lawns - fine textured soil (greater than 40% clay)	
Slope: Flat, 2%	0.13-0.17
Average, 2-7%	0.18-0.22
Steep, 7%	0.25-0.35

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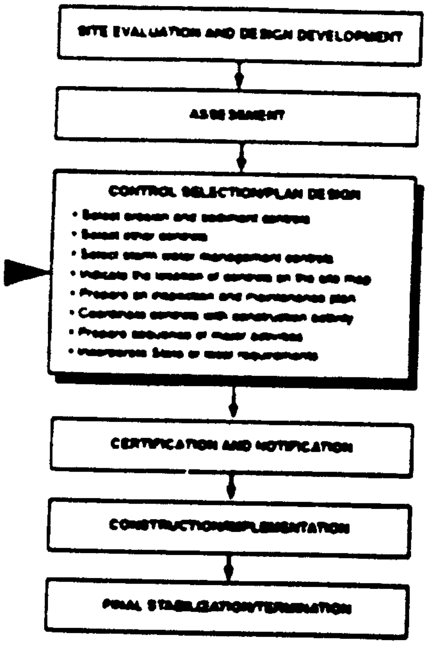
$$C = \frac{(5\ ac.\ x\ .9) + (5\ ac.\ x\ .2) + (5\ ac.\ x\ .1)}{(5\ ac. + 5\ ac. + 5\ ac.)}$$

$$C = \frac{(4.5\ ac.) + (1.0\ ac.) + (.5\ ac.)}{(15\ ac.)}$$

$$C = \frac{6.0\ ac.}{15\ ac.}$$

$$C = .4$$



2.3 CONTROL SELECTION/PLAN DESIGN

Once you have collected the information and made measurements, the next step is to design a plan to prevent and control pollution of storm water runoff from your construction site. Your Storm Water Pollution Prevention Plan should address: erosion and sediment controls, storm water management controls and other controls. The following subsections detail how the controls which you select should be described in the Storm Water Pollution Prevention Plan; however, the methods of selecting the appropriate measures and detailed information about the measures are contained in the following chapters.

2.3.1 Select Erosion and Sediment Controls

The first types of controls which your pollution prevention plan should address are erosion and sediment controls. These controls include stabilization measures for disturbed areas and structural controls to divert runoff and remove sediment. Erosion and sediment controls are implemented during the construction period to prevent and/or control the loss of soil from the construction site into the receiving waters. Erosion and sediment controls can include temporary or permanent measures.

Your selection of the most appropriate erosion and sediment controls for your construction project depends upon a number of factors, but is most dependent on site conditions. The information collected in the site evaluation, design and assessment steps is used to select controls. Chapter 3 provides a series of questions and answers to assist you in selecting the most appropriate measures for your site. There is also a description of the more commonly used sediment and erosion control measures in Chapter 3 and Appendix B provides typical design information for many of the measures described in Chapter 3. Please use these portions of this manual to help you select and design the sediment and erosion controls for your site.

2.3.2 Select Other Controls

In addition to erosion and sediment controls, the pollution prevention plan for your project should address the other potential pollutant sources which may exist on a construction site. They include: proper waste disposal, control of offsite vehicle tracking, compliance with applicable State or local waste disposal, sanitary sewer or septic system regulations, and control of allowable non-storm water discharges. Chapter 4 describes how you can address each of these topics.

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2.3.3 Select Storm Water Management Controls

The final controls which should be addressed in the Storm Water Pollution Prevention Plan are storm water management controls. Storm water management controls are constructed to prevent or control pollution of storm water after the construction is completed. These controls include retention ponds, detention ponds, infiltration measures, vegetated swales, and natural depressions.

As with erosion and sediment controls, your selection of the most appropriate storm water management measures is dependent upon a number of factors, but is most dependent on site conditions. The information collected in the site evaluation, design and assessment steps is used to select controls.

2.3.4 Indicate Location of Controls on the Site Map

Once the pollution prevention controls have been selected, they should be indicated on the site map. Provide the location of each measure used for erosion and sediment control, storm water management and other controls. Below is a list of typical BMPs which illustrate the kinds of controls which you should include on the site map.

1

<u>Erosion and Sediment Control</u>

- Areas of permanent seeding
- Areas of sod stabilization
- Areas of geotextile stabilization
- Silt fence
- Straw bale barrier
- Earth dikes
- Brush barriers
- Drainage swales
- Sediment traps
- Pipe slope drains
- Level spreaders
- Storm drain-inlet protection
- Reinforced soil retaining systems
- Gabions
- Temporary or permanent sediment basins
- Stabilized construction entrances

<u>Storm Water Management Controls</u>

- Storm water detention structures (including wet ponds)
- Storm water retention structures
- Open vegetated swales
- Natural depressions
- Infiltration measures

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The above list may not include every possible control measure. If your plan includes a measure not on this list, you should still indicate it on the site map if possible. It may not be feasible to indicate some controls on the site map, for example it would be very difficult to indicate appropriate waste control on the site map.

Once you have indicated the controls on the site map, it may be necessary to revise the limit of disturbance and/or the drainage boundaries. The limit of disturbance should be indicated outside of any perimeter control, because the construction of most controls does require some soil disturbance. Drainage boundaries are often impacted by diversion structures. This is because the intent of a diversion device is typically to divert runoff from one drainage basin to another. The drainage patterns on the site map should reflect the drainage patterns on the site while the controls are in place.

Once the location of the controls are indicated, the site map is ready to be included in the pollution prevention plan. The table below summarizes the items which are typically required to be indicated on the Storm Water Pollution Prevention Plan site map.

EPA BASELINE GENERAL PERMIT REQUIREMENTS
Storm Water Pollution Prevention Plan Site Plan Requirements Part IV.D.1.e.
The site map shall indicate: • Drainage patterns • Approximate slopes after grading • Area of soil disturbance • Location of major structural and nonstructural controls • Areas where stabilization practices are expected to occur • Location of surface waters.

2.3.5 Prepare Inspection and Maintenance Plan

Once the Storm Water Pollution Prevention Plan is put into effect, you will be responsible for inspecting and maintaining the controls you have proposed to prevent and control pollution of storm water on the construction site.

It is important for you to plan for the inspection and maintenance of vegetation, erosion and sediment control measures and other protective measures which are part of this plan. These controls must be in good operating condition until the area they protect has been completely stabilized or the construction project is complete.

It is recommended that you prepare an inspection and maintenance checklist which addresses each of the control measures proposed for the facility. A blank checklist for your facility could be included in the Storm Water Pollution Prevention Plan prior to starting construction. The inspector could complete a copy of the blank checklist during each inspection. The inspection and maintenance checklist should be prepared based upon the requirements for each individual measure. For example, sediment must be removed from a silt trap when it has filled to one third of its depth. Consult your State/local manuals or Appendix C for maintenance requirements for control measures. Appendix B contains a sample blank Inspection and Maintenance Checklist.

EPA BASELINE GENERAL PERMIT REQUIREMENTS
Maintenance and Inspection Requirements Parts IV.D.3. and IV.D.4. Pollution Prevention Plan shall include: • A description of procedures to maintain in good condition and effective operating condition - Vegetation - Erosion and sediment control measures - Other protective measures identified in the site plan • Qualified personnel shall inspect disturbed areas of the construction site at least once every seven calendar days and within 24 hours of the end of a storm that is 0.5 inches or greater.

2.3.6 Prepare a Description of Controls

Once you have finished planning your construction activities and selected the controls, make a list of each type of control you plan to use on the site. Include in this list a description of each control and what its purpose is and why it is appropriate in this location. The description should also include specific information about the measure such as size, materials, and methods of construction. Read your permit carefully to ensure that your plan includes all of the required controls.

2.3.7 Coordinate Controls with Construction Activity

You also should prepare a sequence of major activities that lists all of the tasks required for: construction of control measures, earth disturbing construction activities, and maintenance activities for control measures in the order in which they will occur. Specific timing requirements for installation and maintenance of control measures are dependent upon the measures and/or the construction activities. Refer to Chapters 3, 4 and 5 for specific timing information on your site's controls. There are, however, several general principles which you should keep in mind when developing the sequence of major activities. These principals are:

1. Downslope and sideslope perimeter controls should be installed <u>before</u> the land disturbing activity occurs.
2. Do not disturb an area until it is necessary for construction to proceed.
3. Cover or stabilize as soon as possible.
4. Time activities to limit impact from seasonal climate changes or weather events.
5. Construction of infiltration measures should be delayed to the end of the construction project when upstream drainage areas have been stabilized.

6. Do not remove temporary perimeter controls until after all upstream areas are stabilized.

Appendix B contains a sample description of controls and sequence of major activities.

2.3.8 Incorporate State or Local Requirements

Construction operations are often subject to State or local sediment and erosion or storm water management program requirements in addition to any requirements in the site's NPDES storm water permit. It is very likely that these State and local requirements will overlap with your site's Storm Water Pollution Prevention Plan requirements. However, since not all localities have such programs, or the programs do not meet the standards set by your NPDES storm water permit, overlap may be limited. Therefore, because State and local programs can vary significantly from locality to locality, the Storm Water Pollution Prevention Plan components of an NPDES storm water permit ensure that a minimum level of pollution prevention is required. Where a construction site has taken measures to comply with State and local requirements, and these measures fulfill requirements of the Storm Water Pollution Prevention Plan conditions, the applicable measures may be incorporated into the plan.

The Permit may require that any State and local sediment and erosion control or storm water management requirements be incorporated by reference into the plan. This approach allows States and localities the flexibility to maintain their existing programs and provides additional authority for enforcement. Therefore, you should check the requirements of your permit to determine if you must include a copy of a sediment and erosion control and/or storm water management plan which is approved by a State or local authority.

EPA BASELINE GENERAL PERMIT REQUIREMENTS
Permit Requirements for State/Local Plans **Part IV.D.2.d.(1).** **Permittees shall incorporate all applicable requirements specified in State or local sediment and erosion control plans or permits, or storm water management plans or permits. The permittee must provide a certification that their Pollution Prevention Plan reflects these requirements, and permittees shall comply with these requirements during the term of the permit.**

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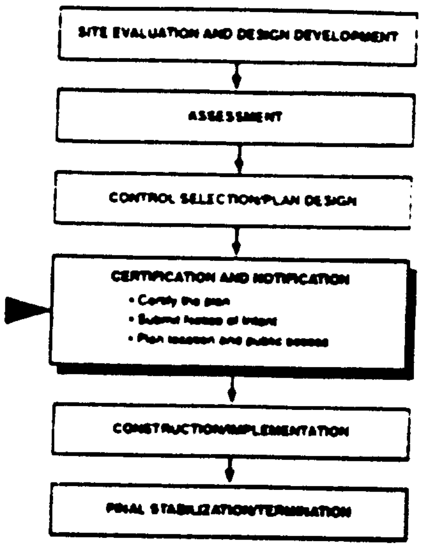

2.4 CERTIFICATION AND NOTIFICATION

Once the site description and controls portion of the Storm Water Pollution Prevention Plan have been prepared then you now can certify the pollution prevention plan. If you intend to be included under the general permit, then you should submit a notice of intent to the appropriate agency.

It is recommended that you read your permit carefully to evaluate whether or not all the required items are included in your Storm Water Pollution Prevention Plan prior to certifying the plan or submitting a Notice of Intent.

2.4.1 Certification

In order to ensure that your site's Storm Water Pollution Prevention Plan is completely developed and adequately implemented, your NPDES storm water permit will typically require that authorized representative(s) of the operator(s) sign and certify the plan. The authorized representative(s) should be individuals at or near the top of the management chain, such as the president, vice president, or a general partner who has been delegated the authority to sign and certify this type of document. In signing the plan, the authorized representative(s) certifies that the information is true and assumes liability for the plan.

Official signatures provide a basis for an enforcement action to be taken against the person signing the document. The permittee should be aware that Section 309 of the Clean Water Act provides for significant penalties where information is false or the permittee violates, either knowingly or negligently, its permit requirements. Specific signatory requirements for the Storm Water Pollution Prevention Plan will be listed in your NPDES storm water permit.

EPA BASELINE GENERAL PERMIT REQUIREMENTS
Signature Requirements **Parts V.B. and VI.G.** All reports, certifications, or information either submitted to the Director or to the operator of a large or medium municipal separate storm sewer system, or required to be maintained by the permittee onsite shall be signed according to the following details:
Parts VI.G.1.a., b., and c. • For a corporation, the plan must be signed by a "responsible corporate officer." A responsible corporate officer may be <u>any one of the following</u>: - A president, secretary, treasurer, or vice-president of the corporation in charge of a principal business function, or any other person who performs similar policy or decision-making functions for the corporation - The manager of one or more manufacturing, production, or operating facilities employing more than 250 persons or having gross annual sales or expenditures exceeding $25,000,000 (in second quarter 1980 dollars) if authority to sign documents has been assigned or delegated to the manager in accordance with corporate procedure. • For a partnership or sole proprietorship, the plan must be signed by a general partner or the proprietor, respectively. • For a municipality, State, Federal, or other public agency, the plan must be signed by either: - The principal executive officer or ranking official, which includes the chief executive officer of the agency, or - The senior officer having responsibility for the overall operations of a principal geographic unit of the agency (e.g., Regional EPA Administrators).
Designating Signatory Authority **Parts VI.G.2.a., b., and c.** Any of the above persons may designate a duly authorized representative to sign for them. The representative may either be a particular individual or a particular named position. If an authorized representative is appointed, the authorization must be put in writing by the responsible signatory and submitted to the Director. Any change in an authorized individual or an authorized position must be made in writing and submitted to the Director.

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EPA BASELINE GENERAL PERMIT REQUIREMENTS
Reports/Documents Certification Requirements
Part VI.G.2.d.
Any person signing documents under this section shall make the following certification: "I certify under penalty of law that this document and all attachments were prepared under my direction or supervision in accordance with a system designed to assure that qualified personnel properly gathered and evaluated the information submitted. Based on my inquiry of the person or persons who manage the system, or those persons directly responsible for gathering the information, the information submitted is, to the best of my knowledge and belief, true, accurate, and complete. I am aware that there are significant penalties for submitting false information, including the possibility of fine and imprisonment for knowing violations."

Construction activities typically have contractors or subcontractors who are responsible for implementing the controls specified in the plan, but may not have the authority to design or modify the plan. Many NPDES permits will require that these contractors certify that they understand the requirements of the permit and the plan.

EPA BASELINE GENERAL PERMIT REQUIREMENTS
Requirements for Contractors and Subcontractors
Parts IV.E.1. and IV.E.2.
The site's Storm Water Pollution Prevention Plan shall provide a list of all contractors and subcontractors who will implement the measures identified in the plan. In addition, these contractors and subcontractors shall sign a certification statement and provide their names, addresses, and telephone numbers. These certifications shall be signed before the contractor begins activities and shall be filed with the site's Storm Water Pollution Prevention Plan.
The following statement shall be signed in accordance with the signatory requirements described above.
"I certify under penalty of law that I understand the terms and conditions of the general National Pollutant Discharge Elimination System (NPDES) permit that authorizes the storm water discharges associated with industrial activity from the construction site identified as part of this certification."

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2.4.2 Notice of Intent

If you intend to include your project under a General Permit for Storm Water Discharges Associated With Industrial Activity from Construction Activities, then you are typically required to submit an NOI prior to commencement of construction. Consult your permit to determine the exact deadline for submitting an NOI. It should be noted that typically the NOI cannot be submitted until the Storm Water Pollution Prevention Plan has been prepared.

In cases where more than one party meets the definition of an "operator" of a construction activity (see Section 1.3 or consult your permit), all of those parties may need to submit an NOI and become co-permittee's.

EPA BASELINE GENERAL PERMIT REQUIREMENTS

Notice of Intent Requirements

Parts II.A.2 and II.B.

Individuals who intend to obtain coverage for storm water discharges from a construction site (where disturbances associated with the construction project begin after October 1, 1992) shall submit an NOI at least 2 days prior to the commencement of construction.

The NOI should include:

1. The mailing address of the construction site for which the notification is submitted. Where a mailing address for the site is not available, the location of the approximate center of the site must be described in terms of the latitude and longitude to the nearest 15 seconds, or the section, township and range to the nearest quarter;

2. The name, address and telephone number of the operator(s) with day to day operational control that have been identified at the time of the NOI submittal, and operator status as a Federal, State, private, public or other entity. Where multiple operators have been selected at the time of the initial NOI submittal, NOIs must be attached and submitted in the same envelope. When an additional operator submits an NOI for a site with a preexisting NPDES permit, the NOI for the additional operator must indicate the number for the preexisting NPDES permit;

3. The name of the receiving water(s), or if the discharge is through a municipal separate storm sewer, the name of the municipal operator of the storm sewer and the ultimate receiving water(s);

4. The number of any NPDES permit for any discharge (including non-storm water discharges) for the site that is currently authorized by an NPDES permit.

5. An indication of whether the facility has existing quantitative data describing the concentration of pollutants in the storm water discharge available (existing data should <u>not</u> be included as part of the NOI); and

6. An estimate of project start date and completion dates, estimates of the number of acres of the site on which soil will be disturbed, and a certification that a storm water pollution prevention plan has been prepared for the site in accordance with Part IV of this permit, and such plan provides compliance with approved State and/or local sediment and erosion plans or permits and/or storm water management plans or permits in accordance with Part IV.D.2.d of this permit. (A copy of the plans or permits should not be included with the NOI submission).

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2.4.3 Plan Location and Public Access

Submittal Requirements/Plan Location

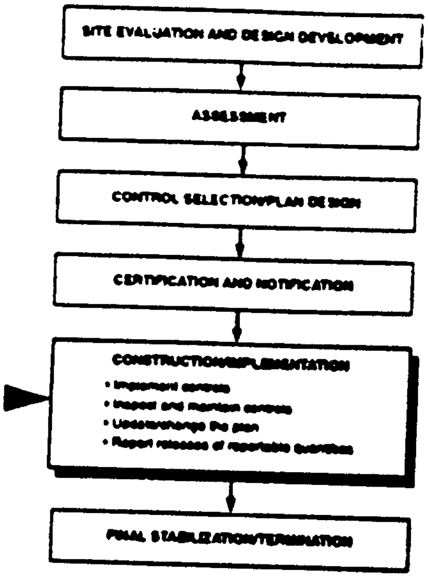
Some NPDES storm water permits for construction sites may require that Storm Water Pollution Prevention Plans be submitted to the Director for review, whereas other permits may only require that plans be maintained onsite. Permitting authorities may prefer not to require plans to be submitted to reduce the administrative burden of reviewing a large number of pollution prevention plans. However, when the Director requests the plan, permittees should submit it in a timely manner. In addition, when requested, permittees should also submit their plan to State or local sediment and erosion or storm water management agencies, or to a municipal operator where the site discharges through an NPDES storm water permitted municipal separate storm sewer system. Examine your permit carefully to determine what requirements apply to your facility regarding submitting plans.

Regardless of whether or not the Storm Water Pollution Prevention Plan should be submitted to the permitting authority or other public agency, site operators are expected to keep the plan and supporting materials at the site of the construction operations at all times throughout the project. In maintaining plans onsite, you should keep all records and supporting documents compiled together in an orderly fashion. Your permit may require that all records be maintained for a certain period of time after the project is completed. This provision ensures that all records are available in case a legal situation arises for which documentation is necessary.

EPA BASELINE GENERAL PERMIT REQUIREMENTS
Submittal/Plan Location Requirements **Parts IV.B. and V.A., B.** Storm Water Pollution Prevention Plans for construction activities shall be maintained onsite of the activity unless the Director, or authorized representative, the operator of a large or medium municipal separate storm sewer system, or a State or local sediment and control agency requests that the plan be submitted. Permittees should keep a copy of the plan at the construction site until the site is finally stabilized. In addition, permittees are required to keep the plan, all reports and data for at least three years after the project is complete.

Public Access

Despite the fact that plans and associated records are not necessarily required to be submitted to the Director, these documents are considered to be "reports" according to Section 308(b) of the Clean Water Act, and therefore, are available to the public. Your permit may require you to provide copies of your plan to your permitting authority, municipal operator, or State or local agency upon request. However, permittees may claim certain portions of their Storm Water Pollution Prevention Plan as confidential according to the regulations at 40 CFR Part 2. Basically, these regulations state that records which contain trade secret information may be claimed as confidential.



2.5 CONSTRUCTION/IMPLEMENTATION

Once you have prepared a Storm Water Pollution Prevention Plan and filed a Notice of Intent, you may then start construction of the project. However, you are not finished meeting the requirements of your permit. You should now do the things which you said you would do in the Storm Water Pollution Prevention Plan.

2.5.1 Implement Controls

The first step you should take is to construct or perform the controls which were selected for the Storm Water Pollution Prevention Plan. The controls should be constructed or applied in accordance with State or local standard specifications. If there are no State or local specifications for control measures then the controls should be constructed in accordance with good engineering practices. Appendix B of this manual lists typical design standards for structural control measures. The controls should be constructed and the stabilization measures applied in the order which you indicated in the sequence of major activities.

To ensure that controls are adequately implemented, it is important that the work crews which install the measures are experienced and/or adequately trained. Improperly installed controls can have little or no effect and may actually increase the pollution of storm water.

It is also important that all other workers on the construction site be made aware of the controls so that they do not inadvertently disturb or remove them.

2.5.2 Inspect and Maintain Controls

Inspection and maintenance of the control measures is as important to pollution prevention as proper planning and design. Chapter 5 describes in further detail the inspection and maintenance activities which should be performed. Inspection should be performed at the frequency specified in the Storm Water Pollution Prevention Plan and/or the permit. The inspector should note any damage or deficiencies in the control measures in an inspection report. The operator should correct damage or deficiencies as soon as practicable after the inspection, and any changes that may be required to correct deficiencies in the Storm Water Pollution Prevention Plan should be made as soon as practicable after the inspection.

2.5.3 Maintain Records of Construction Activities

In addition to the inspection and maintenance reports, the operator should keep records of the construction activity on the site. In particular, the operator should keep a record of:

- The dates when major grading activities occur in a particular area
- The dates when construction activities cease in an area, temporarily or permanently
- The dates when an area is stabilized.

You can use these records to make sure that areas where there is no construction activity will be stabilized within the required timeframe.

2.5.4 Changing the Plan

In order for a construction activity to be in full compliance with its NPDES storm water permit, and in order for the Storm Water Pollution Prevention Plan to be effective, the plan should be consistent with permit conditions, and the plan should accurately reflect site features and operations. Should either of these conditions not be met by the plan, the plan should be changed.

If, at any time during the effective period of the permit, the permitting authority finds that the plan does not meet one or more of the minimum standards established by the pollution prevention plan requirements, the permitting authority will notify the permittee of required changes necessary to bring the plan up to standard.

Storm Water Pollution Prevention Plans are developed based on site-specific features and functions. Where there are changes in design, construction, operation, or maintenance, and that change will have a significant effect on the potential for discharging pollutants in storm water at a site, the Storm Water Pollution Prevention Plan should be modified by the permittee to reflect the changes and new conditions. For example, a change in the construction schedule or design specifications should be incorporated in the Storm Water Pollution Prevention Plan. Another situation in which the plan should be modified is where the plan proves to be ineffective in controlling pollutants. This determination could be made based on the results of regular visual inspections (see Chapter 5).

EPA BASELINE GENERAL PERMIT REQUIREMENTS
Requirements for Storm Water Pollution Prevention Plan Changes **Parts IV.B.3. and IV.C.** Any changes required by the permitting authority shall be made within 7 days of the notification or an individual application should be submitted, unless otherwise provided by the notification. The permittee should submit a certification to the permitting authority that the requested changes have been made. The Storm Water Pollution Prevention Plan requirements also specify that the permittee to update the plan as necessary to reflect any changes onsite which may affect the potential for discharges of pollutants from the site.

2.5.5 Releases of Reportable Quantities

Because construction activities may handle certain hazardous substances over the course of the project, spills of these substances in amounts that equal or exceed Reportable Quantity (RQ) levels are a possibility. EPA has issued regulations which define what reportable quantity levels are for oil and hazardous substances. These regulations are found at 40 CFR Part 110, 40 CFR Part 117, or 40 CFR Part 302 (see Appendix F for a complete list). For oil, if you detect an oily sheen in your storm water runoff, then you have exceeded the reportable quantity level. For hazardous substances, the RQ levels depend on the chemical. For example, for dieldrin, a pesticide, the level is 1 kilogram (kg). If you spill or otherwise release one or more kg of dieldrin, then you have exceeded the RQ threshold. Spill events such as these can be avoided if your site's Storm Water Pollution Prevention Plan addresses this possibility. Chapter 5 discusses spill prevention and control. To do this, your permit may require a description of potential spill areas in your site description or a description of specific procedures to respond to and clean up a spill. Another possibility would be for your permit to establish a RQ release as a trigger for more stringent requirements, such as a requirement to submit an individual application.

EPA BASELINE GENERAL PERMIT REQUIREMENTS

Requirements for Reporting Spills

Part III.B.

If the construction site has a release of a hazardous substance or of oil in an amount which exceeds a reportable quantity (RQ) as defined at 40 CFR Part 110, 40 CFR Part 117, or 40 CFR Part 302 (see Appendix F for a complete list), then the permittee shall do several things:

- The person in charge of the site at the time of the spill shall call the National Response Center to report the spill (800-424-8802, or 202-426-2675);
- Within 14 days after the release is detected, modify the site Storm Water Pollution Prevention Plan. The modification shall include: a description of the release; the date of the release; an explanation of why the spill happened; a description of procedures to prevent future spills and/or releases from happening; and a description of response procedures should a spill or release occur again; and
- Within 14 days of the release, submit a written description of the release including: a description of the release, including the type of material and an estimated amount of spill; the date of the release; an explanation of why the spill happened; and a description of the steps taken to prevent and control future releases.

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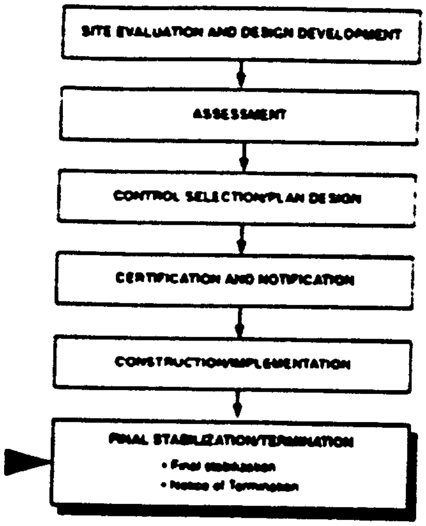

2.6 FINAL STABILIZATION/ TERMINATION

Your permit for discharge of storm water associated with a construction activity may remain in effect until the discharge is eliminated. This does not mean when the storm water discharge is eliminated but that the construction is completed.

Typically, the storm water discharge associated with an industrial activity is eliminated when the site is finally stabilized. When storm water discharge associated with an industrial activity ceases, the permit may allow the owner/operator of the facility to cease coverage by submitting a Notice of Termination.

2.6.1 Final Stabilization

As soon as practicable after construction activities have been completed in a disturbed area, permanent stabilization should be started to prevent further erosion of soil from that area. All disturbed areas of a site (except those portions which are covered by pavement or a structure) should be finally stabilized once all construction activities are completed. Final stabilization requirements may vary from permit to permit. Read your permit to determine exactly what constitutes final stabilization.

EPA BASELINE GENERAL PERMIT REQUIREMENTS
Final Stabilization Requirements
Part IX.
A site can be considered finally stabilized when all soil disturbing activities at the site have been completed and a uniform perennial vegetative cover with a density of 70 percent for the unpaved areas and areas not covered by permanent structures has been established or equivalent permanent stabilization measures have been employed.

2.6.2 Notice of Termination

The Notice of Termination is typically the final task required to comply with the requirements of an NPDES storm water permit for a construction activity. The Notice of Termination communicates to the permit enforcement agency that the construction activity has ceased and the area is stabilized. Your permit may list the requirements for Notice of Termination. Check the permit to see what information is required and when it may be submitted.

EPA BASELINE GENERAL PERMIT REQUIREMENTS

Notice of Termination Requirements

Part VIII.A.

Notice of Termination shall include:

1. The mailing address of the construction site for which the notification is submitted. Where a mailing address for the site is not available, the location of the approximate center of the site must be described in terms of the latitude and longitude to the nearest 15 seconds, or the section, township and range to the nearest quarter;

2. The name, address and telephone number of the operator addressed by the Notice of Termination;

3. The NPDES permit number for the storm water discharge identified by the Notice of Termination;

4. An indication of whether the storm water discharges associated with industrial activity have been eliminated or the operator of the discharges has changed; and

5. The following certification signed in accordance with Part VI.G. (signatory requirements) of this permit:

   "I certify under penalty of law that all storm water discharges associated with industrial activity from the identified facility that are authorized by an NPDES general permit have been eliminated or that I am no longer the operator of the construction activity. I understand that by submitting this notice of termination, that I am no longer authorized to discharge storm water associated with industrial activity under this general permit, and that discharging pollutants in storm water associated with industrial activity to waters of the United States is unlawful under the Clean Water Act where the discharge is not authorized by an NPDES permit. I also understand that the submittal of this notice of termination does not release an operator from liability for any violations of this permit or the Clean Water Act."

For the purposes of this certification, elimination of storm water discharges associated with industrial activity means that all disturbed soils at the identified facility have been finally stabilized and temporary erosion and sediment control measures have been removed or will be removed at an appropriate time, or that all storm water discharges associated with construction activities from the identified site that are authorized by a NPDES general permit have otherwise been eliminated.

2.7 SUMMARY

This chapter has tried to describe the components of an effective Storm Water Pollution Prevention Plan for construction activities. The process of developing and implementing a Storm Water Pollution Prevention Plan has been described on a step-by-step basis in the order that the plan should be assembled. Table 2.2 summarizes the components of a Storm Water Pollution Prevention Plan and indicates where these components are described.

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TABLE 2.2 SUMMARY OF STORM WATER POLLUTION PREVENTION PLAN COMPONENTS FOR CONSTRUCTION ACTIVITIES

Component	See Section:	Further Information Available In
a. SITE DESCRIPTION		
(1) Description of the nature of construction activity	2.1.2	
(2) Estimate of total area of the site and of the area expected to be disturbed	2.2.1	
(3) Runoff coefficient	2.2.3	
(4) Site map including:		
• Drainage patterns	2.1.1	
• Approximate slopes	2.1.3	
• Area of soil disturbance	2.1.3	
• Location of structural and nonstructural controls	2.3.4	Chapters 3, 4, and 5
• Location of stabilization practices	2.3.4	Chapter 3
• Surface waters (Type)	2.1.1	
(5) Receiving waters (Name)	2.1.1	
b. DESCRIPTION OF CONTROLS		
Sequence of major activities	2.3.6	
Timing for each control measure	2.3.6	Chapters 3, 4, and 5
(1) Erosion and Sediment Controls		Chapter 3
(a) Description of Stabilization Practices	2.3.1 and 2.3.6	Chapter 3
(b) Description of Structural Practices	2.3.1 and 2.3.6	Chapter 3
(2) Storm water management	2.3.2 and 2.3.6	
(3) Other controls	2.3.3 and 2.3.6	Chapter 4
(4) Approved State or local plans	2.3.7	Chapter 3
(5) Description of maintenance	2.3.5	Chapter 5
(6) Inspectors		
(b) Changes to the plan	2.5.3	
(c) Inspection reports	2.5.2 and 2.3.5	Chapter 5
5. Non-Storm Water Discharges		
Description of controls for non-storm water discharges	2.3.6	Chapter 5
6. Industrial activities onsite	2.1.3	
7. Contractors		
Certification	2.4.1	

CHAPTER 3

SEDIMENT AND EROSION CONTROL

Soil erosion and sediment controls are measures which are used to reduce the amount of soil particles that are carried off of a land area and deposited in a receiving water. Soil erosion and sediment control is not a new technology. The USDA Soil Conservation Service and a number of State and local agencies have been developing and promoting the use of erosion and sediment control devices for years.

This chapter provides a general description of some of the most commonly used measures today and a method to select the most appropriate measures for your project. The descriptions contained in this chapter are very simple and are intended to provide general understanding rather than specific design information. You are encouraged to consult your State or local guidance books for sediment and erosion control measure design standards. You are also encouraged to consult the design fact sheets contained in Appendix B of this manual.

3.1 SELECTION OF SOIL EROSION AND SEDIMENT CONTROL PRACTICES

Your selection of the best soil erosion and sediment controls for your site should be primarily based upon the nature of the construction activity and the conditions which exist at the construction site.

The soil erosion and sediment control portion of the Storm Water Pollution Prevention Plan should:

- **Minimize the amount of disturbed soil**
- **Prevent runoff from offsite areas from flowing across disturbed areas**
- **Slow down the runoff flowing across the site**
- **Remove sediment from onsite runoff before it leaves the site**
- **Meet or exceed local or State requirements for sediment and erosion control plans.**

Your soil erosion and sediment control plan should meet each of the objectives listed above. How you meet these objectives depends primarily on the nature of the construction activity and the characteristics of the site. The following subsections are presented in a question and answer format. The questions concern certain characteristics of your construction site. Your answer to each of these questions will help you determine what sediment and erosion control practices are best suited for your construction project.

Appendix A includes an Erosion and Sediment Control Checklist. This checklist can be used in your review of the erosion and sediment control portion of your Pollution Prevention Plan to evaluate compliance with typical storm water construction permit requirements. You should also review your projects.

The major problem associated with erosion at construction sites is the movement of soil off the site and its impact on water quality. Construction site erosion is a source of sediments, toxicants, and nutrients which pollute the receiving water(s). Clearing, grading, or otherwise altering previously undisturbed land at a construction site increases the erosion rate by as much as 1,000 times the pre-construction rate. Millions of tons of sediment are generated annually by the construction industry in the United States alone, and erosion rates, typically 100 to 200 tons per acre, have been reported as high as 500 tons per acre (State of North Carolina, 1988).

Q. What is Erosion?

Erosion, by the action of water, wind, and ice, is a natural process in which soil and rock material is loosened and removed. There are two major classifications of erosion: (1) geological erosion, and (2) man-made erosion.

Geological erosion, which includes soil-forming as well as soil-removing, has contributed to the formation of soils and their distribution on the surface of the earth. Man-made erosion, which can greatly accelerate the natural erosion process, includes the breakdown of soil aggregates and the increased removal of organic and mineral particles; it is caused by clearing, grading, or otherwise altering the land. Erosion of soils that occurs at construction sites is man-made erosion.

Factors Influencing Erosion by Water

Erosion of the land surface may be caused by water, wind, ice, or other geological agents. Water erosion, which is the focus of this document, is the loosening and removal of soil from the land by running water, including runoff from melted snow and ice. The major factors affecting soil erosion are soil characteristics, climate, rainfall intensity and duration, vegetation or other surface cover, and topography.

Understanding the factors that effect erosion makes it possible to predict the extent and consequences of onsite erosion.

3.1.1 Minimize the Amount of Disturbed Soil

Why?

Minimizing the amount of disturbed soil on the construction site will decrease the amount of soil which erodes from the site, and it can decrease the amount of controls you have to construct to remove the sediment from the runoff.

Q. How does disturbing soil cause erosion?

Disturbing soil can remove the vegetation. Vegetation is the most effective way to control erosion. Vegetative covers reduce erosion by: (1) shielding the soil surface from the impact of falling rain and thus reducing runoff; (2) dispersing and decreasing the velocity of surface flow; (3) physically restraining soil movement; (4) increasing infiltration rates by improving the soil's structure and porosity through the incorporation of roots and plant residues; and (5) conducting transpiration, which decreases soil moisture content and increases soil moisture storage capacity. Figure 3.1 illustrates some of the ways that vegetation helps control erosion.

Nonvegetative covers such as mulches and stone aggregates similarly protect soils from erosion. Like vegetative covers, these ground covers shield the soil surface from the impact of falling rain, reduce flow velocity, and disperse flow. Each of these types of cover provides a rough surface that slows the runoff velocity and promotes infiltration and deposition of sediment. The condition as well as the type of ground cover influences the rate and volume of runoff. It should be noted that although impervious surfaces (such as parking lots) protect the covered area, they prevent infiltration and consequently increase the peak flow rate which increases the potential for erosion at the discharge area.

Q. Did you develop a site plan that does not require a significant amount of grade changes?

A construction project site should be selected and laid out so that it fits into existing land contours. When you try to significantly change the grades in an area you can increase the amount of disturbed soil which increases the amount of erosion which will occur. Significant regrading can also disturb the natural drainage of an area, and can be more costly.

Q. Are there portions of the site which will not have to be cleared for construction to proceed?

Only clear and grub the portions of the site where it is necessary for construction. When less area is disturbed for construction, there is less erosion of soil. Natural vegetation can also improve the aesthetics of the site. See page 3-24 Preservation of Natural Vegetation for further discussion on this BMP.

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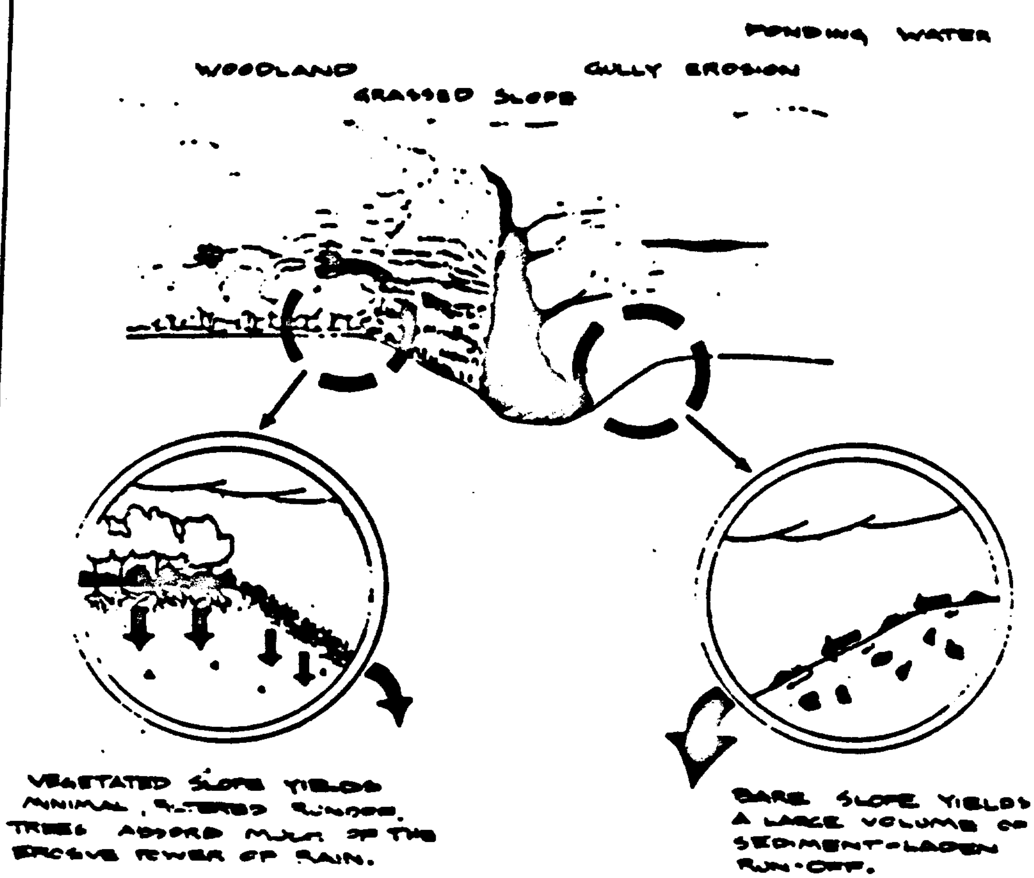

FIGURE 3.1 EROSION PREVENTION BY STABILIZATION
(From State of North Carolina, 1988)

Q. Can the construction be performed in stages, so that the entire site does not have to be cleared at one time?

If your construction project will take place over a wide spread area, consider staging the project so that only a small portion of the site will be disturbed at any one time. For example, if you were developing a 100-acre housing subdivision, rather than clear the entire 100 acres at the start of construction, only clear a 20-acre parcel, grade the area, install the utilities, pave the roads, construct the houses, landscape and seed the lawn areas, then move on to the next 20-acre parcel. Phased construction helps to lessen the risk of erosion by minimizing the amount of disturbed soil that is exposed at any one time.

Q. Are there portions of the site which will be disturbed then left alone for long periods of time?

If there are disturbed portions of the site that will not be re-disturbed for a long period (check your permit to see what the maximum time is), then these areas should be stabilized with Temporary Seeding (see page 3-14) or Mulching (see page 3-16). This will reduce the amount of erosion from these areas until they are disturbed again. For example, if soil excavated from a temporary sediment trap is stockpiled to be used later to backfill the trap (when the area is stabilized) then the stockpile should be stabilized with temporary seed.

Q. Do you stabilize all disturbed areas after construction is complete?

By permanently stabilizing the disturbed areas as soon as possible after construction is complete in those areas, you can significantly reduce the amount of sediment which should be trapped before it leaves your site. An area can be stabilized by Permanent Seeding and Planting (see page 3-20), Mulching (see page 3-16), Geotextiles (see page 3-17), and Sod Stabilization (see page 3-26).

Q. Does snow prevent you from seeding an area?

If snow cover prevents you from seeding a disturbed area or planting other types of vegetation, then you should wait until the snow melts before stabilizing the area.

Q. Is there not enough rainfall to allow vegetation to grow on your construction site.

If there is not enough rainfall on the area you have disturbed to allow vegetation to grow then you should:

- Seed and irrigate the disturbed area (if allowed by your permit-see non storm-water flows) or,
- Stabilize the disturbed areas by non-vegetative methods (See Mulching (page 3-16), Geotextiles (page 3-17), or Chemical Stabilization (page 3-19).

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3.1.2 Prevent Runoff From Offsite Areas From Flowing Across Disturbed Areas

Why?

Diverting offsite runoff around a disturbed area reduces the amount of storm water which comes into contact with the exposed soils. If there is less runoff coming in contact with exposed soil, then there will be less erosion of the soil and less storm water which has to be treated to remove sediment.

Q. Does runoff from undisturbed uphill areas flow onto your construction site?

Overland flow can be diverted around a construction site by installing an Earth Dike (see page 3-37), an Interceptor Dike and Swale (see page 3-41), or a Drainage Swale (see page 3-39). Your choice of diversion methods depends upon the size of the uphill area and the steepness of the slope the diversion must go down. Interceptor dikes and swales are effective in diverting overland flows from smaller areas (3 acres or less) down gentle slopes (10 percent or less). A temporary swale is most effective diverting runoff from concentrated channels and an earth dike is capable of diverting both sheet and concentrated flows from larger areas down steeper slopes. (See Appendix B for specific design information regarding each of these diversion measures.) These devices should be installed from the uphill side of the site down to a point where they can discharge to an undisturbed area on the downhill side of the site.

Q. Will runoff flow down a steeply sloped, disturbed area on the site?

Steeply sloped areas are especially susceptible to erosion. If there are steep areas on your site which will be disturbed, then an Earth Dike (page 3-37) or Interceptor Dike and Swale (page 3-41) may be used to divert the runoff from the top of the slope to the inlet of Pipe Slope Drain (page 3-48) or to a less steeply sloped area. These measures will minimize the amount of runoff flowing across the face of a slope and decrease the erosion of that slope.

Q. Is there a swale or stream which runs through your construction site?

Swales and streams which run through construction sites must be protected from erosion and sediment because they can be significantly damaged. Streams and other water bodies should be protected by Preservation of Natural Vegetation (see page 3-24) or Buffer Zones (see page 3-22). Where possible, these techniques should also be used to protect swales or intermittent streams.

Where construction requires that the stream or swale be disturbed, then the amount of area and time of disturbance should be kept at a minimum. All stream and channel crossings should be made at right angles to the stream, preferably at the most narrow portion of the channel. Once a stream or swale is disturbed, construction should proceed as quickly as possible in this area. Once completed, the stream banks should be stabilized with Stream Bank Stabilization (see page 3-28), Gabions. Swales and intermittent streams disturbed by construction should be seeded and stabilized with Geotextiles (see page 3-17) as soon as possible.

Q. Does construction traffic have to cross a drainage swale or stream?

If it is necessary to cross a swale or stream to get to all or parts of your construction site, then before you begin working on the opposite side of the stream, you should construct a Temporary Stream Crossing (see page 3-43). Stream crossings can be either permanent or temporary depending upon the need to cross the stream after construction is complete.

3.1.3 Slow Down the Runoff Traveling Across the Site

Why?

The quantity and size of the soil particles that are loosened and removed increase with the velocity of the runoff. This is because high runoff velocities reduce infiltration into the soil (and therefore also increase runoff volume) and exert greater forces on the soil particles causing them to detach. It is no surprise, therefore, that high flow velocities are associated with severe rill and gully erosion.

Q. Is your site gently sloped?

When preparing the grading plan, try to make grades as gradual as possible without modifying the existing site conditions significantly. Steeper slopes result in faster moving runoff, which results in greater erosion. Erosion can occur on even the gentlest of slopes depending on soil and climate conditions. The State/local representative of the Soil Conservation Service is a good source of area-specific considerations. (The USDA defines slopes of 2 to 9 percent as gently sloping; slopes of 9 to 15 percent are considered moderately steep; slopes of 30 to 50 percent are considered to be steep slopes; and slopes greater than 50 percent are considered very steep slopes.)

Q. Are there steeply sloped areas on your site?

Steeply sloped areas can be protected from erosion in a number of ways. Section 3.1.2 describes how flow can be diverted away from the face of the slope; however, this technique does not address runoff from the slope itself. Gradient Terraces (see page 3-70) should be used to break the slope and slow the speed of the runoff flowing down the hillside. Surface Roughening (see page 3-67) can also be used on sloped areas as a method to slow down overland flow on a steep slope.

Q. Is your site stabilized with vegetation?

In addition to holding soil in place and shielding it from the impact of rain drops, vegetative cover also increases the roughness of the surface runoff flows over. The rougher surface slows the runoff. An area can be stabilized by Permanent Seeding (see page 3-20), Mulching (see page 3-16), Geotextiles (see page 3-17), and Sod Stabilization (see page 3-26).

Q. Does runoff concentrate into drainage swales on your site?

Concentrated runoff can be more erosive than overland flow. Runoff concentrated into swales or channels can be slowed by reducing the slope and increasing the width of a channel. When site conditions prevent decreasing the slope and widening a channel, then runoff can be slowed with Check Dams (see page 3-65). Runoff can also be slowed in channels by establishing a vegetative cover. Geotextiles (see page 3-17) are often used to hold the channel soil in place while the grass is growing.

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3.1.4 Remove Sediment From Onsite Runoff Before It Leaves the Site

Why?

Despite the many advances in meteorology, it is not possible to predict more than a few days in advance when it will rain. It takes several weeks to establish a grass cover which can effectively control erosion, and, even if there were advanced warning of rainfall, it is not always possible to halt construction activities in an area to allow grass to grow. Therefore, it is necessary on most construction sites to install measures which can remove sediment from runoff before it flows off of the construction site.

Q. Does your construction disturb an area 10 acres or larger that drains to a common location?

The sediment control device which is most suitable for large disturbed areas is the Sediment Basin (see page 3-60). A sediment basin should be installed at all locations where there is an upstream disturbed area of 10 acres or more. Only if a sediment basin is not attainable should other sediment controls be installed. A sediment basin may not be attainable at a location if:

- Shallow bedrock prevents excavation of a basin
- Topography in the common drainage location prohibits the construction of a basin of adequate storage volume
- There is insufficient space available at the common drainage location to construct a basin, due to the presence of existing structures, pavement, or utilities which cannot be relocated
- The only common drainage location is beyond the property line or "right of way" of the construction activity and a temporary construction easement cannot be obtained
- State, local, or other Federal regulations prohibit a basin or the construction of a basin in the common drainage locations.

Q. Does your construction disturb an area less than 10 acres that drains to a common location?

Disturbed areas less than 10 acres in size have more variety in the measures which are suitable for sediment control. Several types of measures can be used for sediment control including: Sediment Basins, Sediment Trap, Silt Fence, and Gravel Filter Berms. The selection among these measures depends upon a number of criteria. The following questions should help you determine which is the most appropriate.

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Q. What if a sediment basin is not attainable on a site where there are 10 or more disturbed acres which drain to a common location?

If you cannot install a sediment basin on your site, then you should install Sediment Traps (see page 3-58), Silt Fences (see page 3-52), or other equivalent sediment control measures such as Gravel Filter Berms (see page 3-54).

Q. Does runoff leave the disturbed area as overland flow?

Sediment can be removed from overland flow using filtration controls such as Silt Fences (see page 3-52) and Gravel Filter Berms (see page 3-54). These methods have limitations (which are described in Section 3.2.2) regarding the specific conditions in which they are effective.

Overland flow runoff from a disturbed area can also be directed to a Sediment Trap (see page 3-58) or a Temporary Sediment Basin (see page 3-60) using diversion devices such as an Earth Dike (see page 3-37) or an Interceptor Dike and Swale (see page 3-41).

Q. Is flow concentrated in channels as it leaves the disturbed area?

Sediment should be removed from concentrated runoff by either a Sediment Trap (see page 3-58) or a Temporary Sediment Basin (see page 3-60) depending upon the disturbed area upstream. Filtration measures are generally not effective when used in concentrated flow because flow will back-up behind the filter until it overtops it.

Q. Are structural controls located along the entire downhill perimeter of all disturbed areas?

Runoff which passes over disturbed soil should pass through sediment controls before it can be allowed to flow off of the construction site. Therefore the entire downslope and side slope borders of the disturbed area should be lined with filtration devices, such as silt fence, or with a diversion device which will carry the runoff to a sediment basin or sediment trap prior to discharging it off site.

Q. Is there a piped storm drain system with inlets in a disturbed area?

If there is a yard drain or curb inlet which receives flow from a disturbed area then a Sediment Basin, Sediment Trap, or Inlet Protection should be constructed to remove the sediment from the runoff before it flows into the inlet.

3.1.5 Meet or Exceed Local/State Requirements for Erosion and Sediment Control

Why?

Many State and local authorities also have sediment and erosion control regulations in place. It is important that these requirements still be met. The NPDES storm water permit your construction project may be required to obtain for storm water is not intended to supersede State or local requirements. It is intended to provide another means to regulate storm water.

Q. Does your State or local government require erosion and sediment control for construction projects?

Consult State or local authorities to determine what, if any, requirements there are for sediment and erosion control on construction projects. Many State and local authorities provide their own design manuals or guidance to assist in preparing a plan which meets their requirements. These State and local requirements should be incorporated into the pollution prevention plan.

If the State or local authority requires review and approval of the sediment and erosion control plan, then a reviewed and approved copy of that plan should be included in the pollution prevention plan.

Q. Does your State or local government have an erosion and sediment control requirement which is different from the requirements of your NPDES storm water permit?

Although most of the provisions of the NPDES storm water permits for construction activities are consistent with most State and local requirements, there may be differences in the specific requirements for control measures. When there is a difference in requirements, you should use the more stringent one. For example, your State may only require you to stabilize a disturbed area within 30 days of the last disturbance; however, the your permit may require you to stabilize an area 14 days after the last disturbance. Under this example, you would be required to stabilize after 14 days.

3.2 SEDIMENT AND EROSION CONTROL PRACTICES

Any site where soils are exposed to water, wind or ice can have soil erosion and sedimentation problems. Erosion is a natural process in which soil and rock material is loosened and removed. Sedimentation occurs when soil particles are suspended in surface runoff or wind and are deposited in streams and other water bodies.

Human activities can accelerate erosion by removing vegetation, compacting or disturbing the soil, changing natural drainage patterns, and by covering the ground with impermeable surfaces (pavement, concrete, buildings). When the land surface is developed or "hardened" in this manner, storm water and snowmelt can not seep into or "infiltrate" the ground. This results in larger amounts of water moving more quickly across a site which can carry more sediment and other pollutants to streams and rivers.

The following sections describe stabilization practices and structural practices for erosion and sediment control. Using the measuras to control erosion and sedimentation is an important part of storm water pollution prevention. These measures are well established and have been required by a number of State and local agencies for years.

3.2.1 Stabilization Practices

Preserving existing vegetation or revegetating disturbed soil as soon as possible after construction is the most effective way to control erosion. A vegetation cover reduces erosion potential in four ways: (1) by shielding the soil surface from the direct erosive impact of raindrops; (2) by improving the soil's water storage porosity and capacity so more water can infiltrate into the ground; (3) by slowing the runoff and allowing the sediment to drop out or deposit; and (4) by physically holding the soil in place with plant roots.

Vegetative cover can be grass, trees, or shrubs. Grasses are the most common type of cover used for revegetation because they grow quickly, providing erosion protection within days. Other soil stabilization practices such as straw or mulch may be used during non-growing seasons to prevent erosion. Newly planted shrubs and trees establish root systems more slowly, so keeping existing ones is a more effective practice.

Vegetative and other site stabilization practices can be either temporary or permanent controls. Temporary controls provide a cover for exposed or disturbed areas for short periods of time or until permanent erosion controls are put in place. Permanent vegetative practices are used when activities that disturb the soil are completed or when erosion is occurring on a site that is otherwise stabilized.

EPA BASELINE GENERAL PERMIT REQUIREMENTS
Stabilization Requirements **Part IV.D.2.a.(1).** Except as provided in paragraphs IV.D.2.(a).(1).(a), (b), and (c) below, stabilization measures shall be initiated as soon as practicable in portions of the site where construction activities have temporarily or permanently ceased, but in no case more than 14 days after the construction activity in that portion of the site has temporarily or permanently ceased. (a). Where the initiation of stabilization measures by the 14th day after construction activity temporary or permanently cease is precluded by snow cover, stabilization measures shall be initiated as soon as practicable. (b). Where construction activity will resume on a portion of the site within 21 days from when activities ceased, (e.g. the total time period that construction activity is temporarily ceased is less than 21 days) then stabilization measures do not have to be initiated on that portion of site by the 14th day after construction activity temporarily ceased. (c). In arid areas (areas with an average annual rainfall of 0-10 inches) and semi-arid areas (areas with an average annual rainfall of 10-20 inches), where the initiation of stabilization measures by the 14th day after construction activity has temporarily or permanently ceased is precluded by seasonal arid conditions, stabilization measures shall be initiated as soon as practicable.

The remainder of this section describes the common vegetative practices listed below:

- Temporary Seeding
- Mulching
- Geotextiles
- Chemical Stabilization
- Permanent Seeding and Planting
- Buffer Zones
- Preservation of Natural Vegetation
- Sod Stabilization
- Stream Bank Stabilization
- Soil Retaining Measures
- Dust Control.

Temporary Seeding

What Is It

Temporary seeding means growing a short-term vegetative cover (plants) on disturbed site areas that may be in danger of erosion. The purpose of temporary seeding is to reduce erosion and sedimentation by stabilizing disturbed areas that will not be stabilized for long periods of time or where permanent plant growth is not necessary or appropriate. This practice uses fast-growing grasses whose root systems hold down the soils so that they are less apt to be carried offsite by storm water runoff or wind. Temporary seeding also reduces the problems associated with mud and dust from bare soil surfaces during construction.

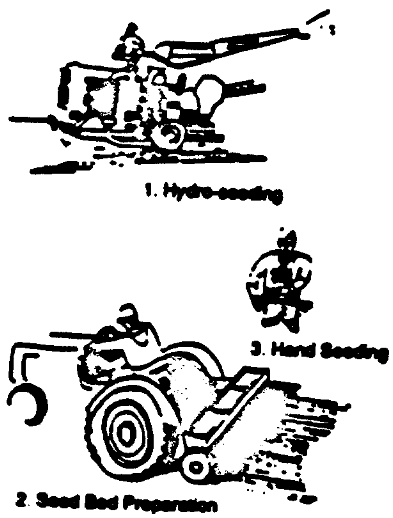

FIGURE 3.2 SEEDING PRACTICES
(Modified from Washington State, 1992)

When and Where to Use It

Temporary seeding should be performed on areas which have been disturbed by construction and which are likely to be redisturbed, but not for several weeks or more. Typical areas might include denuded areas, soil stockpiles, dikes, dams, sides of sediment basins, and temporary roadbanks. Temporary seeding should take place as soon as practicable after the last land disturbing activity in an area. Check the requirements of your permit for the maximum amount of time allowed between the last disturbance of an area and temporary stabilization. Temporary seeding may not be an effective practice in arid and semi-arid regions where the climate prevents fast plant growth, particularly during the dry seasons. In those areas, mulching or chemical stabilization may be better for the short-term (see sections on Mulching, Geotextiles, and Chemical Stabilization).

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What to Consider

Proper seed bed preparation and the use of high-quality seed are needed to grow plants for effective erosion control. Soil that has been compacted by heavy traffic or machinery may need to be loosened. Successful growth usually requires that the soil be tilled before the seed is applied. Topsoiling is not necessary for temporary seeding; however, it may improve the chances of establishing temporary vegetation in an area. Seed bed preparation may also require applying fertilizer and/or lime to the soil to make conditions more suitable for plant growth. Proper fertilizer, seeding mixtures, and seeding rates vary depending on the location of the site, soil types, slopes, and season. Local suppliers, State and local regulatory agencies, and the USDA Soil Conservation Service will supply information on the best seed mixes and soil conditioning methods.

Seeded areas should be covered with mulch to provide protection from the weather. Seeding on slopes of 2:1 or more, in adverse soil conditions, during excessively hot or dry weather, or where heavy rain is expected should be followed by spreading mulch (see section on Mulching). Frequent inspections are necessary to check that conditions for growth are good. If the plants do not grow quickly or thick enough to prevent erosion, the area should be reseeded as soon as possible. Seeded areas should be kept adequately moist. If normal rainfall will not be enough, mulching, matting, and controlled watering should be done. If seeded areas are watered, watering rates should be watched so that over-irrigation (which can cause erosion itself) does not occur.

Advantages of Temporary Seeding
• Is generally inexpensive and easy to do
• Establishes plant cover fast when conditions are good
• Stabilizes soils well, is aesthetic, and can provide sedimentation controls for other site areas
• May help reduce costs of maintenance on other erosion controls (e.g., sediment basins may need to be cleaned out less often)
Disadvantages of Temporary Seeding
• Depends heavily on the season and rainfall rate for success
• May require extensive fertilizing of plants grown on some soils, which can cause problems with local water quality
• Requires protection from heavy use, once seeded
• May produce vegetation that requires irrigation and maintenance

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Mulching

What Is It

Mulching is a temporary soil stabilization or erosion control practice where materials such as grass, hay, woodchips, wood fibers, straw, or gravel are placed on the soil surface. In addition to stabilizing soils, mulching can reduce the speed of storm water runoff over an area. When used together with seeding or planting, mulching can aid in plant growth by holding the seeds, fertilizers, and topsoil in place, by helping to retain moisture, and by insulating against extreme temperatures.

When and Where to Use It

Mulching is often used alone in areas where temporary seeding cannot be used because of the season or climate. Mulching can provide immediate, effective, and inexpensive erosion control. On steep slopes and critical areas such as waterways, mulch matting is used with netting or anchoring to hold it in place.

Mulch seeded and planted areas where slopes are steeper than 2:1, where runoff is flowing across the area, or when seedlings need protection from bad weather.

What to Consider

Use of mulch may or may not require a binder, netting, or the tacking of mulch to the ground. Final grading is not necessary before mulching. Mulched areas should be inspected often to find where mulched material has been loosened or removed. Such areas should be reseeded (if necessary) and the mulch cover replaced immediately. Mulch binders should be applied at rates recommended by the manufacturer.

Advantages of Mulching
• Provides immediate protection to soils that are exposed and that are subject to heavy erosion
• Retains moisture, which may minimize the need for watering
• Requires no removal because of natural deterioration of mulching and matting
Disadvantages of Mulching
• May delay germination of some seeds because cover reduces the soil surface temperature
• Mulch can be easily blown or washed away by runoff if not secured
• Some mulch materials such as wood chips may absorb nutrients necessary for plant growth

Geotextiles

What Are They

Geotextiles are porous fabrics known in the construction industry as filter fabrics, road rugs, synthetic fabrics, construction fabrics, or simply fabrics. Geotextiles are manufactured by weaving or bonding fibers made from synthetic materials such as polypropelene, polyester, polyethylene, nylon, polyvinyl chloride, glass and various mixtures of these. As a synthetic construction material, geotextiles are used for a variety of purposes in the United States and foreign countries. The uses of geotextiles include separators, reinforcement, filtration and drainage, and erosion control. We will discuss the use of geotextiles in preventing erosion at construction sites in this section.

Some geotextiles are also biodegradable materials such as mulch matting and netting. Mulch mattings are materials (jute or other wood fibers) that have been formed into sheets of mulch that are more stable than normal mulch. Netting is typically made from jute, other wood fiber, plastic, paper, or cotton and can be used to hold the mulching and matting to the ground. Netting can also be used alone to stabilize soils while the plants are growing; however, it does not retain moisture or temperature well. Mulch binders (either asphalt or synthetic) are sometimes used instead of netting to hold loose mulches together.

When and Where to Use Them

Geotextiles can be used for erosion control by using it alone. Geotextiles, when used alone, can be used as matting. Mattings are used to stabilize the flow on channels and swales. Also, matting is used on recently planted slopes to protect seedlings until they become established. Also, matting may be used on tidal or stream banks where moving water is likely to wash out new plantings.

Geotextiles are also used as separators. An example of such a use is geotextile as a separator between riprap and soil. This "sandwiching" prevents the soil from being eroded from beneath the riprap and maintaining the riprap's base.

What to Consider

As stated above, the types of geotextiles available are vast, therefore, the selected fabric should match its purpose. Also, State or local requirements, design procedures, and any other applicable requirements should also be consulted. In the field, important concerns include regular inspections to determine if cracks, tears, or breaches are present in the fabric and appropriate repairs should be made.

Effective netting and matting require firm, continuous contact between the materials and the soil. If there is no contact, the material will not hold the soil and erosion will occur underneath the material.

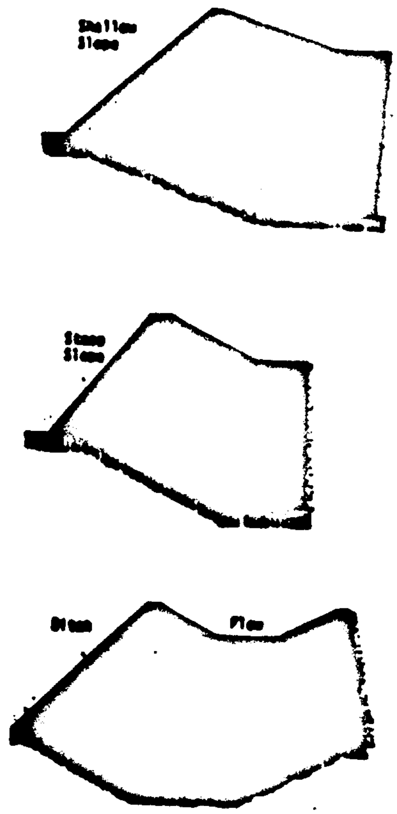

FIGURE 3.3 ORIENTATION OF MULCH NETTING AND MATTING
(Modified from County of Fairfax, 1987)

Advantages of Geotextiles
• Fabrics are relatively inexpensive for certain applications
• Offer convenience to the installer
• Design methodologies for the use of geotextiles are available
• A wide variety of geotextiles to match specific needs are available
• Mulch matting and netting are biodegradable
Disadvantages of Geotextiles
• If the fabric is not properly selected, designed, or installed, the effectiveness may be reduced drastically
• Many synthetic geotextiles are sensitive to light and must be protected prior to installation

Chemical Stabilization

What Is It

Chemical stabilization practices, often referred to as a chemical mulch, soil binder, or soil palliative, are temporary erosion control practices. Materials made of vinyl, asphalt, or rubber are sprayed onto the surface of the soil to hold the soil in place and protect against erosion from storm water runoff and wind. Many of the products used for chemical stabilization are human-made, and many different products are on the market.

When and Where to Use It

Chemical stabilization can be used as an alternative in areas where temporary seeding practices cannot be used because of the season or climate. It can provide immediate, effective, and inexpensive erosion control anywhere erosion is occurring on a site.

What to Consider

The application rates and procedures recommended by the manufacturer of a chemical stabilization product should be followed as closely as possible to prevent the products from forming ponds and from creating large areas where moisture cannot get through.

Advantages of Chemical Stabilization

- Is easily applied to the surface of the soil
- Is effective in stabilizing areas where plants will not grow
- Provides immediate protection to soils that are in danger of erosion

Disadvantages of Chemical Stabilization

- Can create impervious surfaces (where water cannot get through), which may in turn increase the amount and speed of storm water runoff
- May cause harmful effects on water quality if not used correctly
- Is usually more expensive than vegetative cover

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Permanent Seeding and Planting

What Is It

Permanent seeding of grass and planting trees and brush provides stabilization to the soil by holding soil particles in place. Vegetation reduces sediments and runoff to downstream areas by slowing the velocity of runoff and permitting greater infiltration of the runoff. Vegetation also filters sediments, helps the soil absorb water, improves wildlife habitats, and enhances the aesthetics of a site.

FIGURE 3.4 ESTABLISHING PERMANENT COVER WITH VEGETATION
(Modified from State of North Carolina, 1988)

When and Where to Use It

Permanent seeding and planting is appropriate for any graded or cleared area where long-lived plant cover is desired. Some areas where permanent seeding is especially important are filter strips, buffer areas, vegetated swales, steep slopes, and stream banks. This practice is effective on areas where soils are unstable because of their texture, structure, a high water table, high winds, or high slope.

What to Consider

For this practice to work, it is important to select appropriate vegetation, prepare a good seedbed, properly time planting, and to condition the soil. Planting local plants during their regular growing season will increase the chances for success and may lessen the need for watering. Check seeded areas frequently for proper watering and growth conditions.

When seeding in cold climates during fall or winter, cover the area with mulch to provide a protective barrier against cold weather (see Mulching). Seeding should also be mulched if the seeded area slopes 4:1 or more, if soil is sandy or clayey, or if weather is excessively hot or dry.

Plant when conditions are most favorable for growth. When possible, use low-maintenance local plant species.

Topsoil should be used on areas where topsoils have been removed, where the soils are dense or impermeable, or where mulching and fertilizers alone cannot improve soil quality. Topsoiling should be coordinated with the seeding and planting practices and should not be planned while the ground is frozen or too wet. Topsoil layers should be at least 2 inches deep (or similar to the existing topsoil depth).

To minimize erosion and sedimentation, remove as little existing topsoil as possible. All site controls should be in place before the topsoil is removed. If topsoils are brought in from another site, it is important that its texture is compatible with the subsoils onsite; for example, sandy topsoils are not compatible with clay subsoils.

Stockpiling of topsoils onsite requires good planning so soils will not obstruct other operations. If soil is to be stockpiled, consider using temporary seeding, mulching, or silt fencing to prevent or control erosion. Inspect the stockpiles frequently for erosion. After topsoil has been spread, inspect it regularly, and reseed or replace areas that have eroded.

Advantages of Permanent Seeding and Planting
• Improves the aesthetics of a site
• Provides excellent stabilization
• Provides filtering of sediments
• Provides wildlife habitat
• Is relatively inexpensive
Disadvantages of Permanent Seeding and Planting
• May require irrigation to establish vegetation
• Depends initially on climate and weather for success

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Buffer Zones

What Are They

Buffer zones are vegetated strips of land used for temporary or permanent water quality benefits. Buffer zones are used to decrease the velocity of storm water runoff, which in turn helps to prevent soil erosion. Buffer zones are different from vegetated filter strips (see section on Vegetated Filter Strips) because buffer zone effectiveness is not measured by its ability to improve infiltration (allow water to go into the ground). The buffer zone can be an area of vegetation that is left undisturbed during construction, or it can be newly planted.

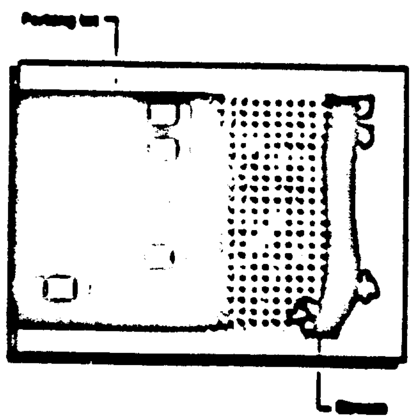

FIGURE 3.5 EXAMPLE BUFFER ZONE
(Modified from Washington State, 1992)

When and Where to Use Them

Buffer zones technique can be used at any site that can support vegetation. Buffer zones are particularly effective on floodplains, next to wetlands, along stream banks, and on steep, unstable slopes.

What to Consider

If buffer zones are preserved, existing vegetation, good planning, and site management are needed to protect against disturbances such as grade changes, excavation, damage from equipment, and other activities. Establishing new buffer strips requires the establishment of a good dense turf, trees, and shrubs (see Permanent Seeding and Planting). Careful maintenance is important to ensure healthy vegetation. The need for routine maintenance such as mowing, fertilizing, liming, irrigating, pruning, and weed and pest control will depend on the species of plants and trees involved, soil types, and climatic conditions. Maintaining planted areas may require debris removal and protection against unintended uses or traffic. Many State/local storm water program or zoning agencies have regulations which define required or allowable buffer zones especially near sensitive areas such as wetlands. Contact the appropriate State/local agencies for their requirements.

Advantages of Buffer Zones
• Provide aesthetic as well as water quality benefits
• Provide areas for infiltration, which reduces amount and speed of storm water runoff
• Provide areas for wildlife habitat
• Provide areas for recreation
• Provide buffers and screens for onsite noise if trees or large bushes are used
• Low maintenance requirements
• Low cost when using existing vegetation
Disadvantages of Buffer Zones
• May not be cost effective to use if the cost of land is high
• Are not feasible if land is not available
• Require plant growth before they are effective

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Preservation of Natural Vegetation

What Is It

The preservation of natural vegetation (existing trees, vines, brushes, and grasses) provides natural buffer zones. By preserving stabilized areas, it minimizes erosion potential, protects water quality, and provides aesthetic benefits. This practice is used as a permanent control measure.

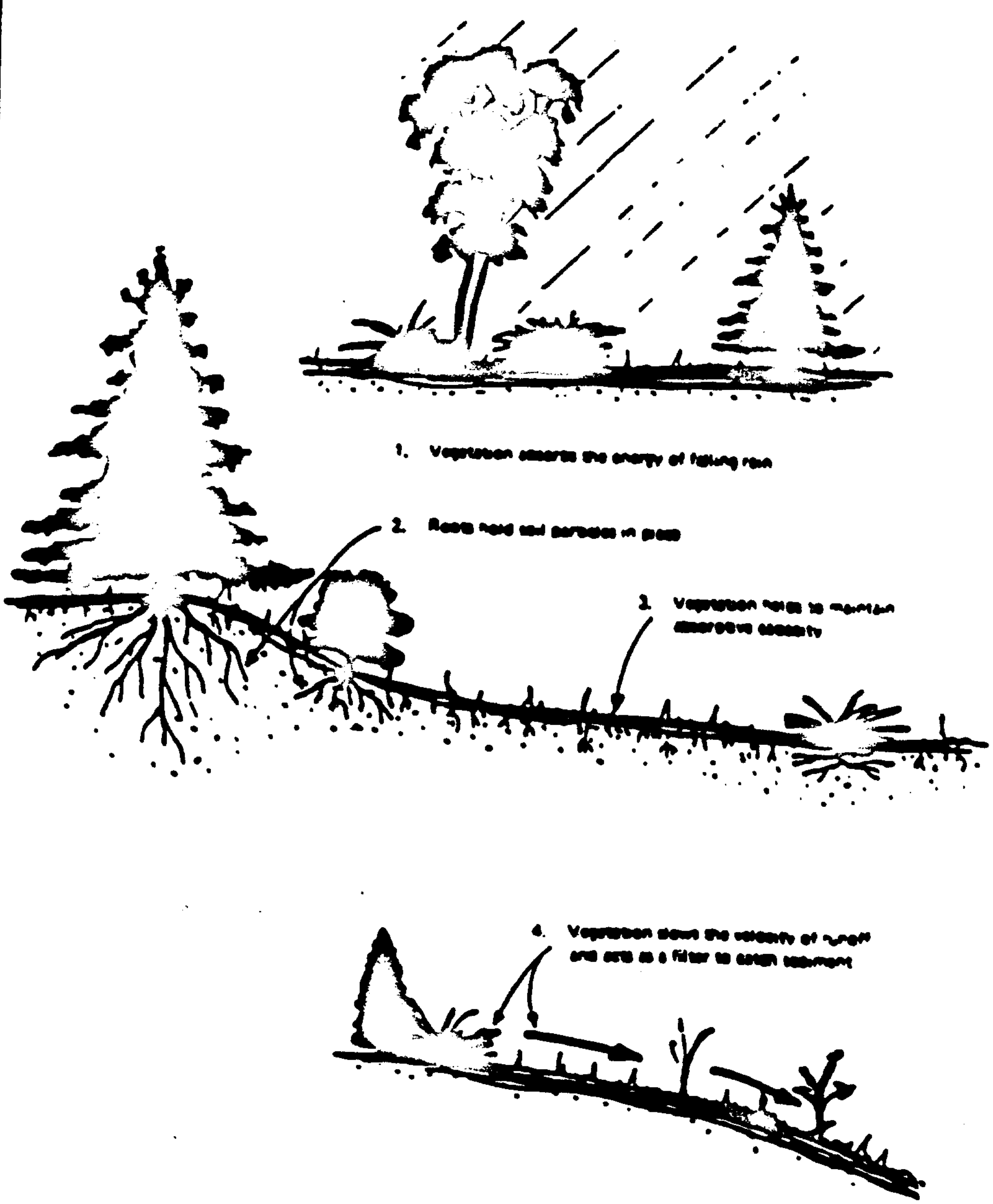
When and Where to Use It

This technique is applicable to all types of sites. Areas where preserving vegetation can be particularly beneficial are floodplains, wetlands, stream banks, steep slopes, and other areas where erosion controls would be difficult to establish, install, or maintain.

What to Consider

Preservation of vegetation on a site should be planned before any site disturbance begins. Preservation requires good site management to minimize the impact of construction activities on existing vegetation. Clearly mark the trees to be preserved and protect them from ground disturbances around the base of the tree. Proper maintenance is important to ensure healthy vegetation that can control erosion. Different species, soil types, and climatic conditions will require different maintenance activities such as mowing, fertilizing, liming, irrigation, pruning, and weed and pest control. Some State/local regulations require natural vegetation to be preserved in sensitive areas; consult the appropriate State/local agencies for more information on their regulations. Maintenance should be performed regularly, especially during construction.

Advantages of Preservation of Natural Vegetation
• Can handle higher quantities of storm water runoff than newly seeded areas • Does not require time to establish (i.e., effective immediately) • Increases the filtering capacity because the vegetation and root structure are usually denser in preserved natural vegetation than in newly seeded or base areas • Enhances aesthetics • Provides areas for infiltration, reducing the quantity and velocity of storm water runoff • Allows areas where wildlife can remain undisturbed • Provides noise buffers and screens for onsite operations • Usually requires less maintenance (e.g., irrigation, fertilizer) than planting new vegetation
Disadvantages of Preservation of Natural Vegetation
• Requires planning to preserve and maintain the existing vegetation • May not be cost effective with high land costs • May constrict area available for construction activities



Construction Operations Relative to Location of Protected Trees

FIGURE 3.6 BENEFITS OF PRESERVING NATURAL VEGETATION
(Modified from Washington State, 1992)

Sod Stabilization

What Is It

Sodding stabilizes an area by immediately covering the surface with vegetation and providing areas where storm water can infiltrate into the ground.

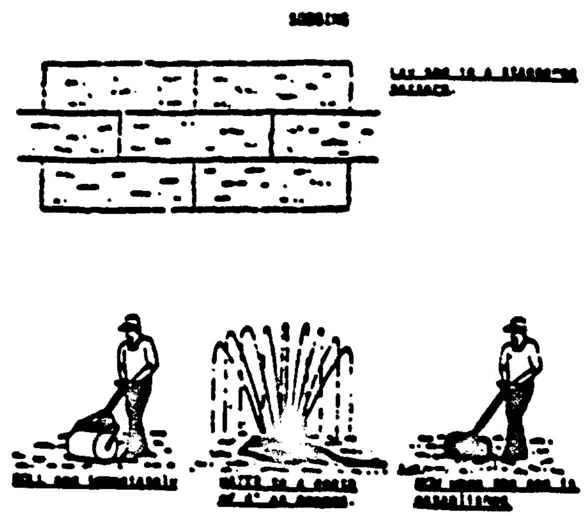


FIGURE 3.7 SODDING
(Modification from County of Fairfax, 1987)

When and Where to Use It

Sodding is appropriate for any graded or cleared area that might erode and where a permanent, long-lived plant cover is needed immediately. Examples of where sodding can be used are buffer zones, stream banks, dikes, swales, slopes, outlets, level spreaders, and filter strips.

What to Consider

The soil surface should be fine-graded before laying down the sod. Topsoil may be needed in areas where the soil textures are inadequate (see topsoil discussion in section on Permanent Seeding and Planting). Lime and fertilizers should be added to the soil to promote good growth conditions. Sodding can be applied in alternating strips or other patterns, or alternate areas can be seeded to reduce expense. Sod should not be planted during very hot or wet weather. Sod should not be placed on slopes that are greater than 3:1 if they are to be mowed. If placed on steep slopes, sod should be laid with staggered joints and/or be pegged. In areas such as steep slopes or next to running waterways, chicken wire, jute, or other netting can be placed over the sod for extra protection against lifting (see Mulching and Geotextiles). Roll or compact immediately after installation to ensure firm contact with the underlying topsoil. Inspect the sod frequently after it is first installed, especially after large storm events, until it is established as permanent cover. Remove and replace dead sod. Watering may be necessary after planting and during periods of intense heat and/or lack of rain (drought).

Advantages of Sod Stabilization
• Can provide immediate vegetative cover and erosion control • Provides more stabilizing protection than initial seeding through dense cover formed by sod • Produces lower weed growth than seeded vegetation • Can be used for site activities within a shorter time than can seeded vegetation • Can be placed at any time of the year as long as moisture conditions in the soil are favorable
Disadvantages of Sod Stabilization
• Purchase and installation costs are higher than for seeding • May require continued irrigation if the sod is placed during dry seasons or on sandy soils

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Stream Bank Stabilization

What Is It

Stream bank stabilization is used to prevent stream bank erosion from high velocities and quantities of storm water runoff. Typical methods include the following:

- Riprap–Large angular stones placed along the stream bank or lake
- Gabion–Rock-filled wire cages that are used to create a new stream bank
- Reinforced Concrete–Concrete bulkheads and retaining walls that replace natural stream banks and create a nonerosive surface
- Log Cribbing–Retaining walls built of logs to anchor the soils against erosive forces. Usually built on the outside of stream bends
- Grid Pavers–Precast or poured-in-place concrete units that are placed along stream banks to stabilize the stream bank and create open spaces where vegetation can be established
- Asphalt–Asphalt paving that is placed along the natural stream bank to create a nonerosive surface.

When and Where to Use It

Stream bank stabilization is used where vegetative stabilization practices are not practical and where the stream banks are subject to heavy erosion from increased flows or disturbance during construction. Stabilization should occur before any land development in the watershed area. Stabilization can also be retrofitted when erosion of a stream bank occurs.

What to Consider

Stream bank stabilization structures should be planned and designed by a professional engineer licensed in the State where the site is located. Applicable Federal, State, and local requirements should be followed, including Clean Water Act Section 404 regulations. An important design feature of stream bank stabilization methods is the foundation of the structure; the potential for the stream to erode the sides and bottom of the channel should be considered to make sure the stabilization measure will be supported properly. Structures can be designed to protect and improve natural wildlife habitats; for example, log structures and grid pavers can be designed to keep vegetation. Only pressure-treated wood should be used in log structures. Permanent structures should be designed to handle expected flood conditions. A well-designed layer of stone can be used in many ways and in many locations to control erosion and sedimentation. Riprap protects soil from erosion and is often used on steep slopes built with fill materials that are subject to harsh weather or seepage. Riprap can also be used for flow channel liners, inlet and outlet protection at culverts, stream bank protection, and protection of shore lines subject to wave action. It is used where water is turbulent and fast flowing and where soil may erode under the design flow conditions. It is used to expose the water to air as well as to reduce water energy. Riprap and gabion (wire mesh cages filled with rock) are usually placed over a filter blanket (i.e., a gravel layer or filter cloth). Riprap is either a uniform size or graded (different sizes) and is usually applied in an even layer throughout the stream. Reinforced concrete structures may require positive

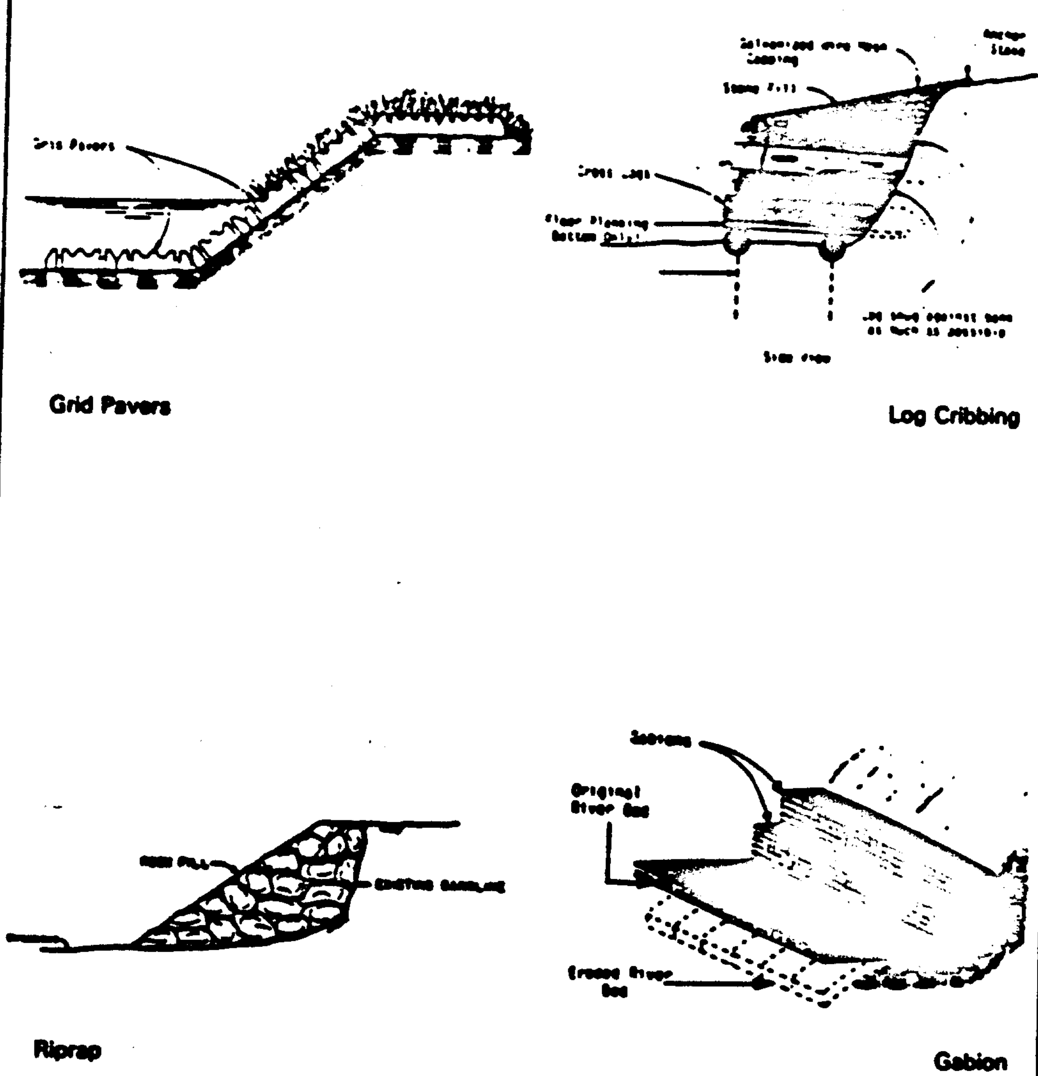

FIGURE 3.8 EXAMPLES OF STREAM BANK STABILIZATION PRACTICES
(Modified from Commonwealth of Virginia, 1980, and Commonwealth of Pennsylvania, 1990)

drainage behind the bulkhead or retaining wall to prevent erosion around the structure. Gabion and grid pavers should be installed according to manufacturers' recommendations.

Stream bank stabilization structures should be inspected regularly and after each large storm event. Structures should be maintained as installed. Structural damage should be repaired as soon as possible to prevent further damage or erosion to the stream bank.

Advantages of Stream Bank Stabilization
• Can provide control against erosive forces caused by the increase in storm water flows created during land development • Usually will not require as much maintenance as vegetative erosion controls • May provide wildlife habitats • Forms a dense, flexible, self-healing cover that will adapt well to uneven surfaces (riprap)
Disadvantages of Stream Bank Stabilization
• Does not provide the water quality or aesthetic benefits that vegetative practices could • Should be designed by qualified professional engineers, which may increase project costs • May be expensive (materials costs) • May require additional permits for structure • May alter stream dynamics which cause changes in the channel downstream • May cause negative impacts to wildlife habitats

Soil Retaining Measures

What Are They

Soil retaining measures refer to structures or vegetative stabilization practices used to hold the soil firmly to its original place or to confine as much as possible within the site boundary. There are many different methods for retaining soil; some are used to control erosion while others are used to protect the safety of the workers (i.e., during excavations). Examples of soil retaining measures include reinforced soil retaining systems, wind breaks, and stream bank protection using shrubs and reeds.

Reinforced soil retaining measures refer to using structural measures to hold in place loose or unstable soil. During excavation, for example, soil tiebacks and retaining walls are used to prevent cave-ins and accidents. But these same methods can be used to retain soils and prevent them from moving. While detailed discussion of soil retaining methods is beyond the scope of this manual, several are briefly described.

- **Skeleton Sheeting**—Skeleton sheeting, the least expensive soil bracing system, requires the soil to be cohesive (i.e., like clay). Construction grade lumber is used to brace the excavated face of the slope.
- **Continuous Sheeting**—Continuous sheeting involves using a material that covers the face of the slope in a continuous manner. Struts and boards are placed along the slope which provide continuous support to the slope face. The material used can be steel, concrete, or wood.
- **Permanent Retaining Walls**—Permanent construction walls may be necessary to provide support to the slope well after the construction is complete. In this instance, concrete masonry or wood (railroad tie) retaining walls can be constructed and left in place.

When and Where to Use Them

Use reinforced soil retaining methods where using other methods of soil retention (e.g., vegetation) is not practical. Some sites may have slopes or soils that do not lend themselves to ordinary practices of soil retention. In these instances, a reinforced soil retaining measure should be considered.

What to Consider

As emphasized earlier, the use of reinforced soil retaining practices serve both safety and erosion control purposes. Since safety is the first concern, the design should be performed by qualified and certified engineers. Such design normally involves understanding the nature of soil, location of the ground water table, the expected loads, and other important design considerations.

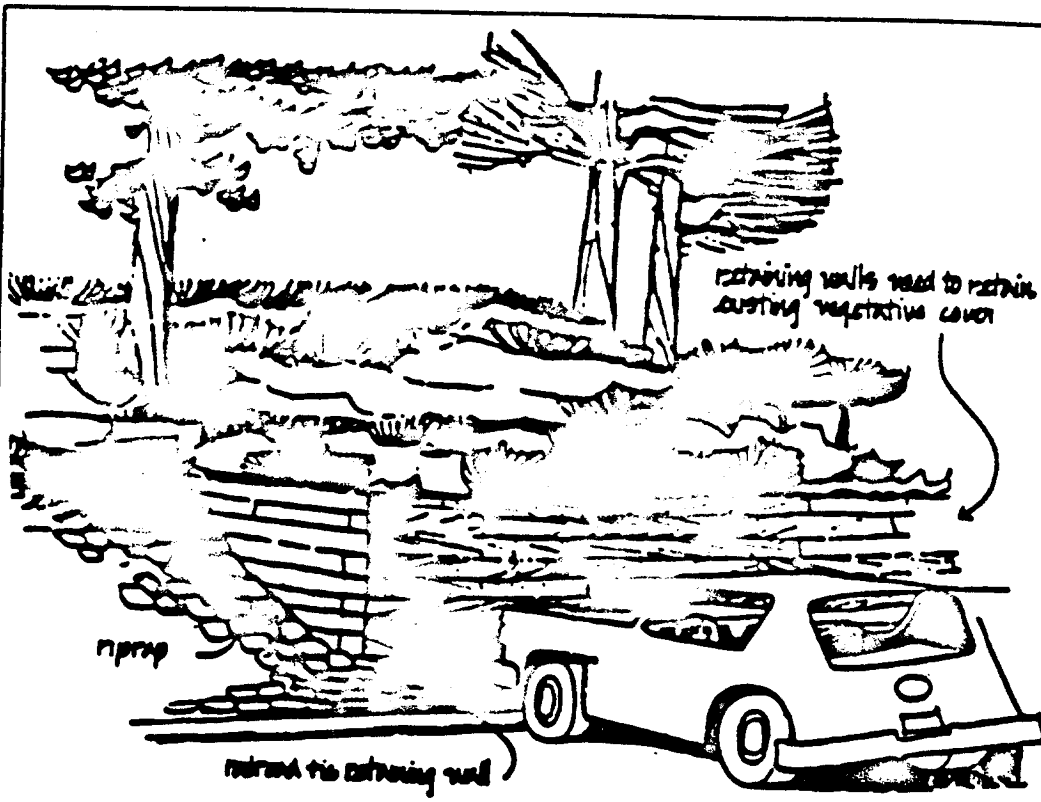

FIGURE 3.9 USE OF RETAINING WALLS
(Modification from Washington State, 1992)

Advantages of Soil Retaining Measures
• Provide safety to workers, and some types of reinforced retention can be left as permanent structures • Prevent erosion of soil difficult to stabilize using conventional methods
Disadvantages of Soil Retaining Measures
• Require the expertise of a professional engineer and may be expensive to design and install

Dust Control

What Is It

Wind is capable of causing erosion, particularly in dry climates or during the dry season. Wind erosion can occur wherever the surface soil is loose and dry, vegetation is sparse or absent, and the wind is sufficiently strong. Wind erodes soils and transports the sediments offsite, where they may be washed into the receiving water by the next rainstorm. Therefore, various methods of dust control may need to be employed to prevent dust from being carried away from the construction site. There are many ways to accomplish this and some are described below:

- **Vegetative Cover**—For disturbed areas not subject to traffic, vegetation provides the most practical method of dust control (see Temporary Seeding and Permanent Seeding and Planting).
- **Mulch (Including Gravel Mulch)**—When properly applied, mulch offers a fast, effective means of controlling dust (see Mulching).
- **Spray-on Adhesive**—Asphalt emulsions, latex emulsions, or resin in water can be sprayed onto mineral soil to prevent their blowing away (see Chemical Stabilization).
- **Calcium Chloride**—Calcium chloride may be applied by mechanical spreader as loose, dry granules or flakes at a rate that keeps the surface moist but not so high as to cause water pollution or plant damage.
- **Sprinkling**—The site may be sprinkled until the surface is wet. Sprinkling is especially effective for dust control on haul roads and other traffic routes.
- **Stone**—Used to stabilize construction roads; can also be effective for dust control.
- **Barriers**—A board fence, wind fence, sediment fence, or similar barrier can control air currents and blowing soil. All of these fences are normally constructed of wood and they prevent erosion by obstructing the wind near the ground and preventing the soil from blowing offsite.

  Barriers can be part of long-term dust control strategy in arid and semiarid areas; however, they are not a substitute for permanent stabilization. A wind barrier generally protects soil downward for a distance of 10 times the height of the barrier. Perennial grass and stands of existing trees may also serve as wind barriers.

When and Where to Use It

The above measures for dust control should be used when open dry areas of soil are anticipated on the site. Clearing and grading activities create the opportunity for large amounts of dust to be blown, therefore, one or several dust control measures should be considered prior to clearing and grading. One should also note that many of the water erosion control measures indirectly prevent wind erosion.

As the distance across bare soil increases, wind erosion becomes more and more severe. In arid and semiarid regions where rainfall is insufficient to establish vegetative cover, mulching may be used to conserve moisture, prevent surface crusting, reduce runoff and erosion, and help establish vegetation. It is a critical treatment on sites with erosive slopes.

What to Consider

The direction of the prevailing winds and careful planning of clearing activities are important considerations. As a standard practice, any exposed area should be stabilized using vegetation to prevent both wind and water erosion. If your site is located in an arid or semiarid area, you may wish to contact the USDA Soil Conservation Service representative in your area or the appropriate State/local government agency for additional information.

Advantages of Dust Control
• Reduces movement of soil to offsite areas
Disadvantages of Dust Control
• Excessive sprinkling may result in non-storm water discharges from the site

3.2.2 Structural Erosion and Sediment Control Practices

Structural practices used in sediment and erosion control divert storm water flows away from exposed areas, convey runoff, prevent sediments from moving offsite, and can also reduce the erosive forces of runoff waters. The controls can either be used as permanent or temporary measures. Practices discussed include the following:

- Earth Dike
- Drainage Swale
- Interceptor Dikes and Swales
- Temporary Stream Crossing
- Temporary Storm Drain Diversion
- Pipe Slope Drains
- Subsurface Drains
- Silt Fence
- Gravel or Stone Filter Berm
- Storm Drain Inlet Protection
- Sediment Trap
- Temporary Sediment Basin
- Outlet Protection
- Check Dams
- Surface Roughening
- Gradient Terraces.

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EPA BASELINE GENERAL PERMIT REQUIREMENTS
Structural Practices Parts IV.D.2.a.(2).(a). and (b). For common drainage locations that serve an area with 10 or more disturbed acres at one time, a temporary (or permanent) sediment basin providing 3,600 cubic feet of storage per acre drained, or equivalent control measures, shall be provided where attainable until final stabilization of the site. The 3,600 cubic feet of storage area per acre drained does not apply to flows from offsite areas and flows from onsite areas that are either undisturbed or have undergone final stabilization where such flows are diverted around the sediment basin. For drainage locations which serve 10 or more disturbed acres at one time and where a temporary sediment basin providing 3,600 cubic feet of storage per acre drained, or equivalent controls is not attainable, sediment traps should be used. At a minimum, silt fences or equivalent sediment controls are required for all sideslope and downslope boundaries of the construction area. For drainage locations serving less than 10 acres, sediment traps, silt fences or equivalent sediment controls are required for all sideslope and downslope boundaries of the construction area unless a sediment basin providing storage for 3,600 cubic feet of storage per acre drained is provided.

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Earth Dike

What Is It

An earth dike is a ridge or ridge and channel combination used to protect work a[illegible]as from upslope runoff and to divert sediment-laden water to appropriate traps or stable outlets. The dike consists of compacted soil and stone, riprap, or vegetation to stabilize the channel.

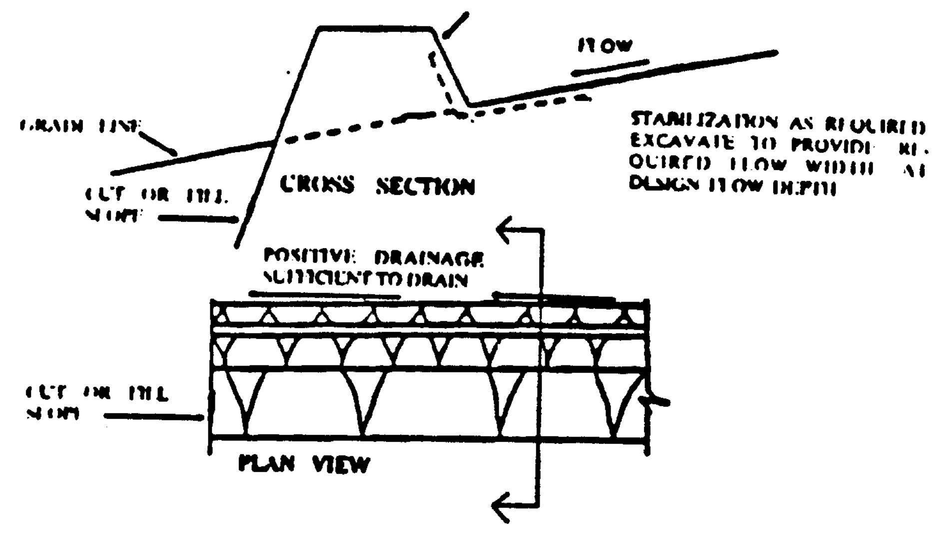

FIGURE 3.10 EARTH DIKE
(Modified from Maryland Department of the Environment, 1991)

When and Where to Use It

Earth dikes are used in construction areas to control erosion, sedimentation, or flood damage. Earth dikes can be used in the following situations:

- Above disturbed existing slopes and above cut or fill slopes to prevent runoff over the slope
- Across unprotected slopes, as slope breaks, to reduce slope length
- Below slopes to divert excess runoff to stabilized outlets
- To divert sediment laden water to sediment traps
- At or near the perimeter of the construction area to keep sediment from leaving the site

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- Above disturbed areas before stabilization to prevent erosion and maintain acceptable working conditions

- Temporary diversions may also serve as sediment traps when the site has been overexcavated on a flat grade or in conjunction with a sediment fence.

What to Consider

Despite an earth dike's simplicity, improper design can limit its effectiveness; therefore, the State or local requirements should be consulted. Some general considerations include proper compaction of the earth dike, appropriate location to divert the intercepted runoff, and properly designed ridge height and thicknesses. Earth dikes should be constructed along a positive grade. There should be no dips or low points in an earth dike where the storm water will collect (other than the discharge point). Also, the intercepted runoff from disturbed areas should be diverted to a sediment-trapping device. Runoff from undisturbed areas can be channeled to an existing swale or to a level spreader. Stabilization for the dike and flow channel of the drainage swale should be accomplished as soon as possible. Stabilization materials can include vegetation or stone/riprap.

Advantages of an Earth Dike
• Can be constructed from materials and equipment which are typically already present on a construction site
Disadvantages of an Earth Dike
• Frequent inspection and maintenance required

Drainage Swale

What Is It

A drainage swale is a channel with a lining of vegetation, riprap, asphalt, concrete, or other material. It is constructed by excavating a channel and applying the appropriate stabilization.

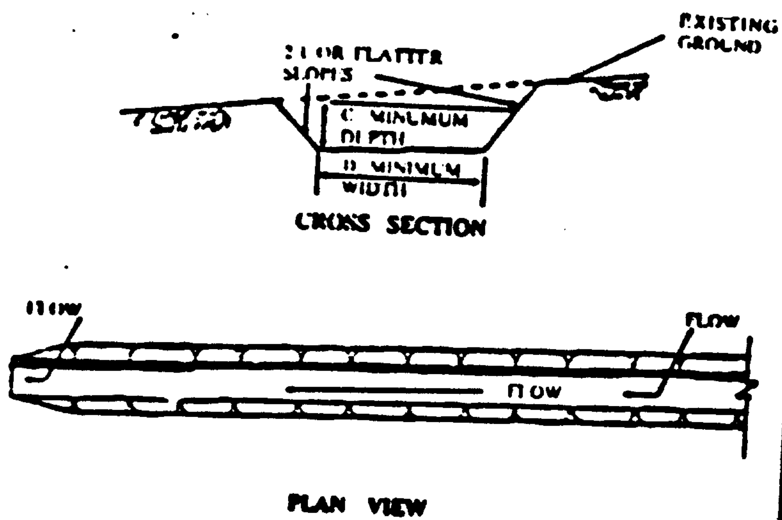

FIGURE 3.11 TEMPORARY SWALE
(Modified from Maryland Department of the Environment, 1991)

When and Where to Use It

A drainage swale applies when runoff is to be conveyed without causing erosion. Drainage swales can be used to convey runoff from the bottom or top of a slope. Drainage swales accomplish this by intercepting and diverting the flow to a suitable outlet. For swales draining a disturbed area, the outlet can be to a sediment trapping device prior to its release.

What to Consider

Since design flows, channel linings, and appropriate outlet devices will need to be considered, consult your State's requirements on such erosion control measures prior to constructing a drainage swale. General considerations include:

- Divert the intercepted runoff to an appropriate outlet.

- The swale should be lined using geotextiles, grass, sod, riprap, asphalt, or concrete. The selection of the liner is dependent upon the volume and the velocity of the anticipated runoff.

- The swale should have a positive grade. There should be no dips or low points in the swale where storm water will collect.

Advantages of a Drainage Swale
• Excavation of swale can be easily performed with earth moving equipment
• Can transport large volumes of runoff
Disadvantages of a Drainage Swale
• Stabilization and design costs can make construction expensive
• Use is restricted to areas with relatively flat slopes

Interceptor Dikes and Swales

What Are They

Interceptor dikes (ridges of compacted soil) and swales (excavated depressions) are used to keep upslope runoff from crossing areas where there is a high risk of erosion. They reduce the amount and speed of flow and then guide it to a stabilized outfall (point of discharge) or sediment trapping area (see sections on Sediment Traps and Temporary Sediment Basins). Interceptor dikes and swales divert runoff using a combination of earth dike and vegetated swale. Runoff is channeled away from locations where there is a high risk of erosion by placing a diversion dike or swale at the top of a sloping disturbed area. Dikes and swales also collect overland flow, changing it into concentrated flows. Interceptor dikes and swales can be either temporary or permanent storm water control structures.

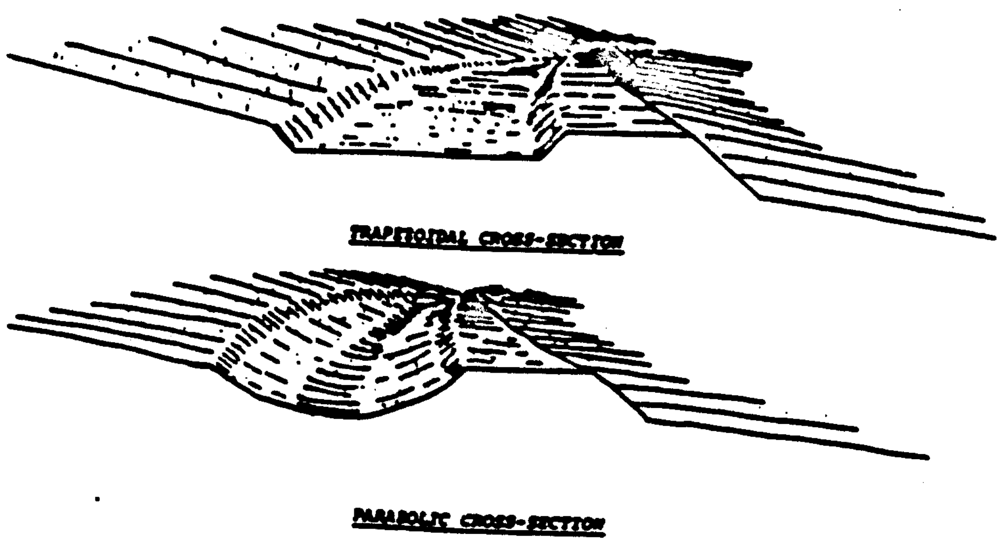

FIGURE 3.12 TYPICAL INTERCEPTOR DIKES AND SWALES
(Modified from State of Maryland, 1983)

When and Where to Use Them

Interceptor dikes and swales are generally built around the perimeter of a construction site before any major soil disturbing activity takes place. Temporary dikes or swales may also be used to protect existing buildings; areas, such as stockpiles; or other small areas that have not yet been fully stabilized. When constructed along the upslope perimeter of a disturbed or high-risk area (though not necessarily all the way around it), dikes or swales prevent runoff from uphill areas from crossing the unprotected slope. Temporary dikes or swales constructed on the down slope side of the disturbed or high-risk area will prevent runoff that contains sediment from leaving the site before sediment is removed. For short slopes, a dike or swale at the top of the slope reduces the amount of runoff reaching the disturbed area. For longer slopes, several dikes or swales are placed across the slope at intervals. This practice reduces the amount of runoff that accumulates on the face of the slope and carries the runoff safely down the slope. In all cases, runoff is guided to a sediment trapping area or a stabilized outfall before release.

What to Consider

Temporary dikes and swales are used in areas of overland flow; if they remain in place longer than 15 days, they should be stabilized. Runoff channeled by a dike or swale should be directed to an adequate sediment trapping area or stabilized outfall. Care should be taken to provide enough slope for drainage but not too much slope to cause erosion due to high runoff flow speed. Temporary interceptor dikes and swales may remain in place as long as 12 to 18 months (with proper stabilization) or be rebuilt at the end of each day's activities. Dikes or swales should remain in place until the area they were built to protect is permanently stabilized. Interceptor dikes and swales can be permanent controls. However, permanent controls: should be designed to handle runoff after construction is complete; should be permanently stabilized; and should be inspected and maintained on a regular basis. Temporary and permanent control measures should be inspected once each week on a regular schedule and after every storm. Repairs necessary to the dike and flow channel should be made promptly.

Advantages of Interceptor Dikes and Swales
• Are simple and effective for channeling runoff away from areas subject to erosion • Can handle flows from large drainage areas • Are inexpensive because they use materials and equipment normally found onsite
Disadvantages of Interceptor Dikes and Swales
• If constructed improperly, can cause erosion and sediment transport since flows are concentrated • May cause problems to vegetation growth if water flow is too fast • Require additional maintenance, inspections, and repairs

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Temporary Stream Crossing

What Is It

A temporary stream crossing is a bridge or culvert across a stream or watercourse for short-term use by construction vehicles or heavy equipment. Vehicles moving over unprotected stream banks will damage the bank, thereby releasing sediments and degrading the stream bank. A stream crossing provides a means for construction vehicles to cross streams or watercourses without moving sediment to streams, damaging the streambed or channel, or causing flooding.

When and Where to Use It

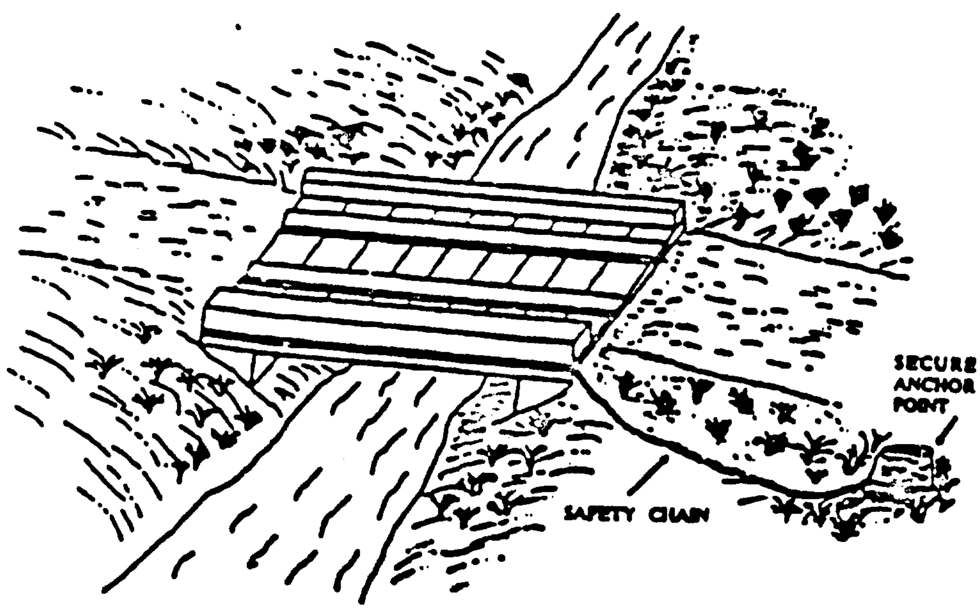
A temporary stream crossing is used when heavy equipment should be moved from one side of a stream channel to another, or where light-duty construction vehicles have to cross the stream channel frequently for a short period of time. Temporary stream crossings should be constructed only when it is necessary to cross a stream and a permanent crossing is not yet constructed.

- **Bridges**—Where available materials and designs are adequate to bear the expected loadings, bridges are preferred as a temporary stream crossing.
- **Culverts**—Culverts are the most common type of stream crossings and are relatively easy to construct. A pipe, which is to carry the flow, is laid into the channel and covered by gravel.

What to Consider

When feasible, one should always attempt to minimize or eliminate the need to cross streams. Temporary stream crossings are a direct source of pollution; therefore, every effort should be made to use an alternate method (e.g., longer detour), when feasible. When it becomes necessary to cross a stream, a well planned approach will minimize the damage to the stream bank and reduce erosion. The design of temporary stream crossings requires knowledge of the design flows and other information; therefore, a professional engineer and specific State and local requirements should be consulted. State/local jurisdictions may require a separate permit for temporary stream crossings; contact them directly to learn about their exact requirements.

The specific loads and the stream conditions will dictate what type of stream crossing to employ. Bridges are the preferred method to cross a stream as they provide the least obstruction to flows and fish migration.



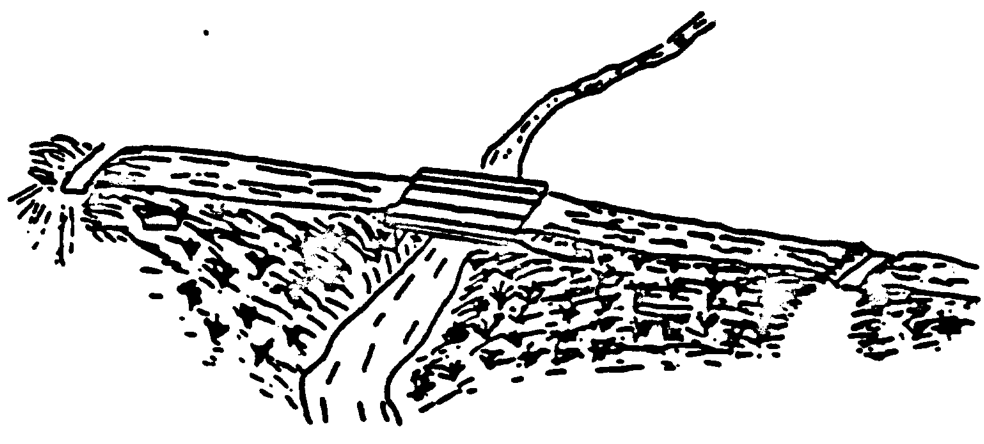


FIGURE 3.13 TEMPORARY ACCESS BRIDGE
(Modified from Maryland Department of the Environment, 1991)

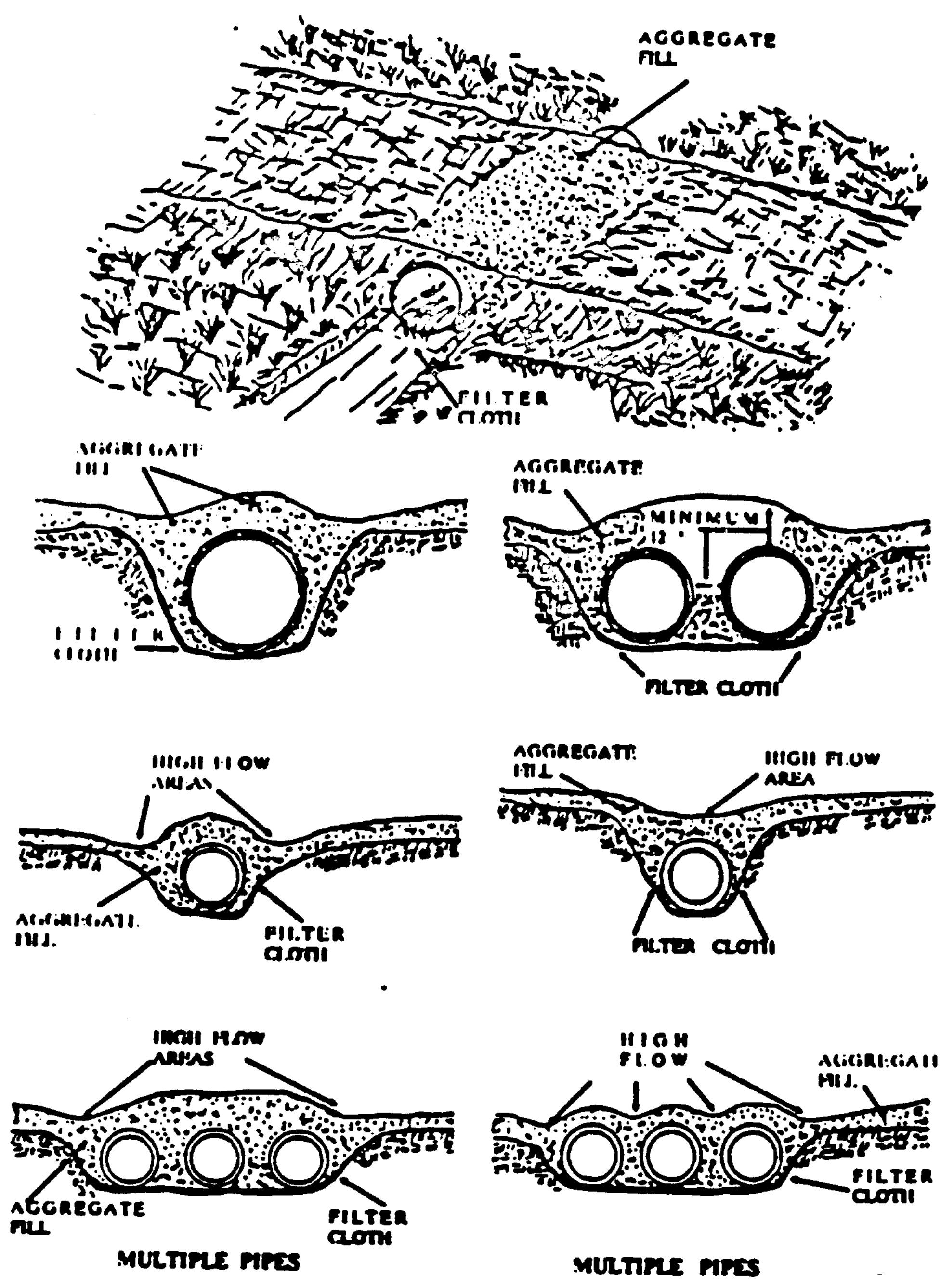


FIGURE 3.14 TEMPORARY ACCESS CULVERT
(Modified from Maryland Department of the Environment, 1991)

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Advantages of a Temporary Stream Crossing
• Bridges provide the least obstruction to flow and fish migration and the construction material can be salvaged • Culverts are inexpensive and easily installed structures
Disadvantages of a Temporary Stream Crossing
• Bridges are expensive to design and install • Culverts cause greater disturbances during installation and removal

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Temporary Storm Drain Diversion

What Is It

A temporary storm drain is a pipe which redirects an existing storm drain system or outfall channel to discharge into a sediment trap or basin.

When and Where to Use It

Use storm drain diversions to temporarily divert flow going to a permanent outfall. This diverted flow should be directed to a sediment-trapping device. A temporary storm drain diversion should remain in place as long as the area draining to the storm sewer remains disturbed. Another method is to delay completion of the permanent outfall and instead using temporary diversions to a sediment trapping device before discharge. Finally, a sediment trap or basin can be constructed below a permanent storm drain outfall. The basin would be designed to trap any sediment before final discharge.

What to Consider

Since the existing storm draining systems will be modified, careful consideration to piping configuration and resulting impact of installing a temporary storm drain diversion should be given. The temporary diversions will also need to be moved, once the construction has ceased and it is necessary to restore the original storm drainage systems. Therefore, appropriate restoration measures such as flushing the storm drain prior to removal of the sediment trap or basin, stabilizing the outfall, restoration of grade areas, etc. should be taken. And finally, the State or local requirements should be consulted for detailed requirements.

Advantages of a Temporary Storm Drain Diversion
• Requires little maintenance once installed
Disadvantages of a Temporary Storm Drain Diversion
• Disturbs existing storm drainage patterns

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Pipe Slope Drains

What Are They

Pipe slope drains reduce the risk of erosion by discharging runoff to stabilized areas. Made of flexible or rigid pipe, they carry concentrated runoff from the top to the bottom of a slope that has already been damaged by erosion or is at high risk for erosion. They are also used to drain saturated slopes that have the potential for soil slides. Pipe slope drains can be either temporary or permanent depending on the method of installation and material used.

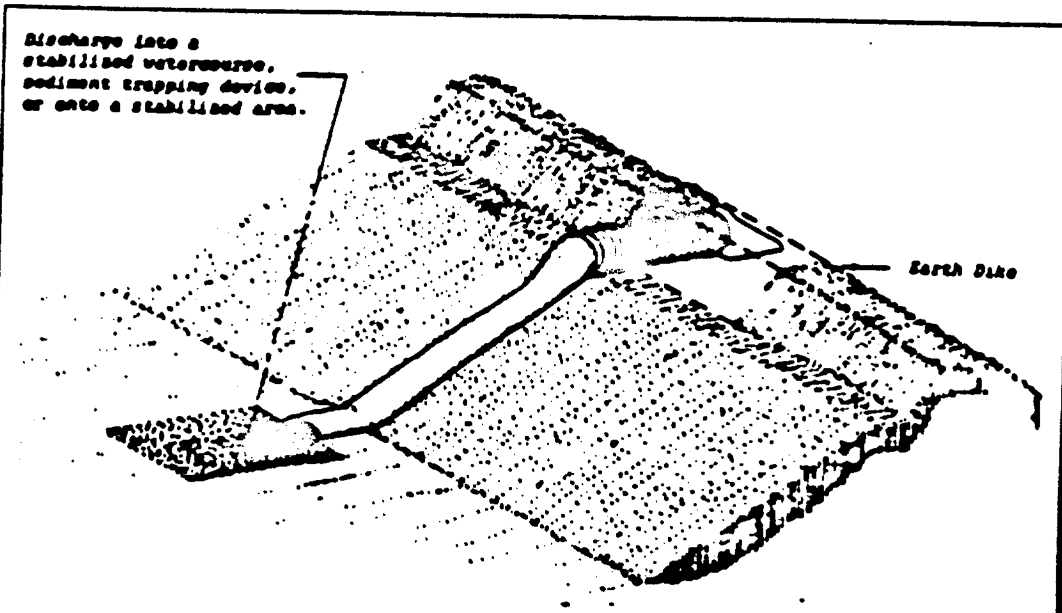


FIGURE 3.15 FLEXIBLE PIPE SLOPE DRAIN
(Modified from State of Maryland, 1983)

When and Where to Use Them

Pipe slope drains are used whenever it is necessary to convey water down a slope without causing erosion. They are especially effective before a slope has been stabilized or before permanent drainage structures are ready for use. Pipe slope drains may be used with other devices, including diversion dikes or swales, sediment traps, and level spreaders (used to spread out storm water runoff uniformly over the surface of the ground). Temporary pipe slope drains, usually flexible tubing or conduit, may be installed prior to the construction of permanent drainage structures. Permanent slope drains may be placed on or beneath the ground surface; pipes, sectional downdrains, paved chutes, or clay tiles may be used.

Paved chutes may be covered with a surface of concrete or other impenetrable material. Subsurface drains can be constructed of concrete, PVC, clay tile, corrugated metal, or other permanent material.

What to Consider

The drain design should be able to handle the volume of flow. The inlets and outlets of a pipe slope drain should be stabilized. This means that a flared end section should be used at the entrance of the pipe. The soil around the pipe entrance should be fully compacted. The soil at the discharge end of the pipe should be stabilized with riprap (a combination of large stones, cobbles, and boulders). The riprap should be placed along the bottom of a swale which leads to a sediment trapping structure or another stabilized area.

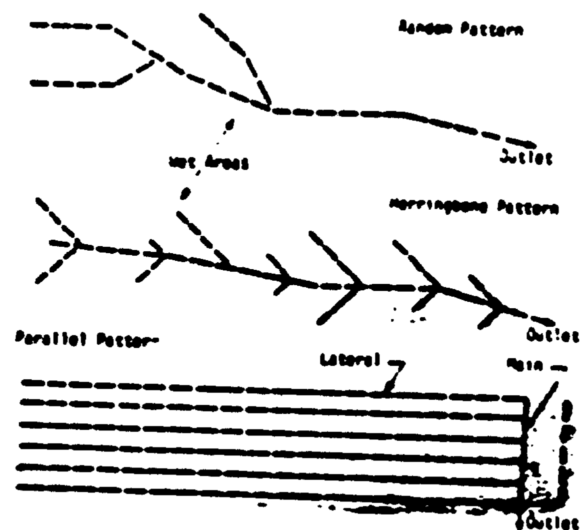
Pipe slope drains should be inspected on a regular schedule and after any major storm. Be sure that the inlet from the pipe is properly installed to prevent bypassing the inlet and undercutting the structure. If necessary, install a headwall, riprap, or sandbags around the inlet. Check the outlet point for erosion and check the pipe for breaks or clogs. Install outlet protection if needed and promptly clear breaks and clogs.

Advantages of Pipe Slope Drains
• Can reduce or eliminate erosion by transporting runoff down steep slopes or by draining saturated soils
• Are easy to install and require little maintenance
Disadvantages of Pipe Slope Drains
• Require that the area disturbed by the installation of the drain should be stabilized or it, too, will be subject to erosion
• May clog during a large storm

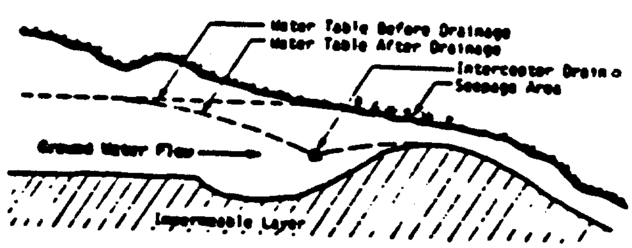
Subsurface Drains

What Are They

A subsurface drain is a perforated pipe or conduit placed beneath the surface of the ground at a designed depth and grade. It is used to drain an area by lowering the water table. A high water table can saturate soils and prevent the growth of certain types of vegetation. Saturated soils on slopes will sometimes "slip" down the hill. Installing subsurface drains can help prevent these problems.



Typical Subsurface Drain Patterns



Effect of Subsurface Drains on Water Table

FIGURE 3.16 SUBSURFACE DRAINS
(Modified from Commonwealth of Virginia, 1980)

When and Where to Use Them

There are two types of subsurface drains: relief drains and interceptor drains. Relief drains are used to dewater an area where the water table is high. They may be placed in a gridiron, herringbone, or random pattern. Interceptor drains are used to remove water where sloping soils are excessively wet or subject to slippage. They are usually placed as single pipes instead of in patterns. Generally, subsurface drains are suitable only in areas where the soil is deep enough for proper installation. They are not recommended where they pass under heavy vehicle crossings.

What to Consider

Drains should be placed so that tree roots will not interfere with drainage pipes. The drain design should be adequate to handle the volume of flow. Areas disturbed by the installation of a drain should be stabilized or they, too, will be subject to erosion. The soil layer must be deep enough to allow proper installation.

Backfill immediately after the pipe is placed. Material used for backfill should be open granular soil that is highly permeable. The outlet should be stabilized and should direct sediment-laden storm water runoff to a sediment trapping structure or another stabilized area.

Inspect subsurface drains on a regular schedule and check for evidence of pipe breaks or clogging by sediment, debris, or tree roots. Remove blockage immediately, replace any broken sections, and restabilize the surface. If the blockage is from tree roots, it may be necessary to relocate the drain. Check inlets and outlets for sediment or debris. Remove and dispose of these materials properly.

Advantages of Subsurface Drains
• Provide an effective method for stabilizing wet sloping soils
• Are an effective way to lower the water table
Disadvantages of Subsurface Drains
• May be pierced and clogged by tree roots
• Should not be installed under heavy vehicle crossings
• Cost more than surface drains because of the expenses of excavation for installation

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Silt Fence

What Is It

A silt fence, also called a "filter fence," is a temporary measure for sedimentation control. It usually consists of posts with filter fabric stretched across the posts and sometimes with a wire support fence. The lower edge of the fence is vertically trenched and covered by backfill. A silt fence is used in small drainage areas to detain sediment. These fences are most effective where there is overland flow (runoff that flows over the surface of the ground as a thin, even layer) or in minor swales or drainageways. They prevent sediment from entering receiving waters. Silt fences are also used to catch wind blown sand and to create an anchor for sand dune creation. Aside from the traditional wooden post and filter fabric method, there are several variations of silt fence installation including silt fence which can be purchased with pockets presewn to accept use of steel fence posts.

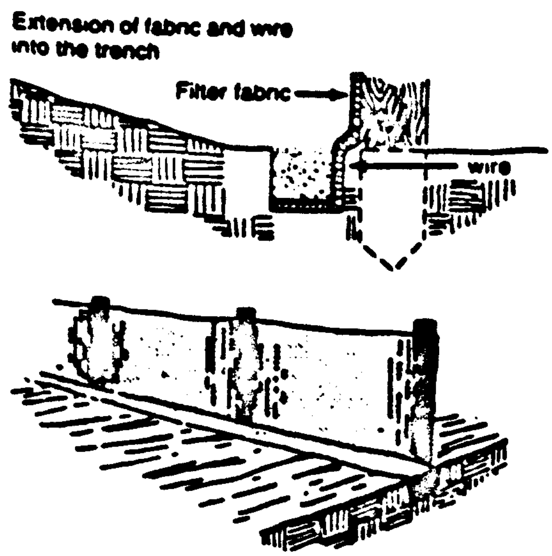

FIGURE 3.17 SILT FENCE DETAILS
(Modified from State of North Carolina, 1988;
and State of Wisconsin, 1988)

When and Where to Use It

A silt fence should be installed prior to major soil disturbance in the drainage area. The fence should be placed across the bottom of a slope along a line of uniform elevation (perpendicular to the direction of flow). It can be used at the outer boundary of the work area. However, the fence does not have to surround the work area completely. In addition, a silt fence is effective where sheet and rill erosion may be a problem. Silt fences should not be constructed in streams or swales.

What to Consider

A silt fence is not appropriate for controlling runoff from a large area. This type of fence can be more effective than a straw bale barrier if properly installed and maintained. It may be used in combination with other erosion and sediment practices.

The effective life span for a silt fence depends upon the material of construction and maintenance. The fence requires frequent inspection and prompt maintenance to maintain its effectiveness. Inspect the fence after each rainfall. Check for areas where runoff eroded a channel beneath the fence, or where the fence was caused to sag or collapse by runoff flowing over the top. Remove and properly dispose of sediment when it is one-third to one-half the height of the fence or after each storm.

Advantages of a Silt Fence
• Removes sediments and prevents downstream damage from sediment deposits
• Reduces the speed of runoff flow
• Minimal clearing and grubbing required for installation
• Inexpensive
Disadvantages of a Silt Fence
• May result in failure from improper choice of pore size in the filter fabric or improper installation
• Should not be used in streams
• Is only appropriate for small drainage areas with overland flow
• Frequent inspection and maintenance is necessary to ensure effectiveness

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Gravel or Stone Filter Berm

What Is It

A gravel or stone filter berm is a temporary ridge constructed of loose gravel, stone, or crushed rock. It slows and filters flow, diverting it from an exposed traffic area. Diversions constructed of compacted soil may be used where there will be little or no construction traffic within the right-of way. They are also used for directing runoff from the right-of-way to a stabilized outlet.

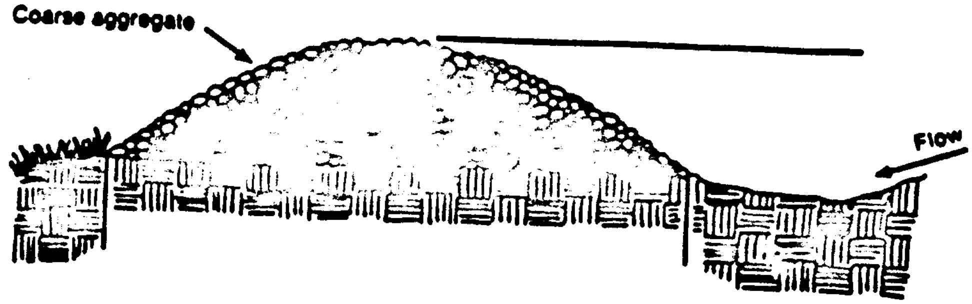

FIGURE 3.18 TYPICAL GRAVEL FILTER BERM
(Modified from Commonwealth of Virginia, 1980)

When and Where to Use It

This method is appropriate where roads and other rights-of-way under construction should accommodate vehicular traffic. Berms are meant for use in areas with gentle slopes. They may also be used at traffic areas within the construction site.

What to Consider

Berm material should be well graded gravel or crushed rock. The spacing of the berms will depend on the steepness of the slope: berms should be placed closer together as the slope increases. The diversion should be inspected regularly after each rainfall, or if breached by construction or other vehicles. All needed repairs should be performed immediately. Accumulated sediment should be removed and properly disposed of and the filter material replaced, as necessary.

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Advantages of a Gravel or Stone Filter Berm
• Is a very efficient method of sediment control • Reduces the speed of runoff flow
Disadvantages of a Gravel or Stone Filter Berm
• Is more expensive than methods that use onsite materials • Has a very limited life span • Can be difficult to maintain because of clogging from mud and soil on vehicle tires

Storm Drain Inlet Protection

What Is It

Storm drain inlet protection is a filtering measure placed around any inlet or drain to trap sediment. This mechanism prevents the sediment from entering inlet structures. Additionally, it serves to prevent the silting-in of inlets, storm drainage systems, or receiving channels. Inlet protection may be composed of gravel and stone with a wire mesh filter, block and gravel, filter fabric, or sod.

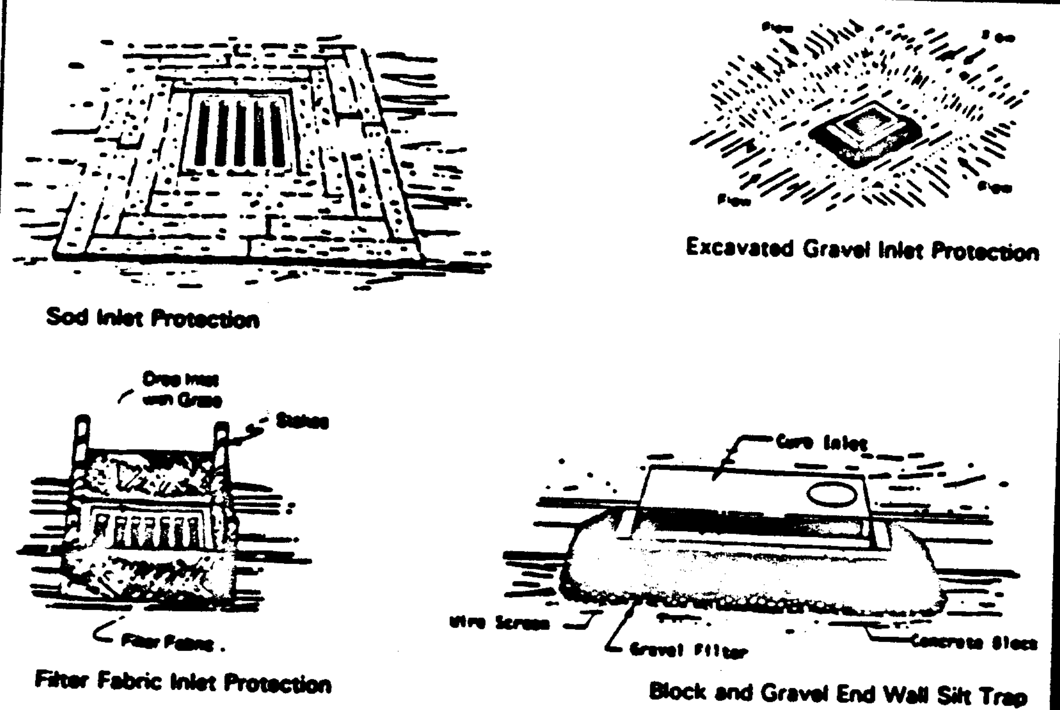

FIGURE 3.19 EXAMPLES OF STORM DRAIN INLET PROTECTION
(Modified from State of North Carolina, 1988; Washington State, 1992; and County of Fairfax, 1987)

When and Where to Use It

This type of protection is appropriate for small drainage areas where storm drain inlets will be ready for use before final stabilization. Storm drain inlet protection is also used where a permanent storm drain structure is being constructed onsite. Straw bales are not recommended for this purpose. Filter fabric is used for inlet protection when storm water flows are relatively small with low velocities. This practice cannot be used where inlets are paved because the filter fabric should be staked. Block and gravel filters can be used where velocities are higher. Gravel and mesh filters can be used where flows are higher and subject to disturbance by site traffic. Sod inlet filters are generally used where sediments in the storm water runoff are low.

What to Consider

Storm drain inlet protection is not meant for use in drainage areas exceeding 1 acre or for large concentrated storm water flows. Installation of this measure should take place before any soil disturbance in the drainage area. The type of material used will depend on site conditions and the size of the drainage area. Inlet protection should be used in combination with other measures, such as small impoundments or sediment traps, to provide more effective sediment removal. Inlet protection structures should be inspected regularly, especially after a rainstorm. Repairs and silt removal should be performed as necessary. Storm drain inlet protection structures should be removed only after the disturbed areas are completely stabilized.

Advantages of Storm Drain Inlet Protection
• Prevents clogging of existing storm drainage systems and the siltation of receiving waters • Reduces the amount of sediment leaving the site
Disadvantages of Storm Drain Inlet Protection
• May be difficult to remove collected sediment • May cause erosion elsewhere if clogging occurs • Is practical only for low sediment, low volume flows (disturbed areas less than one acre)

Sediment Trap

What Is It

A sediment trap is formed by excavating a pond or by placing an earthen embankment across a low area or drainage swale. An outlet or spillway is constructed using large stones or aggregate to slow the release of runoff. The trap retains the runoff long enough to allow most of the silt to settle out.

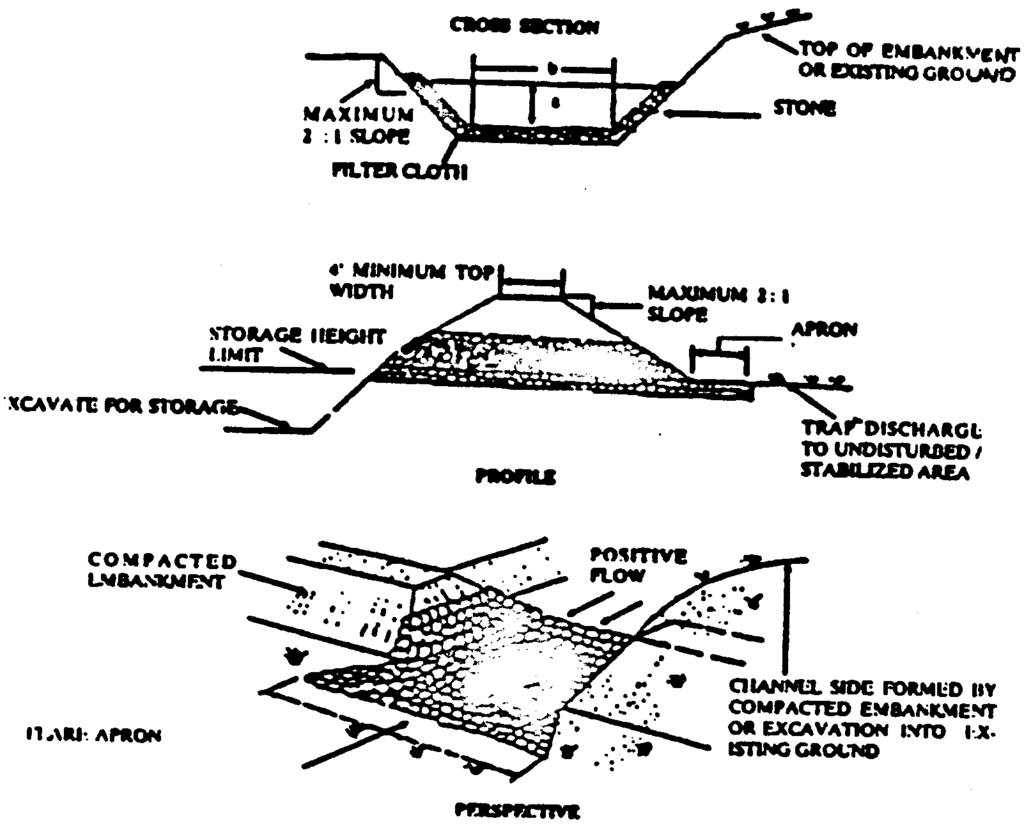

FIGURE 3.20 TYPICAL SEDIMENT TRAP
(Modified from State of Maryland, 1991)

When and Where to Use It

A temporary sediment trap may be used in conjunction with other temporary measures, such as gravel construction entrances, vehicle wash areas, slope drains, diversion dikes and swales, or diversion channels.

What to Consider

Sediment traps are suitable for small drainage areas, usually no more than 10 acres. The trap should be large enough to allow the sediments to settle and should have a capacity to store the collected sediment until it is removed. The volume of storage required depends upon the amount and intensity of expected rainfall and on estimated quantities of sediment in the storm water runoff. Check your Permit to see if it specifies a minimum storage volume for sediment traps.

The effective life of a sediment trap depends upon adequate maintenance. The trap should be readily accessible for periodic maintenance and sediment removal. Traps should be inspected after each rainfall and cleaned when no more than half the design volume has been filled with collected sediment. The trap should remain in operation and be properly maintained until the site area is permanently stabilized by vegetation and/or when permanent structures are in place.

Advantages of a Temporary Sediment Trap
• Protects downstream areas from clogging or damage due to sediment deposits
• Is inexpensive and simple to install
• Can simplify the design process by trapping sediment at specific spots onsite
Disadvantages of a Temporary Sediment Trap
• Is suitable only for a limited area
• Is effective only if properly maintained
• Will not remove very fine silts and clays

Temporary Sediment Basin

What is it

A temporary sediment basin is a settling pond with a controlled storm water release structure used to collect and store sediment produced by construction activities. A sediment basin can be constructed by excavation and/or by placing an earthen embankment across a low area or drainage swale. Sediment basins can be designed to maintain a permanent pool or to drain completely dry. The basin detains sediment-laden runoff from larger drainage areas long enough to allow most of the sediment to settle out.

The pond has a riser and pipe outlet with a gravel outlet or spillway to slow the release of runoff and provide some sediment filtration. By removing sediment, the basin helps prevent clogging of offsite conveyance systems and sediment-loading of receiving waterways. In this way, the basin helps prevent destruction of waterway habitats.

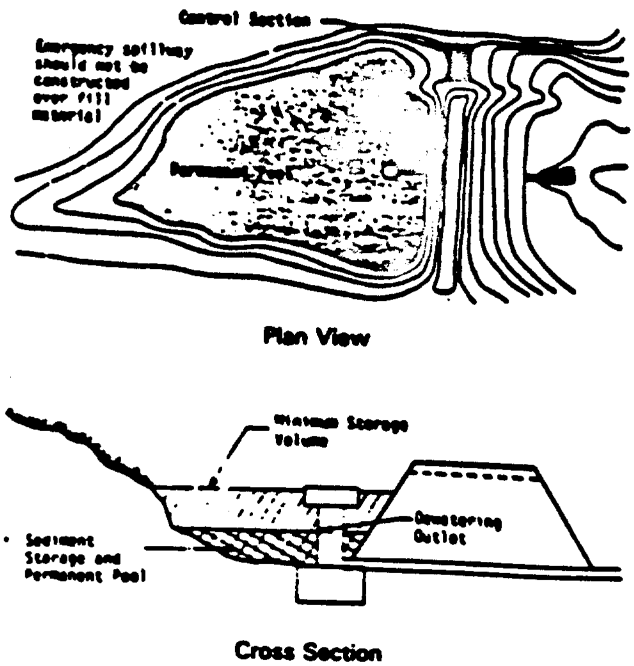

FIGURE 3.21 TEMPORARY SEDIMENT BASIN
(Modified from Commonwealth of Virginia, 1980)

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When and Where to Use It

A temporary sediment basin should be installed before clearing and grading is undertaken. It should not be built on an embankment in an active stream. The creation of a dam in such a site may result in the destruction of aquatic habitats. Dam failure can also result in flooding. A temporary sediment basin should be located only if there is sufficient space and appropriate topography. The basin should be made large enough to handle the maximum expected amount of site drainage. Fencing around the basin may be necessary for safety or vandalism reasons.

A temporary sediment basin used in combination with other control measures, such as seeding or mulching, is especially effective for removing sediments.

What to Consider

Temporary sediment basins are usually designed for disturbed areas larger than 5 acres. The pond should be large enough to hold runoff long enough for sediment to settle. Sufficient space should be allowed for collected sediments. Check the requirements of your permit to see if there is a minimum storage requirement for sediment basins. The useful life of a temporary sediment basin is dependent upon adequate maintenance.

Sediment trapping efficiency is improved by providing the maximum surface area possible. Because finer silts may not settle out completely, additional erosion control measures should be used to minimize release of fine silt. Runoff should enter the basin as far from the outlet as possible to provide maximum retention time.

Sediment basins should be readily accessible for maintenance and sediment removal. They should be inspected after each rainfall and be cleaned out when about half the volume has been filled with sediment. The sediment basin should remain in operation and be properly maintained until the site area is permanently stabilized by vegetation and/or when permanent structures are in place. The embankment forming the sedimentation pool should be well compacted and stabilized with vegetation. If the pond is located near a residential area, it is recommended for safety reasons that a sign be posted and that the area be secured by a fence. A well built temporary sediment basin that is large enough to handle the post construction runoff volume may later be converted to use as a permanent storm water management structure.

The sediment basins outlet pipe and spill way should be designed by an engineer based upon an analysis of the expected runoff flow rates from the site. Consult your state/local requirements to determine the frequency of the storm for which the outlet must be designed.

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EPA BASELINE GENERAL PERMIT REQUIREMENTS
Sediment Basin Requirements Part IV.D.2.a.(2).(a).
For common drainage locations that serve an area with 10 or more disturbed acres at one time, a temporary (or permanent) sediment basin providing 3,600 cubic feet of storage per acre drained, or equivalent control measures, shall be provided where attainable until final stabilization of the site. The 3,600 cubic feet of storage area per acre drained does not apply to flows from offsite areas and flows from onsite areas that are either undisturbed or have undergone final stabilization where such flows are diverted around the sediment basin. For drainage locations which serve 10 or more disturbed acres at one time and where a temporary sediment basin providing 3,600 cubic feet of storage per acre drained, or equivalent controls is not attainable, sediment traps, silt fences, or equivalent sediment controls are required for all sideslope and downslope boundaries of the construction area.

Advantages of a Temporary Sediment Basin
• Protects downstream areas from clogging or damage due to sediment deposits generated during construction activities • Can trap smaller sediment particles than sediment traps can because of the longer detention time • Can be converted to a permanent storm water detention structure, once construction is complete
Disadvantages of a Temporary Sediment Basin
• Is generally suitable for small areas • Requires regular maintenance and cleaning • Will not remove very fine silts and clays unless used in conjunction with other measures • Is a more expensive way to remove sediment than several other methods • Requires careful adherence to safety practices since ponds are attractive to children

Outlet Protection

What Is It

Outlet protection reduces the speed of concentrated storm water flows and therefore it reduces erosion or scouring at storm water outlets and paved channel sections. In addition, outlet protection lowers the potential for downstream erosion. This type of protection can be achieved through a variety of techniques, including stone or riprap, concrete aprons, paved sections and settling basins installed below the storm drain outlet.

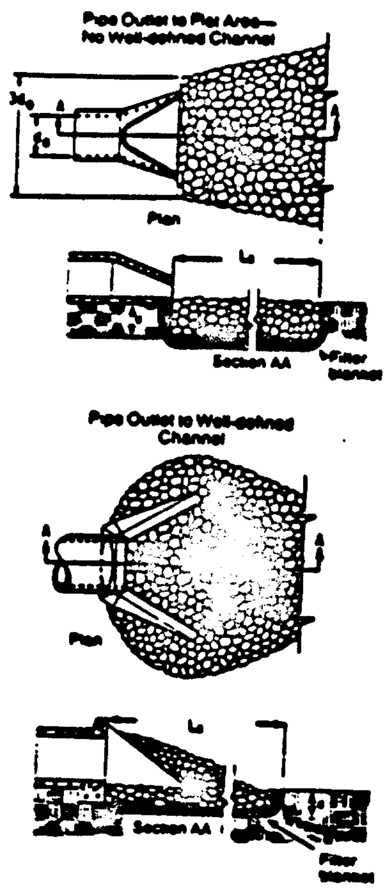

FIGURE 3.22 TYPICAL DETAILS FOR ROCK OUTLET PROTECTION
(Modified from State of North Carolina, 1988)

When and Where to Use It

Outlet protection should be installed at all pipe, interceptor dike, swale, or channel section outlets where the velocity of flow may cause erosion at the pipe outlet and in the receiving channel. Outlet protection should also be used at outlets where the velocity of flow at the design capacity may result in plunge pools (small permanent pools located at the inlet to or the outfall from BMPs). Outlet protection should be installed early during construction activities, but may be added at any time, as necessary.

What to Consider

The exit velocity of the runoff as it leaves the outlet protection structure should be reduced to levels that minimize erosion. Outlet protection should be inspected on a regular schedule to look for erosion and scouring. Repairs should be made promptly.

Advantages of Outlet Protection
• Provides, with riprap-line apron (the most common outlet protection), a relatively low cost method that can be installed easily on most sites • Removes sediment in addition to reducing flow speed • Can be used at most outlets where the flow speed is high • Is an inexpensive but effective measure • Requires less maintenance than many other measures
Disadvantages of Outlet Protection
• May be unsightly • May cause problems in removing sediment (without removing and replacing the outlet protection structure itself) • May require frequent maintenance for rock outlets with high velocity flows

Check Dams

What Are They

A check dam is a small, temporary or permanent dam constructed across a drainage ditch, swale, or channel to lower the speed of concentrated flows. Reduced runoff speed reduces erosion and gullying in the channel and allows sediments to settle out.

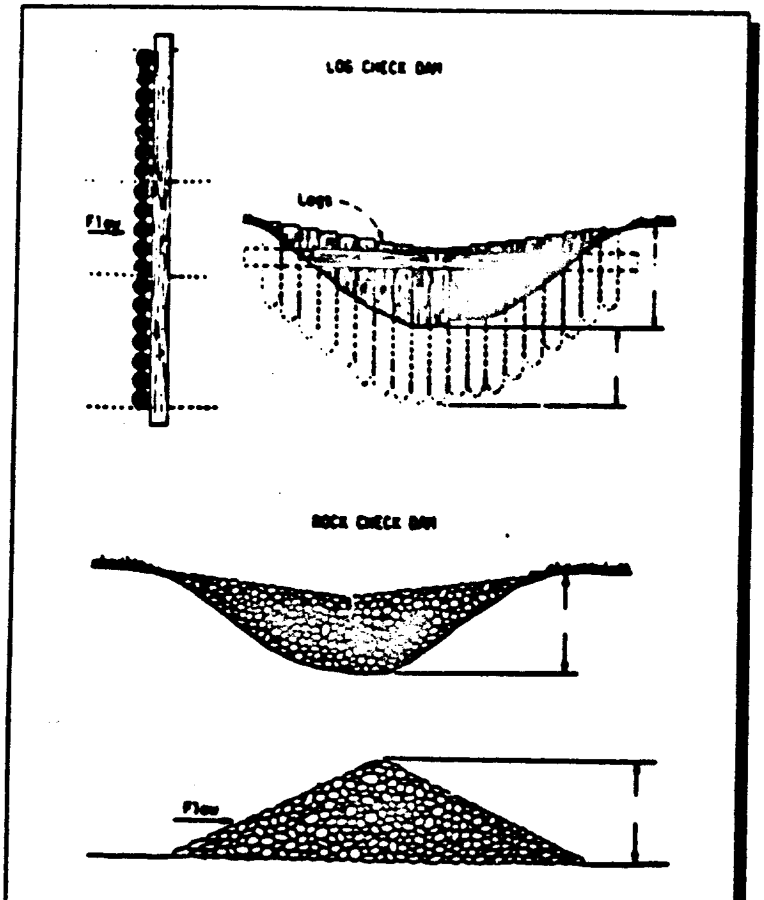

FIGURE 3.23 TYPICAL CHECK DAMS
(Modified from Commonwealth of Virginia, 1980)

When and Where to Use Them

- A check dam should be installed in steeply sloped swales, or in swales where adequate vegetation cannot be established. A check dam may be built from logs, stone, or pea gravel-filled sandbags.

What to Consider

Check dams should be used only in small open channels which will not be overtopped by flow once the dams are constructed. The dams should not be placed in streams (unless approved by appropriate State authorities). The center section of the check dam should be lower than the edges. Dams should be spaced so that the toe of the upstream dam is at the same elevation as the top of the downstream dam.

After each significant rainfall, check dams should be inspected for sediment and debris accumulation. Sediment should be removed when it reaches one half the original dam height. Check for erosion at edges and repair promptly as required. After construction is complete, all stone and riprap should be removed if vegetative erosion controls will be used as a permanent erosion control measure. It will be important to know the expected erosion rates and runoff flow rate for the swale in which this measure is to be installed. Contact the State/local storm water program agency or a licensed engineer for assistance in designing this measure.

Advantages of Check Dams
• Are inexpensive and easy to install • May be used permanently if designed properly • Allow a high proportion of sediment in the runoff to settle out • Reduce velocity and may provide aeration of the water • May be used where it is not possible to divert the flow or otherwise stabilize the channel
Disadvantages of Check Dams
• May kill grass linings in channels if the water level remains high after it rains or if there is significant sedimentation • Reduce the hydraulic capacity of the channel • May create turbulence which erodes the channel banks

Surface Roughening

What Is It

Surface roughening is a temporary erosion control practice. The soil surface is roughened by the creation of horizontal grooves, depressions, or steps that run parallel to the contour of the land. Slopes that are not fine-graded and that are left in a roughened condition can also control erosion. Surface roughening reduces the speed of runoff, increases infiltration, and traps sediment. Surface roughening also helps establish vegetative cover by reducing runoff velocity and giving seed an opportunity to take hold and grow.

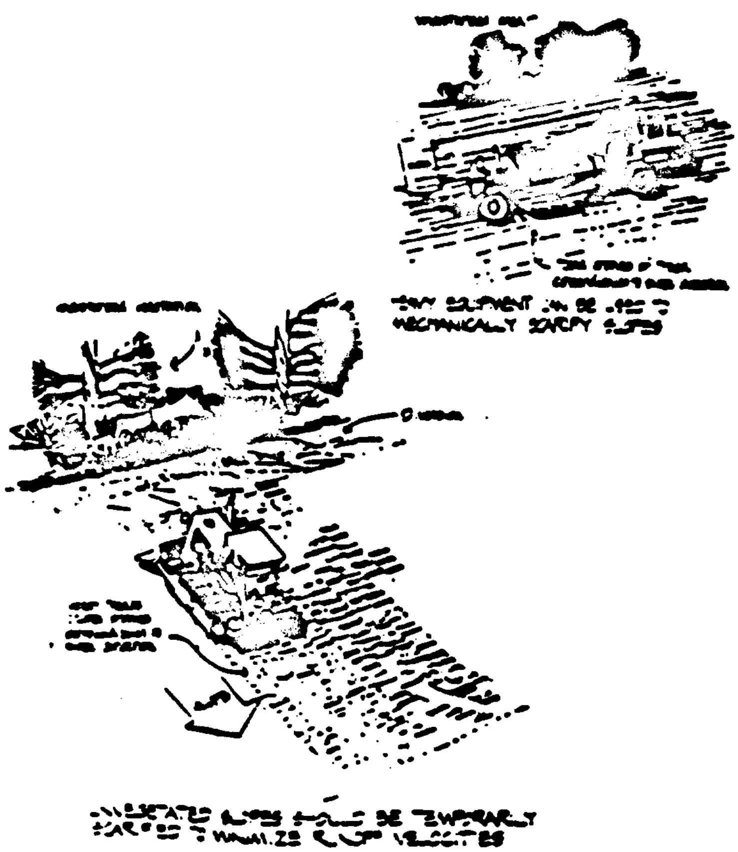

FIGURE 3.24 SURFACE ROUGHENING
(Modified from Washington State, 1992)

When and Where to Use It

Surface roughening is appropriate for all slopes. To slow erosion, roughening should be done as soon as possible after the vegetation has been removed from the slope. Roughening can be used with both seeding and planting and temporary mulching to stabilize an area. For steeper slopes and slopes that will be left roughened for longer periods of time, a combination of surface roughening and vegetation is appropriate. Surface roughening should be performed immediately after grading activities have ceased (temporarily or permanently) in an area.

What to Consider

Different methods can be used to roughen the soil surface on slopes. They include stair-step grading, grooving (using disks, spring harrows, or teeth on a front-end loader), and tracking (driving a crawler tractor up and down a slope, leaving the cleat imprints parallel to the slope contour). The selection of an appropriate method depends on the grade of the slope, mowing requirements after vegetative cover is established, whether the slope was formed by cutting or filling, and type of equipment available.

Cut slopes with a gradient steeper than 3:1 but less than 2:1 should be stair-step graded or groove cut. Stair-step grading works well with soils containing large amounts of small rock. Each step catches material discarded from above and provides a level site where vegetation can grow. Stairs should be wide enough to work with standard earth moving equipment. Grooving can be done by any implement that can be safely operated on the slope, including those described above. Grooves should not be less than 3 inches deep nor more than 15 inches apart. Fill slopes with a gradient steeper than 3:1 but less than 2:1 should be compacted every 9 inches of depth. The face of the slope should consist of loose, uncompacted fill 4 to 6 inches deep that can be left rough or can be grooved as described above, *if necessary*.

Any cut or filled slope that will be mowed should have a gradient less than 3:1. Such a slope can be roughened with shallow grooves parallel to the slope contour by using normal tilling. Grooves should be close together (less than 10 inches) and not less than 1 inch deep. Any gradient with a slope greater than 2:1 should be stair-stepped.

It is important to avoid excessive compacting of the soil surface, especially when tracking, because soil compaction inhibits vegetation growth and causes higher runoff speed. Therefore, it is best to limit roughening with tracked machinery to sandy soils that do not compact easily and to avoid tracking on clay soils. Surface roughened areas should be seeded as quickly as possible. Also, regular inspections should be made of all surface roughened areas, especially after storms. If rills (small watercourses that have steep sides and are usually only a few inches deep) appear, they should be filled, graded again, and reseeded immediately. Proper dust control procedures should be followed when surface roughening.

Advantages of Surface Roughening
• Provides a degree of instant erosion protection for bare soil while vegetative cover is being established • Is inexpensive and simple for short-term erosion control
Disadvantages of Surface Roughening
• Is of limited effectiveness in anything more than a gentle rain • Is only temporary; if roughening is washed away in a heavy storm, the surface will have to be re-roughened and new seed laid

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Gradient Terraces

What Are They

Gradient terraces are earth embankments or ridge-and-channels constructed along the face of a slope at regular intervals. Gradient terraces are constructed at a positive grade. They reduce erosion damage by capturing surface runoff and directing it to a stable outlet at a speed that minimizes erosion.

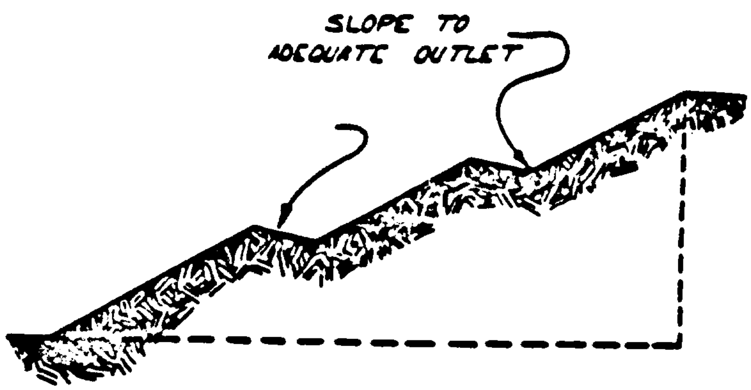

FIGURE 3.25 GRADIENT TERRACE
(Washington State, 1992)

When and Where to Use Them

Gradient terraces are usually limited to use on long, steep slopes with a water erosion problem, or where it is anticipated that water erosion will be a problem. Gradient terraces should not be constructed on slopes with sandy or rocky soils. They will be effective only where suitable runoff outlets are or will be made available.

What to Consider

Gradient terraces should be designed and installed according to a plan determined by an engineering survey and layout. It is important that gradient terraces are designed with adequate outlets, such as a grassed waterway, vegetated area, or tile outlet. In all cases, the outlet should direct the runoff from the terrace system to a point where the outflow will not cause erosion or other damage. Vegetative cover should be used in the outlet where possible. The design elevation of the water surface of the terrace should not be lower than the design elevation of the water surface in the outlet at their junction, when both are operating at design flow. Terraces should be inspected regularly at least once a year and after major storms. Proper vegetation/stabilization practices should be followed while constructing these features.

Advantages of Gradient Terraces
• Reduce runoff speed and increase the distance of overland runoff flow
• Hold moisture better than do smooth slopes and minimize sediment loading of surface runoff

Disadvantages of Gradient Terraces
• May significantly increase cut and fill costs and cause sloughing if excessive water infiltrates the soil
• Are not practical for sandy, steep, or shallow soils

3.3 SUMMARY

Erosion of disturbed soils on construction sites can be prevented in many cases. When it is not possible to prevent the erosion, then the sediment can be trapped onsite. This chapter describes the measures used for erosion and sediment control and provides guidance for selecting the most appropriate measure for a particular site. The descriptions of the measures contained in this chapter are intended to provide general understanding of the measures rather than detailed design information. Check with your State or local erosion and sediment control agency to obtain a copy of their design standards or guidance. If your State or local agency does not have design standards or guidance, then refer to the design "Fact Sheets" contained in Appendix B of this manual.

Erosion and sediment control measures are a critical component of a Storm Water Pollution Prevention Plan and of a construction project. These measures should be designed and constructed in the most effective manner.

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CHAPTER 4

OTHER CONTROLS

Sections 3 and 4 of this manual discuss erosion, sediment, and storm water management controls which are used to prevent or reduce pollution from construction sites; however, these are not the only potential sources of pollution from construction activity. Chemicals and other materials used and stored on a construction site, and construction activities themselves can become significant sources of pollution. This chapter will cover some of the control measures and practices used to prevent contact between storm water and potential sources of contamination or pollution. It will also help you to identify many potential sources including specific materials and chemicals, problem areas, procedures, and general construction practices. The controls and practices are called Best Management Practices (BMPs) and are an important part of site-specific controls in your Storm Water Pollution Prevention Plan. The BMPs in this chapter deal with prevention—that is, limiting contact between storm water and a potential pollutant. BMPs aimed at the removal of pollutants are considered treatment type BMPs.

This chapter also addresses how to control allowable non-storm water discharges on your site. This chapter provides guidance as to what types of non-storm water discharges are allowable and what measures should be taken to limit or control pollution caused by these discharges.

Q. Are there other controls that should be used on all construction sites?

Typically, there are no specific BMPs that should be used on all construction sites. Only the controls which best address site-specific conditions should be implemented to control or eliminate contamination of storm water. There are four areas of control (in addition to erosion and sedimentation controls and storm water management) that should be addressed in each Storm Water Pollution Prevention Plan. The controls that should be addressed include: minimization of offsite vehicle tracking of sediments; disposal of building material wastes; compliance with applicable State or local waste disposal, sanitary sewer, or septic system regulations; and appropriate pollution prevention measures for allowable non-storm water components of discharge. These controls along with additional controls are discussed in the following sections.

Q. How will I know what other BMPs to consider?

Read the section(s) indicated if any of the areas or materials listed below apply to your site. Using the list and the information sections in this chapter should help you to identify potential risks on your site and select the appropriate BMPs.

Activity	Section	Page No.
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Hazardous Products	4.2.2	4-5
Control of Allowable Non-Storm Water Discharges	4.7	4-19
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Q. What information should you include in your Storm Water Pollution Prevention Plan regarding the controls you are planning for your site?

The following basic information should be a part of your Storm Water Pollution Prevention Plan:

- Provide a narrative description of each practice
- Show the location of each control measure on your site map (if possible)
- Describe the maintenance, inspection, repair, and recordkeeping procedures that will ensure control measures remain effective and in working order during the construction activity
- Describe employee training necessary for the operation and maintenance of the practice or control.

See Chapter 5 for additional information on maintenance, inspection, repair, and employee training.

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4.1 GOOD HOUSEKEEPING

Good housekeeping is basically keeping a clean, orderly construction site. One of the first steps towards preventing storm water contamination is improving housekeeping practices and using good common sense. Good housekeeping practices reduce the possibility of accidental spills, improve the response time if there is a spill, and reduce safety hazards as well.

Q. Are good housekeeping practices expensive?

No, good housekeeping practices are inexpensive, relatively easy to implement, and are often effective in preventing storm water contamination.

Q. What are some examples of good housekeeping practices?

Examples of good housekeeping on a construction site include:

- Neat and orderly storage of any chemicals, pesticides, fertilizers, fuels, etc., that are being stored at the site
- Regular garbage, rubbish, construction waste, and sanitary waste disposal
- Prompt cleanup of any spills that have occurred of liquid or dry materials
- Cleanup of sediments that have been tracked by vehicles or have been transported by wind or storm water about the site or onto nearby roadways.

4.2 WASTE DISPOSAL

Proper management and disposal of building materials and other construction site wastes is an important part of pollution prevention. Construction site materials which were overlooked as potential sources of storm water contamination in the past, should now be managed more carefully. This section will help you identify the obvious and not so obvious sources on your site. These may be materials, practices, or locations where there is potential risk of pollution. These materials include surplus or refuse building materials as well as hazardous wastes. Practices include trash disposal, recycling, material handling, and spill prevention and cleanup measures. Controls and practices should meet the requirements of your permit and the Federal, State, and local requirements your site is subject to.

This section discusses some of the waste materials encountered at construction sites and discusses generally how these materials should be stored and handled so that their exposure to storm water is minimized. However, this section does not provide specific details on how to handle or dispose of these materials. You should contact the appropriate waste management agency to find out more about waste disposal regulations, or the appropriate occupational health and safety agency to find out about material storage and handling.

4.2.1 Construction Wastes

Construction projects tend to generate a great deal of solid waste material which is unique to this activity. These wastes are sometimes called "construction wastes."

Construction wastes may include but are not limited to:

- Trees and shrubs removed during clearing and grubbing or other phases of construction
- Packaging materials (including wood, paper, plastic, etc.),
- Scrap or surplus building materials, e.g., scrap metals, rubber, plastic and glass pieces, masonry products, and other solid waste materials
- Paints and paint thinners
- Materials resulting from the demolition of structures (rubble).

Q. What steps should be taken to ensure that construction waste is properly disposed of?

The following steps will help ensure proper disposal of construction wastes:

- Select a designated waste collection area onsite
- Provide an adequate number of containers with lids or covers that can be placed over the container prior to rainfall
- When possible, locate containers in a covered area.
- Arrange for waste collection before containers overflow

- If a container does spill, provide cleanup immediately
- Plan for additional containers and more frequent pickups during the demolition phase of construction
- Make sure that construction waste is collected, removed, and disposed of only at authorized disposal areas
- Check with your local solid waste management agency for specific guidance.

4.2.2 Hazardous Products

Many of the materials found at a construction site may be hazardous to the environment or to personnel. It is always important to read the labels of the materials or products you have onsite; they may contain warning information that will help you to be aware of a potential problem. At a minimum, you should consider any products in the categories listed below to be hazardous products (also see Section 4.5 for Material Management):

- Paints
- Acids for cleaning masonry surfaces
- Cleaning solvents
- Chemicals additives used for soil stabilization (e.g., palliative such as calcium chloride)
- Concrete curing compounds and additives.

Q. What are some basic management practices you can use to minimize or prevent impacts on storm water from hazardous products on construction sites?

Most problem situations involving hazardous materials are the result of carelessness or not using good common sense. The practices listed here will help you to avoid problems associated with the disposal of hazardous materials. Section 4.5 contains further information on storing and handling hazardous materials:

- Check with local waste management authorities to determine what the requirements are for disposing of hazardous materials.
- Use all of the product before disposing of the container.
- Do not remove the original product label from the container, it contains important information.
- If you must dispose of surplus products, do not mix products together unless specifically recommended by the manufacturer.
- The correct method of disposal of these products varies with the product used. Follow the manufacturer's recommended method, which is often found on the label.

4.2.3 Contaminated Soils

Contaminated soils are soils which have been exposed to and still contain hazardous substances. Contaminated soils may be encountered onsite during earthmoving activities or during the cleanup of a spill or leak of a hazardous product. Material storage areas may also have been contaminated by undetected spills. The nature of the contaminants may or may not be known.

Q. Where can I get information on disposal options?

Your State or local solid waste regulatory agency should be contacted concerning information and procedures necessary to treat or dispose of contaminated soils. Some landfills may accept contaminated soil; however, laboratory tests may be required prior to a final decision. Private firms can also be consulted concerning disposal options.

4.2.4 Concrete Trucks

Most construction projects include some sort of concrete work. Usually, concrete is mixed offsite and delivered to the project by truck. The concrete is poured and there is a residual amount of concrete remaining in the truck, or occasionally, excess concrete is delivered, or the concrete is found to be unacceptable and is rejected by the construction inspector or foreman. The truck should be cleaned and the residual concrete dumped before it "sets up" (hardens) in the truck.

Q. Are you allowing concrete trucks to washout or dump onsite?

Emptying or wash out of excess concrete may be allowed onsite. Excess concrete and wash water should be disposed of in a manner that prevents contact between these materials and storm water which will be discharged from the site. For example, dikes could be constructed around the area to contain these materials until they harden, at which time they may be properly disposed of.

4.2.5 Sandblasting Grits

Sandblasting is a commonly used technique to remove paint, dirt, etc., from surfaces. Sand is sprayed on the surface to be cleaned. Sandblasting grits consist of both the spent sand and the particles of paint and dirt removed from the surface.

Q. Why are sandblasting grits a problem?

Sandblasting grits are hazardous waste if they were used to clean old structures where lead, cadmium, or chrome based paints were used. They should not be washed into the storm or sanitary sewer.

Q. What is the best way to dispose of sandblasting grits?

A licensed waste management or transport and disposal firm should be contacted to dispose of this type of used grit.

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4.3 MINIMIZING OFFSITE VEHICLE TRACKING OF SEDIMENTS

Day-to-day site practices can have a major impact on storm water contamination because of their potential for generating sediments. A common problem area is offsite vehicle tracking. Two practices are commonly used for minimizing offsite vehicle tracking of sediments: stabilized construction entrances and construction access road stabilization.

Q. What measures have you taken to prevent offsite vehicle tracking?

Controlling offsite tracking of sediments may require attention at most times when there is vehicle traffic at the construction site. The measures listed here are effective if used properly.

- A stabilized construction entrance and construction road are very effective methods for reducing offsite tracking of mud, dirt, and rocks
- Paved streets adjacent to the site should be swept to remove any excess mud, dirt, or rock tracked from the site
- Deliveries or other traffic should be scheduled at a time when you will have personnel available to provide cleanup if it is required.

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4.3.1 Construction Road Stabilization

What Is It

A stabilized construction road is a road built to provide a means for construction vehicles to move around the site without causing significant erosion. A stabilized construction road is designed to be well drained so that water does not puddle or flood the road during wet weather. It typically will have a swale along one or both sides of the road to collect and carry away runoff. Stabilized construction roads should be have a layer of crushed stone or gravel which will cover and protect the soil below from erosion.

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When and Where to Use It

A stabilized construction road should be installed in a disturbed area where there will be a high volume of construction traffic expected. A construction road should be stabilized at the beginning of construction and maintained throughout construction. Construction parking areas should be stabilized as well as the roads. A stabilized construction road should not be located in a cut or fill area until after grading has been performed.

What to Consider

Stabilized construction roads should be built to conform to the site grades; this will require a minimum amount of cut and fill. They should also be designed so that the side slopes and road grades are not excessively steep. Construction roads should not be constructed in areas which are wet, or on highly erodible soils.

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Advantages of Construction Road Stabilization
• Reduces the amount of erosion, dust, and tracking of soil off of the site • Provides an effective way for vehicles to move around the construction site, even during wet weather
Disadvantages of Construction Road Stabilization
• Can be expensive • May require maintenance to replace gravel or repair ruts

4.3.2 Stabilized Construction Entrance

What Is It

A stabilized construction entrance is a portion of the construction road which is constructed with filter fabric and large stone. The primary purpose of a stabilized construction entrance is to reduce the amount of soil tracked off of the construction site by vehicles leaving the site. The rough surface of the stone will shake and pull the soil off of the vehicles tires as it drives over the entrance. The stone will also reduce erosion and rutting on the portion of the road where it is installed by protecting the soil below. The filter fabric separates the stone from the soil below, preventing the large stone from being ground into the soil. The fabric also reduces the amount of rutting caused by the vehicle tires by spreading the weight of the vehicles over a larger soil area than just the tire width.

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When and Where to Use It

A stabilized construction entrance should be installed at every point where traffic leaves or enters a disturbed area before construction begins on the site. Typically, stabilized construction entrances are installed at the locations where the construction traffic enters or leaves an existing paved road; however, a stabilized construction entrance should not be installed over an existing pavement (except for a slight overlap as shown in Figure 4.1). Where the construction will require a permanent access road or driveway, it is recommended that a stabilized construction entrance be installed in this location prior to the permanent pavement.

What to Consider

Stabilized construction entrances should be wide enough and long enough so that the largest construction vehicle will fit in the entrance with room to spare. If a large amount of traffic is expected at an entrance, then the stabilized construction entrance should be wide enough to fit two vehicles across with room to spare.

If the stabilized construction entrance has to cross a swale or stream, then a stream crossing should be provided (see page 3-42).

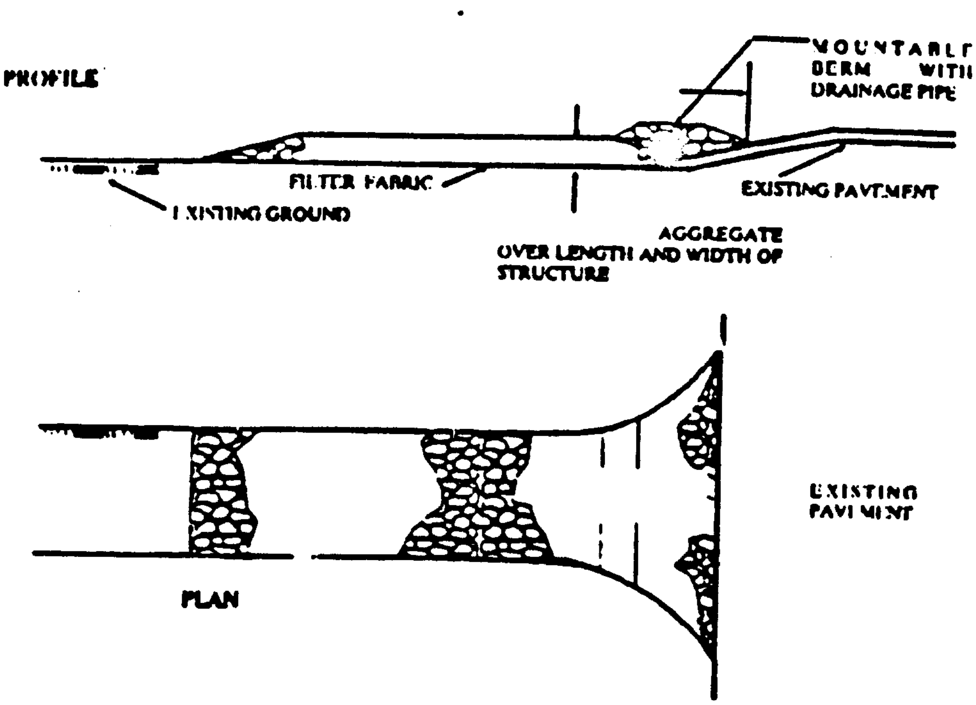

FIGURE 4.1 STABILIZED CONSTRUCTION ENTRANCE
(Modified from Maryland Department of the Environment, 1991)

Stone used for the construction entrance should be large enough so that it is does not get picked up and tracked off of the site by the vehicle traffic. Sharp edged stone should not be used to avoid puncturing tires.

If vehicles will be turning onto the paved road or drive from the stabilized construction entrance, then an apron should be provided as shown above so that vehicles do not go off of the stabilized construction entrance before they leave the site.

The temporary construction entrance may be provided with a vehicle wash rack which drains to a temporary sediment trap or other sediment removing measure. This will allow vehicle tires to be washed prior to leaving the site and ensure that wash water sediments are removed and can be properly disposed of.

Advantages of a Stabilized Construction Entrance
• Is an effective means for reducing the amount of soil tracked off of a construction site • Can improve the appearance of the construction site from the public's point of view
Disadvantages of a Stabilized Construction Entrance
• Only works if it is installed at every location where traffic leaves and enters the site • Cannot always remove all of the soil tracked off of the disturbed areas by vehicles; when soil is tracked onto a road, it should be cleaned up immediately • Stone may have to be added to keep it effective

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4.4 SANITARY/SEPTIC DISPOSAL

Q. How should I manage sanitary or septic wastes on a construction site?

Almost all construction sites have sanitary facilities for onsite personnel. The most commonly found facilities are portable facilities that store the sanitary wastes and should be emptied periodically. Other facilities include temporary facilities that employ septic systems for treatment and disposal of the sewage, or temporary facilities that discharge to a sanitary sewer system. Sanitary or septic wastes that are generated onsite should be treated or disposed of in accordance with State or local requirements. Depending upon the facilities that will be used onsite, this may require one or more of the following:

- Domestic waste haulers should be contracted to regularly remove the sanitary and septic wastes and to maintain the facilities in good working order. This will prevent overloading of the system which could allow discharges to storm water runoff.
- Wastes should be treated to an appropriate level before discharging.
- Facilities should be properly hooked into the sanitary sewer system to prevent illicit discharges.

Untreated, raw sewage or septage should never be discharged or buried onsite.

Q. What do I need to do to ensure and demonstrate that I am complying with State or local sanitary or septic system regulations?

To ensure that you are in compliance with State or local requirements for sanitary or septic wastes, you should contact your local government and State regulatory agencies. Many States have regulations concerning On Site Disposal Systems (OSDS) or discharges to sanitary sewers. Localities often have ordinances which deal with the proper management of sanitary and septic wastes. In addition, if sewage is being discharged to the sanitary sewer, the local Publicly Owned Treatment Works (POTW) should be contacted because they may have certain requirements as well. If wastes are being hauled offsite, your State may have a licensing program for waste haulers. If your State does have this, you should only contract with these licensed haulers. If your State does not, a reputable hauler should be chosen.

Contacting the proper authorities prior to the development of your Storm Water Pollution Prevention Plan will provide you with the information needed for demonstrating compliance with the appropriate regulations.

4.5 MATERIAL MANAGEMENT

Material management is important because the best way to avoid a problem is to try to prevent it at its source. On a construction site the material storage area can become a major source of risk due to possible mishandling of materials or accidental spills. An inventory of the material storage area and of the site should be made. Special care should be taken to identify any materials that have the potential to come in contact with storm water. This will help raise your awareness and to plan effective controls.

There are a number of risks (other than contamination of storm water) to consider in the management of materials on a construction site, including health and safety of employees, or contamination of groundwater. This section; however, only addresses measures to minimize the risk of storm water contamination. Contact your local regulatory agency to find out about measures to minimize other risks.

Q. What types of materials should be considered when evaluating potential risks?

The following are some of materials commonly found on a construction site. The material inventory list should include these for risk assessment:

- Pesticides
- Petroleum products
- Fertilizers and detergents (nutrients)
- Construction chemicals
- Other pollutants
- Hazardous products (also see Hazardous Products Section 4.2.2).

Q. What information would be useful to consider when identifying risks onsite?

The types of information that should be considered and the questions you should ask yourself when identifying risks include:

- What types of materials are stored onsite?
- How long will the materials be stored before use?
- Are you storing more than is really needed?
- How are the materials stored and distributed?
- How can potential storm water contact be avoided?

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Q. What methods are helpful in reducing potential risks?

Good housekeeping and material management practices for storage and use will help minimize exposure risks. This chapter contains suggested storage and handling practices for your use for the various categories of risks. Writing your spill prevention plan (Section 4.6) will also help you to identify ways to cut down the risk of exposure of materials to storm water.

4.5.1 Pesticides

Pesticides include insecticides, rodenticides, and herbicides which are often used on construction sites.

Q. What steps should be taken to reduce the risks in using this type of material?

The steps that should be taken to reduce the risks of using pesticides include the following:

- Handle the materials as infrequently as possible
- Observe all applicable Federal, State, and local regulations when using, handling, or disposing of these materials (Process, Procedures, and Methods to Control Pollution Resulting from All Construction Activity, U.S. EPA).

Q. What management practices could you use for these materials?

The management practices used to reduce the amounts of pesticides that could contact storm water include the following:

- Store pesticides in a dry covered area
- Provide curbs or dikes to contain the pesticide if it should spill
- Have measures on site to contain and clean up spills of pesticides
- Strictly follow recommended application rates, recommended application methods, (i.e., only apply the amounts necessary for the job).

4.5.2 Petroleum Products

Oil, gasoline, lubricants, and asphaltic substances such as paving materials are considered petroleum products. These materials should be handled carefully to minimize their exposure to storm water.

Q. Where do petroleum products usually occur onsite?

Petroleum products usually occur in two site areas.

- Areas where road construction of some type is occurring
- Vehicle storage areas or areas of onsite fueling or equipment maintenance.

Q. What steps should be taken to reduce the risks in using this type of material?

These following practices will help to reduce the risks in using petroleum products:

- Have equipment to contain and clean up petroleum spills in fuel storage areas or on board maintenance and fueling vehicles
- Where possible, store petroleum products and fuel vehicles in covered areas and construct dikes to contain any spills
- Contain and clean up petroleum spills immediately
- Preventive maintenance for onsite equipment is one BMP to prevent leakage (e.g., check for and fix gas or oil leaks in construction vehicles on a regular basis.)
- Proper application of asphaltic substances (see manufacturers' instructions) will also reduce the risk of a spill.

4.5.3 Fertilizers/Detergents

Nutrients such as phosphorous and nitrogen are found on construction sites in both fertilizers and detergents. Fertilizers are needed on construction sites to provide the nutrients for plant growth; however, when excess quantities of fertilizers are used or when fertilizers are washed away by storm water runoff, they may be a major source of pollution. An excess of nutrients reaching a body of water can cause an overgrowth of water plants which then use up the oxygen in the water, creating an unfavorable environment. Detergents can contribute to water pollution if wash waters are released into the environment (see the discussion on non-storm water discharges).

Q. What steps can be taken to reduce the risks of nutrient pollution?

The steps that can be taken to reduce the risks of nutrient pollution include:

- Limit the application of fertilizers to the minimum area and the minimum recommended amounts
- Reduce exposure of nutrients to storm water runoff by working the fertilizer deep into the soil (depth of 4 to 6 inches) (Process, Procedures, and Methods to Control Pollution Resulting from All Construction Activity, U.S. EPA), instead of letting it remain on the surface
- Apply fertilizer more frequently, but at lower application rates

- Hydro seeding where lime and fertilizers are applied to the ground surface in one application should be limited where possible
- Limit the use of detergents onsite; wash water containing detergents should not be discharged in the storm water system.
- Implement good erosion and sediment control to help reduce the amount of fertilizers that can leave the site as well as sediments
- Apply fertilizer and use detergents only in the recommended manner and only in recommended amounts.

4.5.4 Natural Geologic Drainage

Other pollutants include acid and alkaline solutions from exposed soil of rock units high in acid, and alkaline forming natural elements.

Q. What steps should be taken to reduce the risks in using this type of material?

The control of these pollutants involves good site planning and pre-construction geological surveys. Neutralizing acid or alkaline solutions often provides the best treatment.

- Seal fractures in the bedrock with grout and bentonite, this method will often reduce the amount of acid or alkaline seepage.

4.5.5 Hazardous Products

Q. What materials are in this category?

As discussed in Section 4.2.2, hazardous materials include (but are not limited to) paints, acids for cleaning masonry surfaces, cleaning solvents, chemical additives used for soil stabilization, and concrete curing compounds.

Q. What are some basic management practices you can use to minimize or prevent impacts from hazardous products on construction sites?

Most problem situations involving hazardous materials and other pollutants are the result of carelessness or not using good common sense. The practices listed below will help to avoid pollution of storm water by these materials.

- Have equipment to contain and clean up spills of hazardous materials in the areas where these materials are stored or used.
- Contain and clean up spills immediately after they occur.
- Keep materials in a dry covered area.

4.6 SPILLS

Spills are a source of storm water contamination, and construction site spills are no exception. Spills can contaminate soil and water, waste materials, and result in potential health risks. In addition to the other measures and practices you have adopted, you should prepare to deal quickly and effectively with accidental spills. A spill control plan can help you to be prepared. This section discusses your additional responsibilities if there is a reportable quantity spill.

Q. Do you have a spill control plan for your site?

Construction site supervisors should create and adopt a spill control plan which would include measures to:

- Stop the source of the spill
- Contain the spill
- Clean up the spill
- Dispose of materials contaminated by the spill
- Identify and train personnel responsible for spill prevention and control.

Q. Do you know what specific spill prevention methods and response to use?

The following measures would be appropriate for a spill prevention and response plan.

- Store and handle materials to prevent spills.
  - Tightly seal containers.
  - Make sure all containers are clearly labeled.
  - Stack containers neatly and securely.
- Reduce storm water contact if there is a spill.
  - Have cleanup procedures clearly posted.
  - Have cleanup materials readily available.
  - Contain any liquid.
  - Stop the source of the spill.
  - Cover spill with absorbent material such as kitty litter or sawdust.
- Dispose of contaminated materials according to manufacturer's instructions or according to State or local requirements.
- Identify personnel responsible for responding to a spill of toxic or hazardous materials.
  - Provide personnel spill response training.
  - Post names of spill response personnel.

- **Keep the spill area well ventilated.**
- **If necessary, use a private firm that specializes in spill cleanup.**

Check the spill reporting requirements listed in your permit, typically any spill should be reported. See Section 2.

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4.7 CONTROL OF ALLOWABLE NON-STORM WATER DISCHARGES

NPDES storm water permits for construction activities typically include a prohibition against non-storm water discharges. Permits will state that all discharges covered by the permit must be composed entirely of storm water. However, permits may list some non-storm water discharges that, when combined with storm water discharges, may be authorized by the permit. These exemptions may be allowed provided they are addressed in the Storm Water Pollution Prevention Plan for the site. The following is a list of non-storm water discharges which are typically permitted. However, check your permit to determine what non-storm water discharges are allowable.

- Discharges from fire fighting activities
- Fire hydrant flushings
- Potable water sources (including waterline flushings)
- Uncontaminated ground water (including dewatering ground water infiltration)
- Foundation or footing drains where flows are not contaminated with process materials such as solvents
- Springs, riparian habitats, and wetlands
- Irrigation water
- Exterior building washdown
- Pavement wash waters where spills or leaks of toxic or hazardous materials have not occurred and where detergents are not used
- Air conditioning condensate.

Q. How do these allowable non-storm water discharges relate to discharges on construction sites?

Common construction activity discharges that fall under the allowable non-storm water discharges include the following:

- Waterline flushings from the disinfection of newly installed potable water piping systems
- Irrigation water discharged during seeding and planting practices
- New construction exterior building washdown discharges
- Pavement wash waters from dust control and general housekeeping practices
- Foundation and footing drain discharges from subsurface drainage systems
- Uncontaminated ground waters from dewatering of excavated areas.

Q. What should be done with non-allowable non-storm water discharges?

You have three choices for handling non-storm water discharges which are not allowed by your permit:

1. Eliminate the source of the discharge.
2. Apply for a separate permit for the discharge.
3. Direct the discharge to a sanitary sewer system. Note: You should check first with the operator of the sewer system to see if you are allowed to discharge the material in question into the sanitary sewer.

Q. How should the allowable non-storm water discharges be addressed in the Storm Water Pollution Prevention Plan?

The allowable non-storm water discharges should be identified in the Storm Water Pollution Prevention Plan. For each of the discharges, practices or controls that will be used to prevent pollution from these discharges should be described in detail.

Q. What types of controls or practices can be used to prevent pollution from these discharges?

The following general practices should be considered:

- All downslope site sedimentation and erosion controls should be in place prior to the discharge
- Discharges with sediment loads should be discharged so that sediment pollution is minimized. These discharges include dewatering operation discharges, and discharges from sediment traps and basins.
- Discharge should only be directed to areas that are stabilized to minimize erosion (e.g., buffer zones, vegetated filter strips, inlet and outlet protection, level spreaders, etc.). Do <u>not</u> discharge non-storm water flows onto disturbed areas.

Q. What types of controls can be used for discharges that have sediments?

Discharges with sediment should be directed to pass through a sediment filtering device. Sediment filtering devices include sediment traps, basins, silt fences, vegetated filter strips, sump pits, or sediment tanks.

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4.7.1 Dewatering

What Is It

Dewatering is the method used to remove and discharge excess water from a construction site. The most common procedure used is to pump water out of areas where it does not otherwise drain off, such as excavated areas, sediment basins, and sediment traps. Dewatering may also include methods used to lower the ground water table to provide a stabilized area for construction.

When and Where to Use It

Dewatering may be used during construction to remove accumulated water and sediments from sediment traps and basins to ensure their effectiveness throughout the entire project. At the end of the project, dewatering of sediment traps and basins is appropriate prior to removing the last sediment control measures. Water remaining in excavated areas may be eliminated by dewatering so that construction can proceed on schedule.

What to Consider

Dewatering discharges usually have a very high sediment content; therefore, sediment control should be provided before the discharge enters a receiving water.

Sediment traps and basins are often used to remove sediment from dewatering of excavation areas.

Filtering should also be provided when discharge results from dewatering a sediment trap or basin. Methods to consider for this purpose are noted below in order of preference:

- A sump pit—discussed in detail in Section 4.7.2
- A floating suction hose which allows clean water at the surface to be pumped out before the hose sinks low enough to pick up sediment-laden water
- A standpipe attached to the base of the sediment basin riser with slits to control inflow and wrapping of filter fabric to aid in filtering sediments.

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Advantages of Dewatering
• Provides for the proper discharge of water from sediment traps and basins and excavation areas onsite • Use of efficient sediment removal methods (such as a sump pit, floating hose, or standpipe) allows safe release of dewatering discharges into a receiving water
Disadvantages of Dewatering
• The floating hose method requires careful monitoring since pumping should be stopped as soon as sediments are encountered • Even the initial discharge pumped in the floating hose method requires additional filtering • A location should be found to dispose of sediments properly, meeting appropriate Federal, State, and local regulations

4.7.2 Sump Pit

What Is It

A sump pit is a temporary hole or pit placed so that it can collect water from sediment traps and basins, or excavations. In the center of the pit is a standpipe with holes which is surrounded by stone. Water that collects in the pit flows through the gravel into the standpipe and is pumped out to a filtering device or, in some cases, directly to a receiving water. The sump pit discharge may be pumped directly to a receiving water only if the standpipe has been properly wrapped in filter fabric.

When and Where to Use It

A sump pit may be used to dewater a sediment trap or basin, or it may be used during construction when water collects in an excavation.

What to Consider

The number of sump pits and their location will depend on the individual site and any State or local requirements.

The standpipe should have holes in it to allow water to flow in and should be extended at least a foot over the top of the pit.

If the sump pit is to discharge directly into a receiving water, then the standpipe should be wrapped in filter fabric before the pit is backfilled with stone.

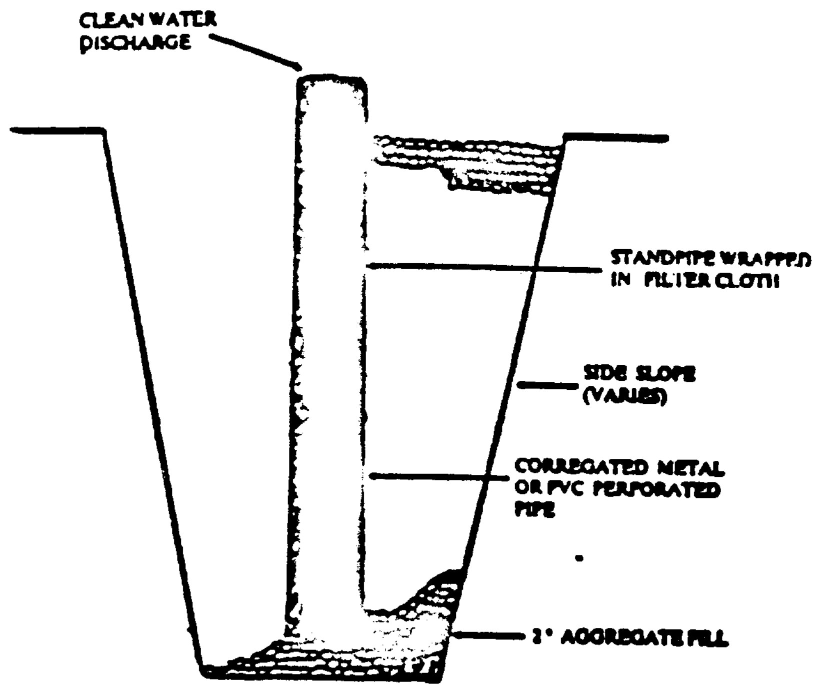

FIGURE 4.2 SUMP PIT
(Modified from Maryland Department of the Environment, 1991

Advantages of a Sump Pit
• A sump pit may be used for dewatering where space is limited, such as in city areas
Disadvantages of a Sump Pit
• If the holes in the standpipe or filter fabric are too small, they will clog

4.8 SUMMARY

There are a number of other controls which should be considered in addition to erosion, sediment, and storm water management while preparing a Storm Water Pollution Prevention Plan. These controls include measures which prevent potentially polluting construction materials from coming into contact with storm water. Measures include good housekeeping and proper waste disposal, as well as controls which prevent sediments from being tracked off site by construction vehicles, and proper control of the non-storm water flows on the site. These other controls should not be overlooked. They are an important part of pollution prevention at construction sites.

CHAPTER 5

MAINTENANCE AND INSPECTION

This Chapter discusses the general maintenance and inspection for proper implementation of a Storm Water Pollution Prevention Plan. Maintenance and inspection of storm water pollution control measures is as important to pollution prevention as selection and installation. This section is presented in a question and answer format. By answering these questions, you will gain an understanding of how you can plan and perform inspection and maintenance on the pollution prevention controls for your project. The following sections address four components which are critical to a Storm Water Pollution Prevention Plan: inspection, maintenance, recordkeeping, and training.

Q: What areas of the construction site will you have to inspect and maintain?

You should inspect and maintain all the disturbed areas of your site, and the areas for material storage. You should also inspect all of the erosion and sediment controls which you identified in the Storm Water Pollution Prevention Plan. These measures may include (but are not limited to) any of the following:

- Seeded areas (permanent or temporary)
- Mulched areas
- Areas stabilized with geotextiles
- Sod stabilized areas
- Silt fences
- Earth dikes
- Brush barriers
- Drainage swales
- Sediment traps
- Subsurface drains
- Pipe slope drains
- Level spreaders

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- Storm drain inlet protection measures
- Rock outlet protection
- Reinforced soil retaining systems
- Gabions
- Sediment basins.

Q: How long will you have to continue to inspect and maintain these measures?

You should inspect and maintain the pollution prevention measures on your construction site as long as a portion of the site remains disturbed. Check the requirements of your permit for the frequency at which inspection and maintenance is required.

Q: At what point should you begin to consider inspection and maintenance requirements?

You should begin to consider maintenance requirements at the same time you choose BMPs. You will notice that some practices take a good deal more maintenance than others and you may wish to be aware of this when you are deciding which measures to use.

Q: What does a maintenance and inspection plan include?

Appendix C includes a sample maintenance and inspection plan. A good maintenance and inspection plan should do the following:

- Identify all of the areas/measures that will be inspected and maintained
- Provide an inspection schedule for each area/measure
- List the typical maintenance procedures for each measure
- Describe the procedure to follow if additional repair is required, e.g., who will be responsible or who to call
- Provide forms and instructions for record keeping practices
- List the names of personnel assigned to each task
- Indicate what training employees will need to be able to do the job.

5.1 INSPECTION

Inspection is the process by which you can evaluate if the pollution prevention measures which have already been installed or applied are still effective. In most cases, inspection of pollution prevention measures requires that an inspector look at all of the disturbed areas and sediment controls on the site and make some measurements of sediment accumulation (depending upon the measures).

Q: How frequently should inspections take place?

Inspections of pollution prevention measures should be performed on a regular interval plus after every significant rainfall. Check your permit to determine the how frequently your site should be inspected and what constitutes a significant rainfall. A regular inspection and maintenance program can reduce the chance of polluting the storm water by finding and correcting problems before the next rain.

Q: What should an inspector look for?

The inspector should look at each measure to determine if it is still effective. Appendix B contains fact sheets with figures and specifications on many of the measures. The inspector should consult these fact sheets or the description included in the Storm Water Pollution Prevention Plan and determine if the measures still meet the minimum requirements. For example: the fact sheet for a silt fence shows the bottom of the fabric is placed in a trench and buried with soil or stone. The inspector could compare this detail with the silt fence installed on the site. If the bottom of the fabric is not buried as shown on the detail, the inspector should note this on the report form.

The fact sheets also list the specific maintenance tasks which are often triggered by some observation about the measure. For example, the fact sheet for a silt fence states that accumulated sediment should be removed from the silt fence when it reaches a height of one third to one half the height of the fence. Based upon this the inspector should measure the accumulated sediment on the silt fence at each inspection.

There are primarily three things an inspector should look for when inspecting a pollution prevention measure. They are: whether or not the measure was installed/performed correctly; whether or not there has been damage to the measure since it was installed or performed; and finally what should be done to correct any problems with the measure.

Q: What should an inspector do with his/her observations?

An inspector should prepare a report documenting his/her findings (see Section 5.3). An inspector should request the required maintenance or repair for the pollution prevention measures, and if the Storm Water Pollution Prevention Plan should be changed to allow for unexpected conditions, then the inspector should make the changes or notify the appropriate person to make the changes.

5.2 MAINTENANCE

Maintenance of pollution prevention measures involves the upkeep and repair of the measures which have been installed to reduce pollution of storm water. Maintenance is important because the control measures you implement may be of little or no use if they have not been properly maintained. Good maintenance helps to insure that these measures are in proper working order when they are really needed under storm or spill conditions.

EPA BASELINE GENERAL PERMIT REQUIREMENTS
Definition of Maintenance Part IV.D.3 Maintenance includes those procedures used to maintain in good and effective operating condition vegetation, erosion and sediment control measures, and other protective measures identified in the site plan.

Q: When do you perform maintenance?

Maintenance should be performed either on a interval specified in the pollution prevention plan or when the inspection finds that it is necessary for the measure to be effective. For example, if an inspector found that sediment had accumulated in a sediment trap to the depth of one half of its storage depth the inspector should request that the accumulated sediment be removed from the trap. Appropriate maintenance practices for erosion and sediment controls are discussed in the Fact Sheets in Appendix B.

Q: What types of activities can be included in maintenance activities for construction sites?

Maintenance activities for erosion and sediment controls are fairly basic. For example, sedimentation structures require removal (and proper disposal) of accumulated sediments to ensure effective trapping capacity. This technique is also appropriate for temporary sediment traps, sediment basins, and silt fences.

5.3 RECORDKEEPING

It is important to document the inspection of the pollution prevention measures. These records can be used to request maintenance and repair and to prove that the inspection and maintenance were performed.

Q: What kinds of records should be kept for maintenance and inspection?

It is recommended that inspection and maintenance forms be prepared prior to the start of the construction activity. The inspection forms should be specific to the construction project and the Storm Water Pollution Prevention Plan. The forms should list each of the measures to be inspected on the site. The form should include blanks for the inspector to fill in: his or her name, the date of inspection, the condition of the measure/area inspected, maintenance or repair performed and any changes which should be made to the Storm Water Pollution Prevention Plan to control or eliminate unforeseen pollution of storm water. (See Appendix C for a sample format).

The inspector could take a blank copy of the form and fill in the appropriate information as he/she inspected the site. This would reduce the time spent preparing the report and would make sure that all the items requiring inspection are covered.

5.4 TRAINING

The inspector of pollution prevention measures should understand what he/she is inspecting. Training and experience are the best way to develop an understanding for pollution prevention measures. Training inspection personnel will improve the chances for the Storm Water Pollution Prevention Plan to be effective.

Q: How should inspection personnel be trained?

Many States and organizations offer general training programs in sediment and erosion control. This sort of training will be helpful. The inspector should also have detailed knowledge about the site's Storm Water Pollution Prevention Plan particularly the following portions:

- The location and type of control measures
- The construction requirements for the control measures
- Maintenance procedures for each of the control measures
- Spill prevention and cleanup measures
- Inspection and maintenance recordkeeping requirements.

5.5 SUMMARY

This Chapter has addressed a crucial part of the Storm Water Pollution Prevention Plan. Without inspection and maintenance of control measures, it is not likely that the measures will remain effective for long periods of time. Without proper training of inspection staff and recordkeeping, it is difficult to determine what maintenance is required. Therefore, do not consider the pollution prevention plan to be something you do only at the beginning and end of a project. You should instead think of it as an ongoing process from start to completion.

CHAPTER 6

STORM WATER MANAGEMENT CONTROLS

A chapter describing the selection of storm water management controls will be published by EPA for insertion in this portion of the manual.

Consult your general permit to determine the measures necessary to fulfill the storm water management control requirement.

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APPENDIX A

STORM WATER POLLUTION PREVENTION PLAN CHECKLISTS

EPA BASELINE CONSTRUCTION GENERAL PERMIT REQUIREMENTS PRE-CONSTRUCTION CHECKLIST

Storm Water Pollution Prevention Plans

1. A site description, including:
   - ☐ The nature of the activity?
   - ☐ Intended sequence of major construction activities
   - ☐ The total area of the site
   - ☐ The area of the site that is expected to undergo excavation
   - ☐ The runoff coefficient of the site after construction is complete
   - ☐ Existing soil or storm water data
   - ☐ A site map with:
     - ☐ Drainage patterns
     - ☐ Approximate slopes after major grading
     - ☐ Area of soil disturbance
     - ☐ Outline of areas which won't be disturbed
     - ☐ Location of major structural and non-structural controls
     - ☐ Areas where stabilization practices are expected to occur
     - ☐ Surface waters
     - ☐ Storm water discharge locations
   - ☐ The name of the receiving water(s)
2. A description of controls:
   - 2.1 Erosion and sediment controls, including:
     - ☐ Stabilization practices for all areas disturbed by construction
     - ☐ Structural practices for all drainage/discharge locations
   - 2.2 Storm water management controls, including:
     - ☐ Measures used to control pollutants occurring in storm water discharges after construction activities are complete.
     - ☐ Velocity dissipation devices to provide nonerosive flow conditions from the discharge point along the length of any outfall channel.
   - 2.3 Other controls including:
     - ☐ Waste disposal practices which prevent discharge of solid materials to waters of the U.S.?
     - ☐ Measures to minimize offsite tracking of sediments by construction vehicles
     - ☐ Measures to ensure compliance with State or local waste disposal, sanitary sewer, or septic system regulations
   - 2.4 ☐ Description of the timing during the construction when measures will be implemented.
3. ☐ Are State or local requirements incorporated into the plans?
4. ☐ Are maintenance procedures for control measures identified in the plan?
5. ☐ Identification of allowable non-storm water discharges and pollution prevention measures.
6. ☐ Contractor certification.
7. ☐ Plan certification.

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EPA BASELINE CONSTRUCTION GENERAL PERMIT CHECKLIST

Storm Water Pollution Prevention Plan
Construction/Implementation Checklist

1. Maintain Records of Construction Activities, including:
   - ☐ Dates when major grading activities occur
   - ☐ Dates when construction activities temporarily cease on a portion of the site
   - ☐ Dates when construction activities permanently cease on a portion of the site
   - ☐ Dates when stabilization measures are initiated on the site
2. Prepare Inspection reports summarizing:
   - ☐ Name of inspector
   - ☐ Qualifications of inspector
   - ☐ Measures/areas inspected
   - ☐ Observed conditions
   - ☐ Changes necessary to the SWPPP
3. Report Releases of Reportable Quantities of Oil or Hazardous Materials (if they occur):
   - ☐ Notify National Response Center 800/424-8802 immediately
   - ☐ Notify permitting authority in writing within 14 days
   - ☐ Modify the pollution prevention plan to include:
     - the date of release
     - circumstances leading to the release
     - steps taken to prevent reoccurrence of the release
4. Modify Pollution Prevention Plan as necessary to:
   - ☐ Comply with minimum permit requirements when notified by EPA that the plan does not comply
   - ☐ Address a change in design, construction operation or maintenance which has an effect on the potential for discharge of pollutants
   - ☐ Prevent reoccurrence of reportable quantity releases of a hazardous material or oil

EPA BASELINE CONSTRUCTION GENERAL PERMIT CHECKLIST

Storm Water Pollution Prevention Plan
Final Stabilization/Termination Checklist

1. ☐ All soil disturbing activities are complete
2. ☐ Temporary erosion and sediment control measures have been removed or will be removed at an appropriate time
3. ☐ All areas of the construction site not otherwise covered by a permanent pavement or structure have been stabilized with a uniform perennial vegetative cover with a density of 70% or equivalent measures have been employed

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POLLUTION PREVENTION PLAN FOR STORM WATER DISCHARGE ASSOCIATED WITH CONSTRUCTION ACTIVITIES
EROSION AND SEDIMENT CONTROL SELECTION CHECKLIST

INSTRUCTIONS: THIS CHECKLIST LISTS THE MINIMUM SEDIMENT EROSION CONTROL REQUIREMENTS UNDER THE USEPA GENERAL PERMIT. CHECK (✓) EACH ITEM AND FILL IN THE BLANKS BELOW TO EVALUATE COMPLIANCE FOR EACH DRAINAGE AREA AND LOCATION. NOTE: THIS CHECKLIST WAS PREPARED FOR THE USEPA GENERAL PERMIT. REQUIREMENTS FOR STATE GENERAL PERMITS MAY VARY.

Stabilization Practices

☐ Stabilization will be initiated on all disturbed areas where construction activity will not occur for a period of more than 21 calendar days by the 14th day after construction activity has permanently or temporarily ceased.

Stabilization measures to be used include:

- ☐ Temporary Seeding
- ☐ Permanent Seeding
- ☐ Mulching
- ☐ Sod Stabilization
- ☐ Geotextiles
- ☐ Other ____________

Structural Practices

☐ Flows from upstream areas will be diverted from exposed soils. Measures to be used include:

- ☐ Earth Dike
- ☐ Drainage Swale
- ☐ Interceptor Dike and Swale
- ☐ Pipe Slope Drain
- ☐ Other

Drainage locations serving less than 10 disturbed acres

☐ Sediment controls will be installed

Sediment controls include:

- ☐ Sediment Basin
- ☐ Sediment Trap
- ☐ Silt Fence or equivalent controls along all sideslope and downslope boundaries

Drainage locations serving 10 or more disturbed acres

☐ A Sediment Basin will be installed

☐ A Sediment Basin is not attainable on the site; therefore, the following sediment controls will be installed:

Sediment Trap

Silt Fence or equivalent controls along the sideslope and downslope boundaries

Sediment Basin Runoff Storage Calculation

______ acres area draining to the sediment basin

x 3,600 cubic feet of storage/acre

= ______ cubic feet of storage required for the basin.

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APPENDIX B

BMP FACT SHEETS

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SILT FENCE

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Design Criteria

- Silt fences are appropriate at the following general locations:
  - Immediately upstream of the point(s) of runoff discharge from a site before flow becomes concentrated (maximum design flow rate should not exceed 0.5 cubic feet per second).
  - Below disturbed areas where runoff may occur in the form of overland flow.
- Ponding should not be allowed behind silt fences since they will collapse under high pressure; the design should provide sufficient outlets to prevent overtopping.
- The drainage area should not exceed 0.25 acre per 100 feet of fence length.
- For slopes between 50:1 and 5:1, the maximum allowable upstream flow path length to the fence is 100 feet; for slopes of 2:1 and steeper, the maximum is 20 feet.
- The maximum upslope grade perpendicular to the fence line should not exceed 1:1.
- Synthetic silt fences should be designed for 6 months of service; burlap is only acceptable for periods of up to 60 days.

Materials

- Synthetic filter fabric should be a pervious sheet of polypropylene, nylon, polyester, or polyethylene yarn conforming to the requirements in Table 1 below.

TABLE 1. SYNTHETIC FILTER FABRIC REQUIREMENTS

Physical Property	Requirements
Filtering Efficiency	75% - 85% (minimum)
Tensile Strength at 20% (maximum) Elongation	Standard Strength - 30 lb/linear inch (minimum)
	Extra Strength - 50 lb/linear inch (minimum)
Slurry Flow Rate	0.3 gal/ft^2/min (minimum)

- Synthetic filter fabric should contain ultraviolet ray inhibitors and stabilizers to provide a minimum of 6 months of expected usable construction life at a temperature range of 0 to 120°F.
- Burlap of 10 ounces per square yard of fabric can also be used.
- The filter fabric should be purchased in a continuous roll to avoid joints.
- While not required, wire fencing may be used as a backin[illegible] reinforce standard strength filter fabric. The wire fence (14 gauge minimum) should be at [illegible] inches wide and should have a maximum mesh spacing of 6 inches.
- Posts should be 2-4 feet long and should be composed of either 2" x 2-4" pine (or equivalent) or 1.00 to 1.33 lb/linear ft steel. Steel posts should have projections for fastening wire and fabric to them.

Construction Specifications

- The maximum height of the filter fence should range between 18 and 36 inches above the ground surface (depending on the amount of upslope ponding expected).

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- Posts should be spaced 8 to 10 feet apart when a wire mesh support fence is used and no more than 6 feet apart when extra strength filter fabric (without a wire fence) is used. The posts should extend 12 to 30 inches into the ground.
- A trench should be excavated 4 to 8 inches wide and 4 to 12 inches deep along the upslope side of the line of posts.
- If standard strength filter fabric is to be used, the optional wire mesh support fence may be fastened to the upslope side of the posts using 1 inch heavy duty wire staples, tie wires, or hog rings. Extend the wire mesh support to the bottom of the trench. The filter fabric should then be stapled or wired to the fence, and 8 to 20 inches of the fabric should extend into the trench (Figure 1).
- Extra strength filter fabric does not require a wire mesh support fence. Staple or wire the filter fabric directly to the posts and extend 8 to 20 inches of the fabric into the trench (Figure 1).
- Where joints in the fabric are required, the filter cloth should be spliced together only at a support post, with a minimum 6-inch overlap, and securely sealed.
- Do not attach filter fabric to trees.
- Backfill the trench with compacted soil or 0.75 inch minimum diameter gravel placed over the filter fabric.

Maintenance

- Inspect filter fences daily during periods of prolonged rainfall, immediately after each rainfall event, and weekly during periods of no rainfall. Make any required repairs immediately.
- Sediment must be removed when it reaches one-third to one-half the height of the filter fence. Take care to avoid damaging the fence during cleanout.
- Filter fences should not be removed until the upslope area has been permanently stabilized. Any sediment deposits remaining in place after the filter fence has been removed should be dressed to conform with the existing grade, prepared, and seeded.

Cost

- Silt fence installation costs approximately $6.00 per linear foot.

Sources

- Commonwealth of Virginia - County of Fairfax, 1987. 1987 Check List For Erosion And Sediment Control - Fairfax County, Virginia.
- State of North Carolina, 1988. Erosion and Sediment Control Planning and Design Manual. North Carolina Sedimentation Control Commission, Department of Natural Resources and Community Development.
- Maryland Department of the Environment, 1991. 1991 Maryland Standards And Specifications For Soil Erosion And Sediment Control - Draft.

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Design Criteria

- Pipe Slope Drains (PSD) are appropriate in the following general locations:
  - On cut or fill slopes before permanent storm water drainage structures have been installed.
  - Where earth dikes or other diversion measures have been used to concentrate flows.
  - On any slope where concentrated runoff crossing the face of the slope may cause gullies, channel erosion, or saturation of slide-prone soils.
  - As an outlet for a natural drainageway.
- The drainage area may be up to 10 acres; however, many jurisdictions consider 5 acres the recommended maximum.
- The PSD design should handle the peak runoff for the 10-year storm. Typical relationships between area and pipe diameter are shown in Table 2 below.

TABLE 2. RELATIONSHIP BETWEEN AREA AND PIPE DIAMETER

Maximum Drainage Area (Acres)	Pipe Diameter (D) (Inches)
0.5	12
0.75	15
1.0	18

Materials

- Pipe may be heavy duty flexible tubing designed for this purpose, e.g., nonperforated, corrugated plastic pipe, corrugated metal pipe, bituminous fiber pipe, or specially designed flexible tubing.
- A standard flared end section secured with a watertight fitting should be use for the inlet. A standard T-section fitting may also be used.
- Extension collars should be 12-inch long sections of corrugated pipe. All fittings must be watertight.

Construction Specifications

- Place the pipe slope drain on undisturbed or well-compacted soil.
- Soil around and under the entrance section must be hand-tamped in 4-inch to 8-inch lifts to the top of the dike to prevent piping failure around the inlet.
- Place filter cloth under the inlet and extend 5 feet in front of the inlet and be keyed in 6-inches on all sides to prevent erosion. A 6-inch metal toe plate may also be used for this purpose.
- Ensure firm contact between the pipe and the soil at all points by backfilling around and under the pipe with stable soil material hand compacted in lifts of 4-inches to 8-inches.
- Securely stake the PSD to the slope using grommets provided for this purpose at intervals of 10 feet or less.
- Ensure that all slope drain sections are securely fastened together and have watertight fittings.

- Extend the pipe beyond the toe of the slope and discharge at a nonerosive velocity into a stabilized area (e.g., rock outlet protection may be used) or to a sedimentation trap or pond.
- The PSD should have a minimum slope of 3 percent or steeper.
- The height at the centerline of the earth dike should range from a minimum of 1.0 foot over the pipe to twice the diameter of the pipe measured from the invert of the pipe. It should also be at least 6 inches higher than the adjoining ridge on either side.
- At no point along the dike will the elevation of the top of the dike be less than 6 inches higher than the top of the pipe.
- Immediately stabilize all areas disturbed by installation or removal of the PSD.

Maintenance

- Inspect regularly and after every storm. Make any necessary repairs.
- Check to see that water is not bypassing the inlet and undercutting the inlet or pipe. If necessary, install headwall or sandbags.
- Check for erosion at the outlet point and check the pipe for breaks or clogs. Install additional outlet protection if needed and immediately repair the breaks and clean any clogs.
- Do not allow construction traffic to cross the PSD and do not place any material on it.
- If a sediment trap has been provided, clean it out when the sediment level reaches 1/3 to 1/2 the design volume.
- The PSD should remain in place until the slope has been completely stabilized or up to 30 days after permanent slope stabilization.

Cost

- Pipe slope drain costs are generally based upon the pipe type and size (generally, flexible PVC at $5.00 per linear foot). Also adding to this cost are any expenses associated with inlet and outlet structures.

Sources

- Commonwealth of Virginia - County of Fairfax, 1987. 1987 Check List For Erosion And Sediment Control - Fairfax County, Virginia.
- State of North Carolina, 1988. Erosion and Sediment Control Planning and Design Manual. North Carolina Sedimentation Control Commission, Department of Natural Resources and Community Development.
- Maryland Department of the Environment, 1991. 1991 Maryland Standards And Specifications For Soil Erosion And Sediment Control - Draft.
- Storm Water Management Manual for the Puget Sound Basin. State of Washington, Department of Ecology, 1991.
- Cost Data:
  - Draft Sediment and Erosion Control, An Inventory of Current Practices, April 20, 1990. Prepared by Kamber Engineering for the U.S. Environmental Protection Agency, Office of Water Enforcement and Permits, Washington, D.C. 20460.

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Design Criteria

- A Stabilized Construction Entrance (SCE) is appropriate in the following locations:
  - Wherever vehicles are leaving a construction site and enter onto a public road
  - At any unpaved entrance/exit location where there is risk of transporting mud or sediment onto paved roads.

- The width should be at least 10 feet to 12 feet or the as wide as the entire width of the access. At sites where traffic volume is high the entrance should be wide enough for two vehicles to pass safely.
- The length should be between 50 to 75 feet in length.
- Flare the entrance where it meets the existing road to provide a turning radius.
- Runoff from a stabilized construction entrance should drain to a sediment trap or sediment basin.
- Pipe placed under the entrance to handle runoff should be protected with a mountable berm.
- Dust control should be provided in accordance with Section 3.2.1.

Materials

- Crushed stone 2-inches-4-inches in diameter
- Geotextile (filter fabric) with the properties listed in Table 3 below.

TABLE 3. GEOTEXTILE REQUIREMENTS

Physical Property	Requirements
Grab Tensile Strength	220 lbs. (ASTM D1682)
Elongation Failure	60 % (ASTM D1682)
Mullen Burst Strength	430 lbs. (ASTM D3768)
Puncture Strength	125 lbs. (ASTM D751) (modified)
Equivalent Opening	Size 40-80 (US std Sieve) (CW-02215)

Construction Specifications

- Clear all vegetation, roots and all other obstructions in preparation for grading.
- Prior to placing geotextile (filter fabric) make sure that the entrance is properly graded and compacted.

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- To reduce maintenance and loss of aggregate place geotextile fabric (filter cloth) over the existing ground before placing the stone for the entrance.
- Stone should be placed to a depth of 6-inches or greater for the entire width and length of the SCE.

Maintenance

- Inspect the measure on a regular basis and after there has been a high volume of traffic or storm event.
- Apply additional stone periodically and when repair is required.
- Immediately remove sediments or any other materials tracked onto the public roadway.
- Ensure that associated sediment control measures are in good working condition.

Cost

- Stabilized construction entrances cost ranges from $1,500 to $5,000 to install.

Sources

- Commonwealth of Virginia - County of Fairfax, 1987. 1987 Check List For Erosion And Sediment Control - Fairfax County, Virginia.
- State of North Carolina, 1988. Erosion and Sediment Control Planning and Design Manual. North Carolina Sedimentation Control Commission, Department of Natural Resources and Community Development.
- Maryland Department of the Environment, 1991. 1991 Maryland Standards And Specifications For Soil Erosion And Sediment Control - Draft.
- Storm Water Management Manual for the Puget Sound Basin. State of Washington, Department of Ecology, 1991.
- Cost Data:
  - Draft Sediment and Erosion Control, An Inventory of Current Practices, April 20, 1990. Prepared by Kamber Engineering for the U.S. Environmental Protection Agency, Office of Water Enforcement and Permits, Washington, D.C. 20460.

FILTER FABRIC INLET PROTECTION

September 1992

Design Criteria

- Inlet protection is appropriate in the following locations:
  - In small drainage areas (less than 1 acre) where the storm drain inlet is functional before the drainage area has been permanently stabilized.
  - Where there is danger of sediment silting in an inlet which is in place prior to permanent stabilization.

- Filter fabric inlet protection is appropriate for most types of inlets where the drainage area is one acre or less.
- The drainage area should be fairly flat with slopes of 5% or less and the area immediately surrounding the inlet should not exceed a slope of 1%.
- Overland flow to the inlet should be no greater than 0.5 cfs.
- This type of inlet protection is not appropriate for use in paved areas because the filter fabric requires staking.
- To avoid failure caused by pressure against the fabric when overtopping occurs, it is recommended that the height of the filter fabric be limited to 1.5 feet above the crest of the drop inlet.
- It is recommended that a sediment trapping sump of 1 to 2 feet in depth with side slopes of 2:1 be provided.

Materials

- Filter fabric (see the fabric specifications for silt fence).
- Wooden stakes 2" x 2" or 2"x 4" with a minimum length of 3 feet.
- Heavy-duty wire staples at least ½ inch in length.
- Washed gravel ¾ inches in diameter.

Construction Specifications

- Place a stake at each corner of the inlet and around the edges at no more than 3 feet apart. Stakes should be driven into the ground 18 inches or at a minimum 8 inches.
- For stability a framework of wood strips should be installed around the stakes at the crest of the overflow area 1.5 feet above the crest of the drop inlet.
- Excavate a trench of 8 inches to 12 inches in depth around the outside perimeter of the stakes. If a sediment trapping sump is being provided then the excavation may be as deep as 2 feet.
- Staple the filter fabric to the wooden stakes with heavy-duty staples, overlapping the joints to the next stake. Ensure that between 12 inches to 32 inches of filter fabric extends at the bottom so it can be formed into the trench.
- Place the bottom of the fabric in the trench and backfill the trench all the way around using washed gravel to a minimum depth of 4 inches.

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Maintenance

- Inspect regularly and after every storm. Make any repairs necessary to ensure the measure is in good working order.
- Sediment should be removed and the trap restored to its original dimensions when sediment has accumulated to ½ the design depth of the trap.
- If the filter fabric becomes clogged it should be replaced immediately.
- Make sure that the stakes are firmly in the ground and that the filter fabric continues to be securely anchored.
- All sediments removed should be properly disposed.
- Inlet protection should remain in place and operational until the drainage area is completely stabilized or up to 30 days after the permanent site stabilization is achieved.

Cost

- The cost of storm drain inlet protection varies dependent upon the size and type of inlet to be protected but generally is about $300.00 per inlet.

Sources

- Commonwealth of Virginia - County of Fairfax, 1987. 1987 Check List For Erosion And Sediment Control - Fairfax County, Virginia.
- State of North Carolina, 1988. Erosion and Sediment Control Planning and Design Manual. North Carolina Sedimentation Control Commission, Department of Natural Resources and Community Development.
- Maryland Department of the Environment, 1991. 1991 Maryland Standards And Specifications For Soil Erosion And Sediment Control - Draft.
- Storm Water Management Manual for the Puget Sound Basin. State of Washington, Department of Ecology, 1991.
- Cost Data:
  - Draft Sediment and Erosion Control, An Inventory of Current Practices, April 20, 1990. Prepared by Kamber Engineering for the U.S. Environmental Protection Agency, Office of Water Enforcement and Permits, Washington, D.C. 20460.

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EXCAVATED GRAVEL INLET PROTECTION

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Design Criteria

- Inlet protection is appropriate in the following locations:
  - In small drainage areas (less than 1 acre) where the storm drain inlet is functional before the drainage area has been permanently stabilized.
  - Where there is danger of sediment silting in an inlet which is in place prior to permanent stabilization.
  - Where ponding around the inlet structure could be a problem to traffic on site.
- Excavated gravel and mesh inlet protection may be used with most inlets where overflow capability is needed and in areas of heavy flows, 0.5 cfs or greater.
- The drainage area should not exceed 1 acre.
- The drainage area should be fairly flat with slopes of 5% or less.
- The trap should have a sediment trapping sump of 1 to 2 feet measured from the crest of the inlet. Side slopes should be 2:1. The recommended volume of excavation is 35 yd^3/acre disturbed.
- To achieve maximum trapping efficiency the longest dimension of the basin should be oriented toward the longest inflow area.

Materials

- Hardware cloth or wire mesh with ½ inch openings.
- Filter fabric (see the fabric specifications for silt fence).
- Washed gravel ¾ inches to 4 inches in diameter.

Construction Specifications

- Remove any obstructions to excavating and grading. Excavate sump area, grade slopes and properly dispose of soil.
- The inlet grate should be secured to prevent seepage of sediment laden water.
- Place wire mesh over the drop inlet so that the wire extends a minimum of 1 foot beyond each side of the inlet structure. Overlap the strips of mesh if more than one is necessary.
- Place filter fabric over the mesh extending it at least 18 inches beyond the inlet opening on all sides. Ensure that weep holes in the inlet structure are protected by filter fabric and gravel.
- Place stone/gravel over the fabric/wire mesh to a depth of at least 1 foot.

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Maintenance

- Inspect regularly and after every storm. Make any repairs necessary to ensure the measure is in good working order.
- Sediment should be removed and the trap restored to its original dimensions when sediment has accumulated to ½ the design depth of the trap.
- Clean or remove and replace the stone filter or filter fabric if they become clogged.
- Inlet protection should remain in place and operational until the drainage area is completely stabilized or up to 30 days after the permanent site stabilization is achieved.

Cost

- The cost of storm drain inlet protection varies dependent upon the size and type of inlet to be protected but generally is about $300.00 per inlet.

Sources

- Commonwealth of Virginia - County of Fairfax, 1987. 1987 Check List For Erosion And Sediment Control - Fairfax County, Virginia.
- State of North Carolina, 1988. Erosion and Sediment Control Planning and Design Manual. North Carolina Sedimentation Control Commission, Department of Natural Resources and Community Development.
- Maryland Department of the Environment, 1991. 1991 Maryland Standards And Specifications For Soil Erosion And Sediment Control - Draft.
- Storm Water Management Manual for the Puget Sound Basin. State of Washington, Department of Ecology, 1991.
- Cost Data:
  - Draft Sediment and Erosion Control, An Inventory of Current Practices, April 20, 1990. Prepared by Kamber Engineering for the U.S. Environmental Protection Agency, Office of Water Enforcement and Permits, Washington, D.C. 20460.

September 1992

Design Criteria

- Inlet protection is appropriate in the following locations:
  - In drainage areas (less than 1 acre) where the storm drain inlet is functional before the drainage area has been permanently stabilized.
  - Where there is danger of sediment silting in an inlet which is in place prior to permanent stabilization.
- Block and gravel inlet protection may be used with most types of inlets where overflow capability is needed and in areas of heavy flows 0.5 cfs or greater.
- The drainage area should not exceed 1 acre.
- The drainage area should be fairly flat with slopes of 5% or less.
- To achieve maximum trapping efficiency the longest dimension of the basin should be oriented toward the longest inflow area.
- Where possible the trap should have sediment trapping sump of 1 to 2 feet in depth with side slopes of 2:1.
- There are several other types of inlet protection also used to prevent siltation of storm drainage systems and structures during construction, they are:
  - Filter Fabric Inlet Protection
  - Excavated Gravel Inlet Protection

Materials

- Hardware cloth or wire mesh with ½ inch openings
- Filter fabric (see the fabric specifications for silt fence)
- Concrete block 4 inches to 12 inches wide.
- Washed gravel ¾ inches to 4 inches in diameter

Construction Specifications

- The inlet grate should be secured to prevent seepage of sediment laden water.
- Place wire mesh over the drop inlet so that the wire extends a minimum of 12 inches to 18 inches beyond each side of the inlet structure. Overlap the strips of mesh if more than one is necessary.
- Place filter fabric (optional) over the mesh and extend it at least 18 inches beyond the inlet structure.
- Place concrete blocks over the filter fabric in a single row lengthwise on their sides along the sides of the inlet. The foundation should be excavated a minimum of 2 inches below the crest of the inlet and the bottom row of blocks should be against the edge of the structure for lateral support.
- The open ends of the block should face outward not upward and the ends of adjacent blocks should abut. Lay one block on each side of the structure on its side to allow for dewatering of the pool.
- The block barrier should be at least 12 inches high and may be up to a maximum of 24 inches high and may be from 4 inches to 12 inches in depth depending on the size of block used.
- Prior to backfilling, place wire mesh over the outside vertical end of the blocks so that stone does not wash down the inlet.
- Place gravel against the wire mesh to the top of the blocks.

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Maintenance

- Inspect regularly and after every storm. Make any repairs necessary to ensure the measure is in good working order.
- Sediment should be removed and the trap restored to its original dimensions when sediment has accumulated to ½ the design depth of the trap.
- All sediments removed should be properly disposed of.
- Inlet protection should remain in place and operational until the drainage area is completely stabilized or up to 30 days after the permanent site stabilization is achieved.

Cost

- The cost of storm drain inlet protection varies dependent upon the size and type of inlet to be protected but generally is about $300.00 per inlet.

Sources

- Commonwealth of Virginia - County of Fairfax, 1987. 1987 Check List For Erosion And Sediment Control - Fairfax County, Virginia.
- State of North Carolina, 1988. Erosion and Sediment Control Planning and Design Manual. North Carolina Sedimentation Control Commission, Department of Natural Resources and Community Development.
- Maryland Department of the Environment, 1991. 1991 Maryland Standards And Specifications For Soil Erosion And Sediment Control - Draft.
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Design Criteria

- Check dams are appropriate for use in the following locations:
  - Across swales or drainage ditches to reduce the velocity of flow.
  - Where velocity must be reduced because a vegetated channel lining has not yet been established.
- Check dams may never be used in a live stream unless approved by the appropriate government agency.
- The drainage area above the check dam should be between 2 acres and 10 acres.
- The dams must be spaced so that the toe of the upstream dam is never any higher than the top of the downstream dam.
- The center of the dam must be 6 inches to 9 inches lower than either edge, and the maximum height of the dam should be 24 inches.
- The check dam should be as much as 18 inches wider than the banks of the channel to prevent undercutting as overflow water re-enters the channel.
- Excavating a sump immediately upstream from the check dam improves its effectiveness.
- Provide outlet stabilization below the lowest check dam where the risk of erosion is greatest.
- Consider the use of channel linings or protection such as plastic sheeting or riprap where there may be significant erosion or prolonged submergence.

Materials

- Stone 2 inches to 15 inches in diameter
- Logs 6 inches to 8 inches in diameter
- Sandbags filled with pea gravel
- Filter fabric (see the fabric specifications for silt fence)

Construction Specifications

- Rock Check Dams
  - Place the stones on the filter fabric either by hand or using appropriate machinery; do not simply dump them in place.
  - Extend the stone 18 inches beyond the banks and keep the side slopes 2:1 or flatter.
  - Lining the upstream side of the dam with ¾ inch to 1½ inch gravel 1 foot in depth is a suggested option.
- Log Check Dams
  - Logs must be firmly embedded in the ground; 18 inches is the recommended minimum depth.
- Sand Bag Check Dams
  - Be sure that bags are all securely sealed.
  - Place bags by hand or use appropriate machinery.

Maintenance

- Inspect regularly and after every storm. Make any repairs necessary to ensure the measure is in good working order.
- Accumulated sediment and leaves should be removed from behind the dams and erosive damage to the channel restored after each storm or when ½ the original height of the dam is reached.
- All accumulated material removed from the dam shall be properly disposed.
- Replace stone as necessary for the dams to maintain their correct height.
- If sand bags are used, the fabric of the bags should be inspected for signs of deterioration.
- Remove stone or riprap if grass lined channel requires mowing.
- Check dams should remain in place and operational until the drainage area and channel are completely stabilized or up to 30 days after the permanent site stabilization is achieved.
- Restore the channel lining or establish vegetation when each check dam is removed.

Cost

- The costs for the construction of check dams varies with the material used. Rock costs about $100 per dam. Log check dams are usually slightly less expensive than rock check dams. All costs vary depending on the width of channel to be checked.

Sources

- Commonwealth of Virginia - County of Fairfax, 1987. 1987 Check List For Erosion And Sediment Control - Fairfax County, Virginia.
- State of North Carolina, 1988. Erosion and Sediment Control Planning and Design Manual. North Carolina Sedimentation Control Commission, Department of Natural Resources and Community Development.
- Maryland Department of the Environment, 1991. 1991 Maryland Standards And Specifications For Soil Erosion And Sediment Control - Draft.
- Storm Water Management Manual for the Puget Sound Basin. State of Washington, Department of Ecology, 1991.
- Cost Data:
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Design Criteria

- Earth dikes are appropriate in the following situations:
  - To divert upslope flows away from disturbed areas such as cut or fill slopes and to divert runoff to a stabilized outlet
  - To reduce the length of the slope runoff will cross
  - At the perimeter of the construction site to prevent sediment-laden runoff from leaving the site
  - To direct sediment-laden runoff to a sediment trapping device.
- When the drainage area to the earth dike is greater than 10 acres, the United States Department of Agriculture - Soil Conservation Service (USDA - SCS) standards and specification for diversions should be consulted.
- Table 4 contains suggested dike design criteria.

TABLE 4. SUGGESTED DIKE DESIGN CRITERIA

Drainage Area	Under 5 Acres	Between 5-10 Acres
Dike Height	18 inches	30 inches
Dike Width	24 inches	36 inches
Flow Width	4 feet	6 feet
Flow Depth	12 inches	24 inches
Side Slopes	2:1 or less	2:1 or less
Grade	0.5% - 10%	0.5% - 10%

- The base for a dike 18 inches high and 24 wide at the top should be between 6 feet - 8 feet. The height of the dike is measured on the upslope side.
- If the dike is constructed using coarse aggregate the side slopes should be 3:1 or flatter.
- The channel formed behind the dike should have a positive grade to a stabilized outlet. The channel should be stabilized with vegetative or other stabilization measures.
- Grades over 10% may require an engineering design.
- Construct the dike where it will not interfere with major areas of construction traffic so that vehicle damage to the dike will be kept to the minimum.
- Diversion dikes should be installed prior to the majority of soil disturbing activity, and may be removed when stabilization of the drainage area and outlet are complete.

Materials

- Compacted Soil
- Coarse Aggregate

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EARTH DIKE

Construction Specifications

- Clear the area of all trees, brush, stumps or other obstructions.
- Construct the dike to the designed cross-section, line and grade making sure that there are no irregularities or bank projections to impede the flow.
- The dike should be compacted using earth moving equipment to prevent failure of the dike.
- The dike must be stabilized as soon as possible after installation.

Maintenance

- Inspect regularly and after every storm, make any repairs necessary to ensure the measure is in good working order.
- Inspect the dike, flow channel and outlet for deficiencies or signs of erosion.
- If material must be added to the dike be sure it is properly compacted.
- Reseed or stabilize the dike as needed to maintain its stability regardless if there has been a storm event or not.

Cost

- The cost associated with earth dike construction is roughly $4.50 per linear foot which covers the earthwork involved in preparing the dike. Also added to this cost is approximately $1.00 per linear foot for stabilization practices. It should be noted that for most construction projects, the cost of earth dike construction is insignificant compared to the overall earthwork project costs.

Sources

- Commonwealth of Virginia - County of Fairfax, 1987. 1987 Check List For Erosion And Sediment Control - Fairfax County, Virginia.
- State of North Carolina, 1988. Erosion and Sediment Control Planning and Design Manual. North Carolina Sedimentation Control Commission, Department of Natural Resources and Community Development.
- Maryland Department of the Environment, 1991. 1991 Maryland Standards And Specifications For Soil Erosion And Sediment Control - Draft.
- Storm Water Management Manual for the Puget Sound Basin. State of Washington, Department of Ecology, 1991.
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Design Criteria

- Temporary drainage swales are appropriate in the following situations:
  - To divert upslope flows away from disturbed areas such as cut or fill slopes and to divert runoff to a stabilized outlet
  - To reduce the length of the slope runoff will cross
  - At the perimeter of the construction site to prevent sediment-laden runoff from leaving the site
  - To direct sediment-laden runoff to a sediment trapping device.
- When the drainage area is greater than 10 acres the United States Department of Agriculture - Soil Conservation Service (USDA - SCS) standards and specifications for diversions should be consulted.
- Swales may have side slopes ranging from 3:1 to 2:1.
- The minimum channel depth should be between 12 inches and 18 inches.
- The minimum width at the bottom of the channel should be 24 inches and the bottom should be level.
- The channel should have a uniform positive grade between 2% and 5%, with no sudden decreases where sediments may accumulate and cause overtopping.
- The channel should be stabilized with temporary or permanent stabilization measures.
- Grades over 10% may require an engineering design.
- Construct the swale away from areas of major construction traffic.
- Runoff must discharge to a stabilized outlet.

Materials

- Grass seed for temporary or permanent stabilization
- Sod
- Coarse aggregate or riprap

Construction Specifications

- Clear the area of all trees, brush, stumps or other obstructions.
- Construct the swale to the designed cross-section, line and grade making sure that there are no irregularities or bank projections to impede the flow.
- The lining should be well compacted using earth moving equipment and stabilization initiated as soon as possible.
- Stabilize lining with grass seed, sod, or riprap.
- Surplus material should be properly distributed or disposed of so that it does not interfere with the functioning of the swale.
- Outlet dissipation measures should be used to avoid the risk of erosion.

Maintenance

- Inspect regularly and after every storm, make any repairs necessary to ensure the measure is in good working order.
- Inspect the flow channel and outlet for deficiencies or signs of erosion.
- If surface of the channel requires material to be added be sure it is properly compacted.
- Reseed or stabilize the channel as needed to prevent erosion during a storm event.

Cost

- Drainage swale can very widely depending on the geometry of the swale and the type of lining material:

  - Grass — $3.00/square yard
  - Sod — $4.00/square year
  - Riprap — $45.00/square year

- No matter which liner type is used, the entire swale must be stabilized (i.e., seeded and mulched at a cost of $1.25/square yard).

Sources

- Commonwealth of Virginia - County of Fairfax, 1987. 1987 Check List For Erosion And Sediment Control - Fairfax County, Virginia.
- State of North Carolina, 1988. Erosion and Sediment Control Planning and Design Manual. North Carolina Sedimentation Control Commission, Department of Natural Resources and Community Development.
- Maryland Department of the Environment, 1991. 1991 Maryland Standards And Specifications For Soil Erosion And Sediment Control - Draft.
- Storm Water Management Manual for the Puget Sound Basin. State of Washington, Department of Ecology, 1991.
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Design Criteria

- Temporary sediment traps are appropriate in the following locations:
  - At the outlet of the perimeter controls installed during the first stage of construction.
  - At the outlet of any structure which concentrates sediment-laden runoff, e.g. at the discharge point of diversions, channels, slope drains, or other runoff conveyances.
  - Above a storm water inlet that is in line to receive sediment-laden runoff.
- Temporary sediment traps may be constructed by excavation alone or by excavation in combination with an embankment.
- Temporary sediment traps are often used in conjunction with a diversion dike or swale.
- The drainage area for the sediment trap should not exceed 5 disturbed acres.
- The trap must be accessible for ease of regular maintenance which is critical to its functioning properly.
- Sediment traps are temporary measures and should not be planned to remain in place longer than between 18 and 24 months.
- The capacity of the sedimentation pool should provide storage volume for 3,600 cubic feet/acre drainage area.
- The outlet should be designed to provide a 2 foot settling depth and an additional sediment storage area 1½ feet deep at the bottom of the trap.
- The embankment may not exceed 5 feet in height.
- The recommended minimum width at the top of the embankment is between 2 feet and 5 feet.
- The minimum recommended length of the weir is between 3 feet and 4 feet, and the maximum is 12 feet in length.
- Table 5 illustrates the typical relationship between the embankment height, the height of the outlet (H_o), and the width (W) at the top of the embankment.

TABLE 5. EMBANKMENT HEIGHT vs. OUTLET HEIGHT AND WIDTH

H	H_o	W
1.5	0.5	2.0
2.0	1.0	2.0
2.5	1.5	2.5
3.0	2.0	2.5
3.5	2.5	3.0
4.0	3.0	3.0
4.5	3.5	4.0
5.0	4.0	4.5

Materials

- Filter fabric (see fabric requirement for silt fence)
- Coarse aggregate or riprap 2 inches to 14 inches in diameter
- Washed gravel ¾ to 1½ inches in diameter
- Seed and mulch for stabilization

TEMPORARY SEDIMENT TRAP

Construction Specifications

- Clear the area of all trees, brush, stumps or other obstructions.
- Construct the embankment in 8 inch lifts compacting each lift with the appropriate earth moving equipment. Fill material must be free of woody vegetation, roots, or large stones.
- Keep cut and fill slopes between 3:1 and 2:1 or flatter.
- Line the outlet area with filter fabric prior to placing stone or gravel.
- Construct the gravel outlet using heavy stones between 6 inches and 14 inches in diameter and face the upstream side with a 12 inch layer of ¾ inch to 1½ inch washed gravel on the upstream side.
- Seed and mulch the embankment as soon as possible to ensure stabilization.

Maintenance

- Inspect regularly and after every storm. Make any repairs necessary to ensure the measure is in good working order.
- Frequent removal of sediment is critical to the functioning of this measure. At a minimum sediment should be removed and the trap restored to its original volume when sediment reaches ½ of the original volume.
- Sediment removed from the trap must be properly disposed.
- Check the embankment regularly to make sure it is structurally sound.

Cost

- Costs for a sediment trap vary widely based upon their size and the amount of excavation and stone required, they usually can be installed for $500 to $7,000.

Sources

- Commonwealth of Virginia - County of Fairfax, 1987. 1987 Check List For Erosion And Sediment Control - Fairfax County, Virginia.
- State of North Carolina, 1988. Erosion and Sediment Control Planning and Design Manual. North Carolina Sedimentation Control Commission, Department of Natural Resources and Community Development.
- Maryland Department of the Environment, 1991. 1991 Maryland Standards And Specifications For Soil Erosion And Sediment Control - Draft.
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APPENDIX C

EXAMPLE STORM WATER POLLUTION PREVENTION PLAN FOR A CONSTRUCTION ACTIVITY

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HOMERVILLE APARTMENTS
CONSTRUCTION POLLUTION PREVENTION PLAN

SITE DESCRIPTION

Project Name and Location: (Latitude, Longitude, or Address)	Homerville Apartments 21 Broadview Avenue Center City, ANY STATE 00000	Owner Name and Address:	Quality Associates 11 Main Street Center City, ANY STATE 00000

Description: (Purpose and Types of Soil Disturbing Activities)

This project will consist of three low-rise, attached apartment buildings with adjacent parking facilities.

Soil disturbing activities will include: clearing and grubbing; installing a stabilized construction entrance, perimeter, and other erosion and sediment controls; grading; excavation for the sedimentation pond, storm sewer, utilities, and building foundations; construction of curb and gutter, road, and parking areas; and preparation for final planting and seeding.

Runoff Coefficient:	The final coefficient of runoff for the site will be c = 0.5.
Site Area:	The site is approximately 11.0 acres of which 9.8 acres will be disturbed by construction activities.

Sequence of Major Activities

The order of activities will be as follows:

1. Install stabilized construction entrance
2. Clear and grub for earth dike and sediment basin
3. Install earth dike
4. Construct sedimentation basin
5. Continue clearing and grading
6. Pile topsoil
7. Stabilize denuded areas and stockpiles within 14 days of last construction activity in that area
8. Install utilities, storm sewer, curb and gutter
9. Apply stone to parking area and road
10. Construct apartment buildings
11. Complete grading and install permanent seeding and plantings
12. Complete final paving
13. Remove accumulated sediment from basin.
14. When all construction activity is complete and the site is stabilized, remove earth dike and reseed any areas disturbed by their removal.

Name of Receiving Waters:	The entire site will drain into Rocky Creek which is approximately one hundred yards from the site.

CONTROLS

Erosion and Sediment Controls

Stabilization Practices

Temporary Stabilization - Top soil stock piles and disturbed portions of the site where construction activity temporarily ceases for at least 21 days will be stabilized with temporary seed and mulch no later than 14 days from the last construction activity in that area. The temporary seed shall be Rye (grain) applied at the rate of 120 pounds per acre. Prior to seeding, 2,000 pounds of ground agricultural limestone and 1,000 pounds of 10-10-10 fertilizer shall be applied to each acre to be stabilized. After seeding, each area shall be mulched with 4,000 pounds per acre of straw. The straw mulch is to be tacked into place by a disk with blades set nearly straight. Areas of the site which are to be paved will be temporarily stabilized by applying geotextile and stone sub-base until bituminous pavement can be applied.

Permanent Stabilization - Disturbed portions of the site where construction activities permanently ceases shall be stabilized with permanent seed no later than 14 days after the last construction activity. The permanent seed mix shall consist of 80 lbs/acre tall fescue, and 40 lbs/acre kobe lespedeza. Prior to seeding, 4,000 pounds of ground agricultural limestone and 2,000 pounds of 10-10-10 fertilizer shall be applied to each acre to be stabilized. After seeding, each area shall be mulched with 4,000 pounds per acre of straw. The straw mulch is to be tacked into place by a disk with blades set nearly straight.

CONTROLS (Continued)

Structural Practices

Earth Dike - will be constructed along the uphill perimeter (north) of the site. A portion of the dike will divert runon around the construction site. The remaining portion of the dike will collect runoff from the disturbed area and direct the runoff to the sediment basin.

Sediment Basin - will be constructed at the common drainage location on the south side of the construction site. The basin will be formed by constructing an embankment across an existing gully and excavating a storage pond with a volume of 36,000 cubic feet (0.82) acre feet. The basin will drain through a corrugated metal riser and outlet pipe to a rip rap outlet apron. Once construction activities are nearly complete, the accumulated sediment will be removed from the basin.

Storm Water Management

Storm water drainage will be provided by curb and gutter, storm sewer and catch basin, for the developed areas. The areas which are not developed will be graded at less that 0.5:1 and have permanent seeding or plantings. Two acres of the site will remain untouched and in its natural state. When construction is complete the entire site will drain to a wet detention basin. The wet detention basin will be in the location of the temporary sediment basin. When upslope areas are stabilized, the accumulated sediment will be removed from the sediment basin, and the areas on the sides of the basin will be planted with vegetation. The wet detention pond is designed with a permanent pool volume of 0.82 (acre-feet). This is equivalent to one inch of runoff for the entire drainage area. It is expected that this wet detention pond design will result in an 80 percent removal of total suspended solids from the site's storm water runoff. The pond has been designed by a professional engineer to keep peak flow rates from the two and ten year/24 hour storms at their pre-development rates. The outlet of the detention basin will be stabilized by a riprap apron.

OTHER CONTROLS

Waste Disposal:

Waste Materials

All waste materials will be collected and stored in a securely lidded metal dumpster rented from the ADF Waste Management Company, which is a licensed solid waste management company in Center City. The dumpster will meet all local Center City and any State solid waste management regulations. All trash and construction debris from the site will be deposited in the dumpster. The dumpster will be emptied a minimum of twice per week or more often if necessary, and the trash will be hauled to the Center City Dump. No construction waste materials will be buried onsite. All personnel will be instructed regarding the correct procedure for waste disposal. Notices stating these practices will be posted in the office trailer and Mr. Doe, the individual who manages the day-to-day site operations, will be responsible for seeing that these procedures are followed.

Hazardous Waste

All hazardous waste materials will be disposed of in the manner specified by local or State regulation or by the manufacturer. Site personnel will be instructed in these practices and Mr. Doe, the individual who manages day-to-day site operations, will be responsible for seeing that these practices are followed.

Sanitary Waste

All sanitary waste will be collected from the portable units a minimum of three times per week by the TIDEE Company, a licensed Center City sanitary waste management contractor, as required by local regulation.

Offsite Vehicle Tracking:

A stabilized construction entrance has been provided to help reduce vehicle tracking of sediments. The paved street adjacent to the site entrance will be swept daily to remove any excess mud, dirt or rock tracked from the site. Dump trucks hauling material from the construction site will be covered with a tarpaulin.

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TIMING OF CONTROLS/MEASURES

As indicated in the Sequence of Major Activities, the earth dike, stabilized construction entrance and sediment basin will be constructed prior to clearing or grading of any other portions of the site. Areas where construction activity temporarily ceases for more than 21 days will be stabilized with a temporary seed and mulch within 14 days of the last disturbance. Once construction activity ceases permanently in an area, that area will be stabilized with permanent seed and mulch. After the entire site is stabilized, the accumulated sediment will be removed from the trap and the earth dike will be removed.

CERTIFICATION OF COMPLIANCE WITH FEDERAL, STATE, AND LOCAL REGULATIONS

The storm water pollution prevention plan reflects Center City requirements for storm water management and erosion and sediment control, as established in Center City ordinance 5-188. To ensure compliance, this plan was prepared in accordance with the Center City Storm Water Management, Erosion and Sediment Control Handbook, published by the Center City Department of Planning, Storm Water Management Section. There are no other applicable State or Federal requirements for sediment and erosion site plans (or permits), or storm water management site plans (or permits)

MAINTENANCE/INSPECTION PROCEDURES

Erosion and Sediment Control Inspection and Maintenance Practices

These are the inspection and maintenance practices that will be used to maintain erosion and sediment controls.

- Less than one half of the site will be denuded at one time.
- All control measures will be inspected at least once each week and following any storm event of 0.5 inches or greater.
- All measures will be maintained in good working order; if a repair is necessary, it will be initiated within 24 hours of report.
- Built up sediment will be removed from silt fence when it has reached one-third the height of the fence.
- Silt fence will be inspected for depth of sediment, tears, to see if the fabric is securely attached to the fence posts, and to see that the fence posts are firmly in the ground.
- The sediment basin will be inspected for depth of sediment, and built up sediment will be removed when it reaches 10 percent of the design capacity or at the end of the job.
- Diversion dike will be inspected and any breaches promptly repaired.
- Temporary and permanent seeding and planting will be inspected for bare spots, washouts, and healthy growth.
- A maintenance inspection report will be made after each inspection. A copy of the report form to be completed by the inspector is attached.
- Mr. Doe, site superintendent, will select three individuals who will be responsible for inspections, maintenance and repair activities, and filling out the inspection and maintenance report.
- Personnel selected for inspection and maintenance responsibilities will receive training from Mr. Doe. They will be trained in all the inspection and maintenance practices necessary for keeping the erosion and sediment controls used onsite in good working order.

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MAINTENANCE/INSPECTION PROCEDURES (Continued)
Non-Storm Water Discharges
It is expected that the following non-storm water discharges will occur from the site during the construction period: • Water from water line flushings. • Pavement wash waters (where no spills or leaks of toxic or hazardous materials have occurred). • Uncontaminated groundwater (from dewatering excavation). All non-storm water discharges will be directed to the sediment basin prior to discharge.

INVENTORY FOR POLLUTION PREVENTION PLAN

The materials or substances listed below are expected to be present onsite during construction:

- Concrete
- Detergents
- Paints (enamel and latex)
- Metal Studs
- Concrete
- Tar
- Fertilizers
- Petroleum Based Products
- Cleaning Solvents
- Wood
- Masonry Block
- Roofing Shingles.

SPILL PREVENTION

Material Management Practices

The following are the material management practices that will be used to reduce the risk of spills or other accidental exposure of materials and substances to storm water runoff.

Good Housekeeping:

The following good housekeeping practices will be followed onsite during the construction project.

- An effort will be made to store only enough product required to do the job
- All materials stored onsite will be stored in a neat, orderly manner in their appropriate containers and, if possible, under a roof or other enclosure
- Products will be kept in their original containers with the original manufacturer's label
- Substances will not be mixed with one another unless recommended by the manufacturer
- Whenever possible, all of a product will be used up before disposing of the container
- Manufacturers' recommendations for proper use and disposal will be followed
- The site superintendent will inspect daily to ensure proper use and disposal of materials onsite.

Hazardous Products:

These practices are used to reduce the risks associated with hazardous materials.

- Products will be kept in original containers unless they are not resealable
- Original labels and material safety data will be retained; they contain important product information
- If surplus product must be disposed of, manufacturers' or local and State recommended methods for proper disposal will be followed.

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SPILL PREVENTION (Continued)

Product Specific Practices

The following product specific practices will be followed onsite:

Petroleum Products:

All onsite vehicles will be monitored for leaks and receive regular preventive maintenance to reduce the chance of leakage. Petroleum products will be stored in tightly sealed containers which are clearly labeled. Any asphalt substances used onsite will be applied according to the manufacturer's recommendations.

Fertilizers:

Fertilizers used will be applied only in the minimum amounts recommended by the manufacturer. Once applied, fertilizer will be worked into the soil to limit exposure to storm water. Storage will be in a covered shed. The contents of any partially used bags of fertilizer will be transferred to a sealable plastic bin to avoid spills.

Paints:

All containers will be tightly sealed and stored when not required for use. Excess paint will not be discharged to the storm sewer system but will be properly disposed of according to manufacturers' instructions or State and local regulations.

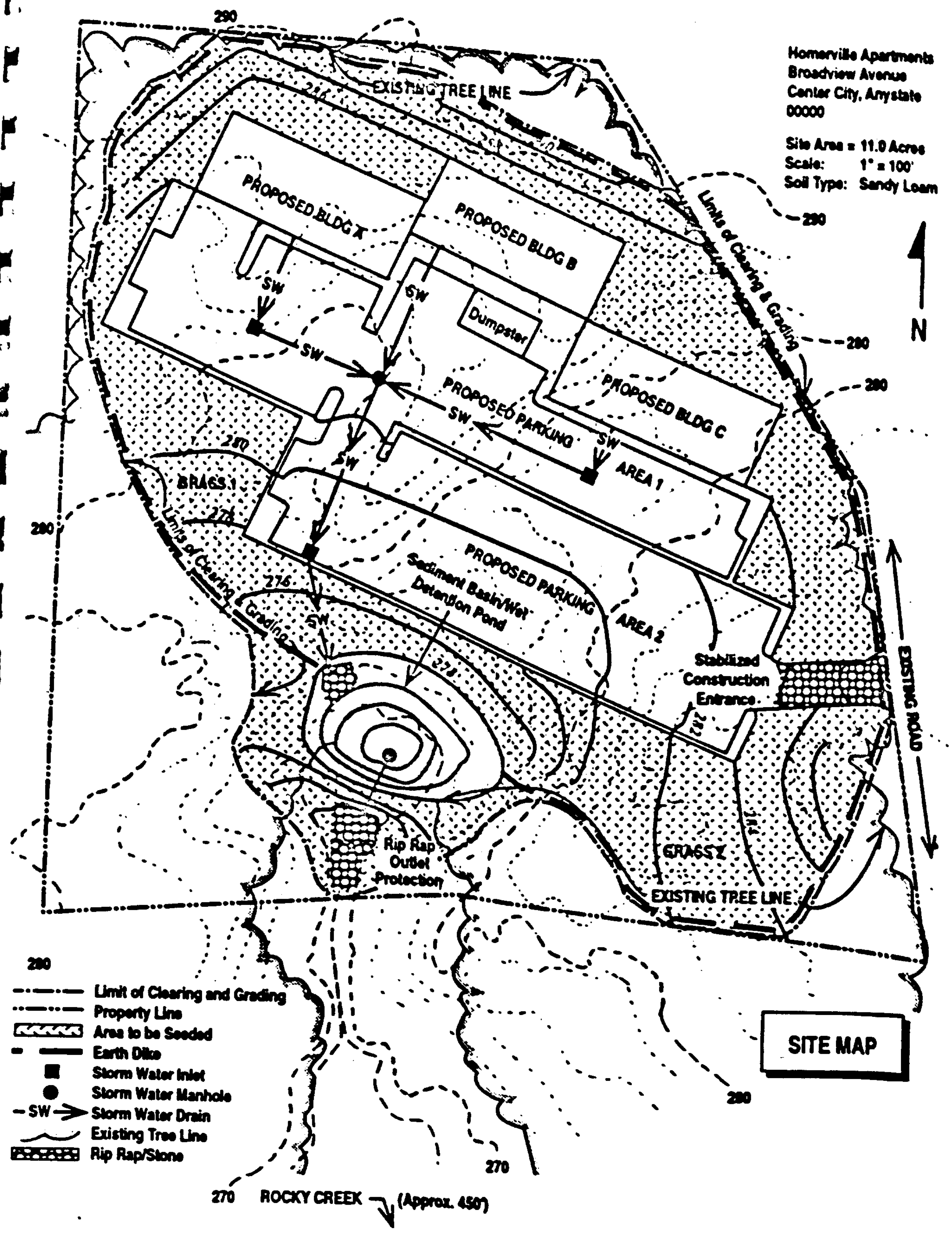
Concrete Trucks:

Concrete trucks will not be allowed to wash out or discharge surplus concrete or drum wash water on the site.

Spill Control Practices

In addition to the good housekeeping and material management practices discussed in the previous sections of this plan, the following practices will be followed for spill prevention and cleanup:

- Manufacturers' recommended methods for spill cleanup will be clearly posted and site personnel will be made aware of the procedures and the location of the information and cleanup supplies.
- Materials and equipment necessary for spill cleanup will be kept in the material storage area onsite. Equipment and materials will include but not be limited to brooms, dust pans, mops, rags, gloves, goggles, kitty litter, sand, sawdust, and plastic and metal trash containers specifically for this purpose.
- All spills will be cleaned up immediately after discovery.
- The spill area will be kept well ventilated and personnel will wear appropriate protective clothing to prevent injury from contact with a hazardous substance.
- Spills of toxic or hazardous material will be reported to the appropriate State or local government agency, regardless of the size.
- The spill prevention plan will be adjusted to include measures to prevent this type of spill from reoccurring and how to clean up the spill if there is another one. A description of the spill, what caused it, and the cleanup measures will also be included.
- Mr. Doe, the site superintendent responsible for the day-to-day site operations, will be the spill prevention and cleanup coordinator. He will designate at least three other site personnel who will receive spill prevention and cleanup training. These individuals will each become responsible for a particular phase of prevention and cleanup. The names of responsible spill personnel will be posted in the material storage area and in the office trailer onsite.



Homerville Apartments
Broadview Avenue
Center City, Anystate
00000
Site Area = 11.0 Acres
Scale: 1" = 100'
Soil Type: Sandy Loam
N
EXISTING TREE LINE
Limits of Clearing & Grading
PROPOSED BLDG A
PROPOSED BLDG B
PROPOSED BLDG C
Dumpster
SW
PROPOSED PARKING
AREA 1
PROPOSED PARKING
AREA 2
GRASS 1
GRASS 2
Sediment Basin/Wet Detention Pond
Stabilized Construction Entrance
EXISTING ROAD
Rip Rap Outlet Protection
EXISTING TREE LINE
290
280
270
SITE MAP
Limit of Clearing and Grading
Property Line
Area to be Seeded
Earth Dike
Storm Water Inlet
Storm Water Manhole
SW Storm Water Drain
Existing Tree Line
Rip Rap/Stone
ROCKY CREEK (Approx. 450')

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POLLUTION PREVENTION PLAN CERTIFICATION

I certify under penalty of law that this document and all attachments were prepared under my direction or supervision in accordance with a system designed to assure that qualified personnel properly gathered and evaluated the information submitted. Based on my inquiry of the person or persons who manage the system, or those persons directly responsible for gathering the information, the information submitted is, to the best of my knowledge and belief, true, accurate, and complete. I am aware that there are significant penalties for submitting false information, including the possibility of fine and imprisonment for knowing violations.

Signed:____________________
John R. Quality,
President
Quality Associates

Date:____________________

CONTRACTOR'S CERTIFICATION

I certify under penalty of law that I understand the terms and conditions of the general National Pollutant Discharge Elimination System (NPDES) permit that authorizes the storm water discharges associated with industrial activity from the construction site identified as part of this certification.

Signature	For	Responsible for
____________________ Joseph Contractor, President Date:____________________	Center City Const., Inc. 21 Elm Street Center City, Any State 00000 (123) 399-8765	General Contractor
____________________ John Planter Vice President of Construction Date:____________________	Green Grass, Inc. 4233 Center Road Outerville, Any State 00001 (123) 823-5678	Temporary and Permanent Stabilization
____________________ Jim Kay, President Date:____________________	Dirt Movers, Inc. 523 Lincoln Ave. Outerville, Any State 00001 (123) 823-8921	Stabilized Construction Entrance, Earth Dikes, Sediment Basin

HOMERVILLE APARTMENTS

STORM WATER POLLUTION PREVENTION PLAN

INSPECTION AND MAINTENANCE REPORT FORM

TO BE COMPLETED EVERY 7 DAYS AND WITHIN 24 HOURS OF
A RAINFALL EVENT OF 0.5 INCHES OR MORE

INSPECTOR:____________________ DATE:________________________

INSPECTOR'S QUALIFICATIONS:

____
____
____
____

DAYS SINCE LAST RAINFALL: ________ AMOUNT OF LAST RAINFALL ______ INCHES

STABILIZATION MEASURES

AREA	DATE SINCE LAST DISTURBED	DATE OF NEXT DISTURBANCE	STABILIZED? (YES/NO)	STABILIZED WITH	CONDITION
BLDG. A					
BLDG. B					
BLDG. C					
PRKNG. 1					
PRKNG. 2					
GRASS 1					
GRASS 2					

STABILIZATION REQUIRED:

____
____
____
____

TO BE PERFORMED BY: ____________________ ON OR BEFORE:____________________

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HOMERVILLE APARTMENTS

STORM WATER POLLUTION PREVENTION PLAN

INSPECTION AND MAINTENANCE REPORT FORM

STRUCTURAL CONTROLS

DATE: ______________

EARTH DIKE:

FROM	TO	IS DIKE STABILIZED?	IS THERE EVIDENCE OF WASHOUT OR OVER-TOPPING?
BUILDING B	STABILIZED CONSTRUCTION ENTRANCE		
STABILIZED CONSTRUCTION ENTRANCE	SEDIMENT BASIN		
BUILDING B	SEDIMENT BASIN		

MAINTENANCE REQUIRED FOR EARTH DIKE:

____

____

____

____

TO BE PERFORMED BY: ______________ ON OR BEFORE: ______________

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HOMERVILLE APARTMENTS

STORM WATER POLLUTION PREVENTION PLAN

INSPECTION AND MAINTENANCE REPORT FORM

SEDIMENT BASIN:

DEPTH OF SEDIMENT IN BASIN	CONDITION OF BASIN SIDE SLOPES	ANY EVIDENCE OF OVERTOPPING OF THE EMBANKMENT?	CONDITION OF OUTFALL FROM SEDIMENT BASIN

MAINTENANCE REQUIRED FOR SEDIMENT BASIN:

____

____

____

____

TO BE PERFORMED BY: ____________ ON OR BEFORE: ____________

OTHER CONTROLS

STABILIZED CONSTRUCTION ENTRANCE:

DOES MUCH SEDIMENT GET TRACKED ON TO ROAD?	IS THE GRAVEL CLEAN OR IS IT FILLED WITH SEDIMENT?	DOES ALL TRAFFIC USE THE STABILIZED ENTRANCE TO LEAVE THE SITE?	IS THE CULVERT BENEATH THE ENTRANCE WORKING?

MAINTENANCE REQUIRED FOR STABILIZED CONSTRUCTION ENTRANCE:

____

____

____

____

TO BE PERFORMED BY: ____________ ON OR BEFORE: ____________

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HOMERVILLE APARTMENTS

STORM WATER POLLUTION PREVENTION PLAN

INSPECTION AND MAINTENANCE REPORT FORM

CHANGES REQUIRED TO THE POLLUTION PREVENTION PLAN:

REASONS FOR CHANGES:

I certify under penalty of law that this document and all attachments were prepared under my direction or supervision in accordance with a system designed to assure that qualified personnel properly gathered and evaluated the information submitted. Based on my inquiry of the person or persons who manage the system, or those persons directly responsible for gathering the information, the information submitted is, to the best of my knowledge and belief, true, accurate, and complete. I am aware that there are significant penalties for submitting false information, including the possibility of fine and imprisonment for knowing violations.

SIGNATURE:______________________________ DATE:_______________

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APPENDIX D

REFERENCES

REFERENCES

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APPENDIX E

GLOSSARY

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GLOSSARY

Aeration: A process which promotes biological degradation of organic matter. The process may be passive (as when waste is exposed to air) or active (as when a mixing or bubbling device introduces the air).

Backfill: Earth used to fill a trench or an excavation.

Baffles: Fin-like devices installed vertically on the inside walls of liquid waste transport vehicles that are used to reduce the movement of the waste inside the tank.

Baseline General Permit: A storm water permit (issued under the NPDES program) intended to initially cover the majority of storm water discharges associated with industrial activities. For example, EPA is planning to issue two baseline general permits: NPDES General Permits for Storm Water Discharges From Construction Activities that are classified as "Associated with Industrial Activity" and NPDES General Permits for Storm Water Discharges from Industrial Activities that are classified as "Associated with Industrial Activities." EPA is also encouraging delegated States which have an approved general permits program to issue baseline general permits.

Berm: An earthen mound used to direct the flow of runoff around or through a structure.

Best Management Practices (BMPs): Schedules of activities, prohibitions of practices, maintenance procedures, and other management practices to prevent or reduce the pollution of waters of the United States. BMPs also include treatment requirements, operating procedures, and practices to control plant site runoff, spillage or leaks, sludge or waste disposal, or drainage from raw material storage. With regard to construction these may include structural devices or nonstructural practices that are designed to prevent pollutants from entering water or to direct the flow of water.

Biodegradable: The ability to break down or decompose under natural conditions and processes.

Boom: 1. A floating device used to contain oil on a body of water. 2. A piece of equipment used to apply pesticides from ground equipment such as a tractor or truck.

Buffer Strip or Zone: Strips of grass or other erosion-resistant vegetation between a waterway and an area of more intensive land use.

By-product: Material, other than the principal product, that is generated as a consequence of an industrial process.

Calibration: A check of the precision and accuracy of measuring equipment.

CERCLA: Comprehensive Emergency Response, Compensation, and Liability Act.

Chock: A block or wedge used to keep rolling vehicles in place.

Clay Lens: A naturally occurring, localized area of clay that acts as an impermeable layer to runoff infiltration.

Commencement of Construction: The initial disturbance of soils associated with clearing, grading, or excavating activities or other construction activities.

Concrete aprons: A pad of nonerosive material designed to prevent scour holes developing at the outlet ends of culverts, outlet pipes, grade stabilization structures, and other water control devices.

Conduit: Any channel or pipe for transporting the flow of water.

Conveyance: Any natural or manmade channel or pipe in which concentrated water flows.

Corrosion: The dissolving and wearing away of metal caused by a chemical reaction such as between water and the pipes that the water contacts, chemicals touching a metal surface, or contact between two metals.

Culvert: A covered channel or a large-diameter pipe that directs water flow below the ground level.

CWA: The Clean Water Act or the Federal Water Pollution Control Act.

Dedicated portable asphalt plant: A portable asphalt plant that is located on or contiguous to a construction site and that provides asphalt only to the construction site that the plant is located on or adjacent to. The term dedicated portable asphalt plant does not include facilities that are subject to the asphalt emulsion effluent limitation guideline at 40 CFR 443.

Dedicated portable concrete plant: A portable concrete plant that is located on or contiguous to a construction site and that provides concrete only to the construction site that the plant is located on or adjacent to.

Denuded: Land stripped of vegetation such as grass, or land that has had vegetation worn down due to impacts from the elements or humans.

Dike: An embankment to confine or control water, often built along the banks of a river to prevent overflow of lowlands; a levee.

Director: The Regional Administrator of the Environmental Protection Agency or an authorized representative.

Discharge: A release or flow of storm water or other substance from a conveyance or storage container.

Drip Guard: A device used to prevent drips of fuel or corrosive or reactive chemicals from contacting other materials or areas.

Emission: Pollution discharged into the atmosphere from smokestacks, other vents, and surface areas of commercial or industrial facilities and from motor vehicle, locomotive, or aircraft exhausts.

Erosion: The wearing away of land surface by wind or water. Erosion occurs naturally from weather or runoff but can be intensified by land-clearing practices related to farming, residential or industrial development, road building, or timber-cutting.

Excavation: The process of removing earth, stone, or other materials.

Fertilizer: Materials such as nitrogen and phosphorus that provide nutrients for plants. Commercially sold fertilizers may contain other chemicals or may be in the form of processed sewage sludge.

Filter Fabric: Textile of relatively small mesh or pore size that is used to (a) allow water to pass through while keeping sediment out (permeable), or (b) prevent both runoff and sediment from passing through (impermeable).

Filter Strip: Usually long, relatively narrow area of undisturbed or planted vegetation used to retard or collect sediment for the protection of watercourses, reservoirs, or adjacent properties.

Final Stabilization: The point at which all soil disturbing activities at the site have been completed, and a uniform perennial vegetative cover with a density of 70% of the cover for unpaved areas and areas not covered by permanent structures has been established or equivalent permanent stabilization measures (such as the use of riprap, gabions, or geotextiles) have been employed.

Flange: A rim extending from the end of a pipe; can be used as a connection to another pipe.

Flow Channel Liner: A covering or coating used on the inside surface of a flow channel to prevent the infiltration of water to the ground.

Flowmeter: A gauge that shows the speed of water moving through a conveyance.

Flow-weighted composite sample: A composite sample consisting of a mixture of aliquots collected at a constant time interval, where the volume of each aliquot is proportional to the flow rate of the discharge.

General Permit: A permit issued under the NPDES program to cover a certain class or category of storm water discharges. These permits allow for a reduction in the administrative burden associated with permitting storm water discharges associated with industrial activities.

Grading: The cutting and/or filling of the land surface to a desired slope or elevation.

Hazardous Substance: 1. Any material that poses a threat to human health and/or the environment. Hazardous substances can be toxic, corrosive, ignitable, explosive, or chemically reactive. 2. Any substance named required by EPA to be reported if a designated quantity of the substance is spilled in the waters of the United States or if otherwise emitted into the environment.

Hazardous Waste: By-products of human activities that can pose a substantial or potential hazard to human health or the environment when improperly managed. Possesses at least one of four characteristics (ignitability, corrosivity, reactivity, or toxicity), or appears on special EPA lists.

Holding Pond: A pond or reservoir, usually made of earth, built to store polluted runoff for a limited time.

Illicit Connection: Any discharge to a municipal separate storm sewer that is not composed entirely of storm water except discharges authorized by an NPDES permit (other than the NPDES permit for discharges from the municipal separate storm sewer) and discharges resulting from fire fighting activities.

Infiltration: 1. The penetration of water through the ground surface into sub-surface soil or the penetration of water from the soil into sewer or other pipes through defective joints, connections, or manhole walls. 2. A land application technique where large volumes of wastewater are applied to land, allowed to penetrate the surface and percolate through the underlying soil.

Inlet: An entrance into a ditch, storm sewer, or other waterway.

Intermediates: A chemical compound formed during the making of a product.

Irrigation: Human application of water to agricultural or recreational land for watering purposes.

Jute: A plant fiber used to make rope, mulch, netting, or matting.

Lagoon: A shallow pond where sunlight, bacterial action, and oxygen work to purify wastewater.

Land Application: Discharge of wastewater onto or into the ground for treatment or reuse.

Land Treatment Units: An area of land where materials are temporarily located to receive treatment. Examples include: sludge lagoons, stabilization pond.

Landfills: 1. Sanitary landfills are land disposal sites for non-hazardous solid wastes at which the waste is spread in layers, compacted to the smallest practical volume, and cover material applied at the end of each operating day. 2. Secure chemical landfills are disposal sites for hazardous waste. They are selected and designed to minimize the chance of release of hazardous substances into the environment.

Large and Medium Municipal Separate Storm Sewer System: All municipal separate storm sewers that are either: (i) located in an incorporated place (city) with a population of 100,000 or more as determined by the latest Decennial Census by the Bureau of Census (these cities are listed in Appendices F and G of 40 CFR Part 122); or (ii) located in the counties with unincorporated urbanized populations of 100,000 or more, except municipal separate storm sewers that are located in the incorporated places, townships or towns within such counties (these counties are listed in Appendices H and I of 40 CFR Part 122); or (iii) owned or operated by a municipality other than those described in paragraph (i) or (ii) and that are designated by the Director as part of the large or medium municipal separate storm sewer system.

Leaching: The process by which soluble constituents are dissolved in a solvent such as water and carried down through the soil.

Level Spreader: A device used to spread out storm water runoff uniformly over the ground surface as sheetflow (i.e., not through channels). The purpose of level spreaders are to prevent concentrated, erosive flows from occurring and to enhance infiltration.

Liming: Treating soil with lime to neutralize acidity levels.

Liner: 1. A relatively impermeable barrier designed to prevent leachate from leaking from a landfill. Liner materials include plastic and dense clay. 2. An insert or sleeve for sewer pipes to prevent leakage or infiltration.

Liquid Level Detector: A device that provides continuous measures of liquid levels in liquid storage areas or containers to prevent overflows.

Material Storage Areas: Onsite locations where raw materials, products, final products, by-products, or waste materials are stored.

Mulch: A natural or artificial layer of plant residue or other materials covering the land surface which conserves moisture, holds soil in place, aids in establishing plant cover, and minimizes temperature fluctuations.

Noncontact Cooling Water: Water used to cool machinery or other materials without directly contacting process chemicals or materials.

Notice of Intent (NOI): An application to notify the permitting authority of a facility's intention to be covered by a general permit; exempts a facility from having to submit an individual or group application.

NPDES: EPA's program to control the discharge of pollutants to waters of the United States. See the definition of "National Pollutant Discharge Elimination System" in 40 CFR 122.2 for further guidance.

NPDES Permit: An authorization, license, or equivalent control document issued by EPA or an approved State agency to implement the requirements of the NPDES program.

Oil and Grease Traps: Devices which collect oil and grease, removing them from water flows.

Oil Sheen: A thin, glistening layer of oil on water.

Oil/Water Separator: A device installed, usually at the entrance to a drain, which removes oil and grease from water flows entering the drain.

Organic Pollutants: Substances containing carbon which may cause pollution problems in receiving streams.

Organic Solvents: Liquid organic compounds capable of dissolving solids, gases, or liquids.

Outfall: The point, location, or structure where wastewater or drainage discharges from a sewer pipe, ditch, or other conveyance to a receiving body of water.

Permeability: The quality of a soil that enables water or air to move through it. Usually expressed in inches/hour or inches/day.

Permit: An authorization, license, or equivalent control document issued by EPA or an approved State agency to implement the requirements of an environmental regulation; e.g., a permit to operate a wastewater treatment plant or to operate a facility that may generate harmful emissions.

Permit Issuing Authority (or Permitting Authority): The State agency or EPA Regional office which issues environmental permits to regulated facilities.

Plunge pool: A basin used to slow flowing water, usually constructed to a design depth and shape. The pool may be protected from erosion by various lining materials.

Pneumatic Transfer: A system of hoses which uses the force of air or other gas to push material through; used to transfer solid or liquid materials from tank to tank.

Point Source: Any discernible, confined, and discrete conveyance, including but not limited to any pipe, ditch, channel, tunnel, conduit, well, discrete fissure, container, rolling stock, concentrated animal feeding operation, landfill leachate collection system, or vessel or other floating craft, from which pollutants are or may be discharged.

Pollutant: Any dredged spoil, solid waste, incinerator residue, filter backwash, sewage, garbage, sewage sludge, munitions, chemical wastes, biological materials, radioactive materials (except those regulated under the Atomic Energy Act of 1954, as amended (42 (U.S.C. 2011 et seq.)), heat, wrecked or discharged equipment, rock, sand, cellar dirt, and industrial, municipal, and agricultural waste discharged into water. It does not mean:
(i) Sewage from vessels; or

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(ii) Water, gas, or other material which is injected into a well to facilitate production of oil or gas, or water derived in association with oil and gas production and disposed of in a well, if the well used either to facilitate production or for disposal purposes is approved by the authority of the State in which the well is located, and if the State determines that the injection or disposal will not result in the degradation of ground or surface water resources (Section 502(6) of the CWA).

Radioactive materials covered by the Atomic Energy Act are those encompassed in its definition of source, byproduct, or special nuclear materials. Examples of materials not covered include radium and accelerator-produced isotopes. See Train v. Colorado Public Interest Research Group, Inc., 426 U.S. 1 (1976).

Porous Pavement: A human-made surface that will allow water to penetrate through and percolate into soil (as in porous asphalt pavement or concrete). Porous asphalt pavement is comprised of irregular shaped crush rock precoated with asphalt binder. Water seeps through into lower layers of gravel for temporary storage, then filters naturally into the soil.

Precipitation: Any form of rain or snow.

Preventative Maintenance Program: A schedule of inspections and testing at regular intervals intended to prevent equipment failures and deterioration.

Process Wastewater: Water that comes into direct contact with or results from the production or use of any raw material, intermediate product, finished product, by-product, waste product, or wastewater.

PVC (Polyvinyl Chloride): A plastic used in pipes because of its strength; does not dissolve in most organic solvents.

Raw Material: Any product or material that is converted into another material by processing or manufacturing.

RCRA: Resource Conservation and Recovery Act.

Recycle: The process of minimizing the generation of waste by recovering usable products that might otherwise become waste. Examples are the recycling of aluminum cans, wastepaper, and bottles.

Reportable Quantity (RQ): The quantity of a hazardous substance or oil that triggers reporting requirements under CERCLA or the Clean Water Act. If a substance is released in amounts exceeding its RQ, the release must be reported to the National Response Center, the State Emergency Response Commission, and community emergency coordinators for areas likely to be affected (see Appendix I for a list of RQs).

Residual: Amount of pollutant remaining in the environment after a natural or technological process has taken place, e.g., the sludge remaining after initial wastewater treatment, or particulates remaining in air after the air passes through a scrubbing or other pollutant removal process.

Retention: The holding of runoff in a basin without release except by means of evaporation, infiltration, or emergency bypass.

Retrofit: The modification of storm water management systems in developed areas through the construction of wet ponds, infiltration systems, wetland plantings, stream bank stabilization, and other BMP techniques for improving water quality. A retrofit can consist of the construction of a new BMP in the developed area, the enhancement of an older storm water management structure, or a combination of improvement and new construction.

Rill Erosion: The formation of numerous, closely spread streamlets due to uneven removal of surface soils by storm water or other water.

Riparian Habitat: Areas adjacent to rivers and streams that have a high density, diversity, and productivity of plant and animal species relative to nearby uplands.

Runon: Storm water surface flow or other surface flow which enters property other than that where it originated.

Runoff: That part of precipitation, snow melt, or irrigation water that runs off the land into streams or other surface water. It can carry pollutants from the air and land into the receiving waters.

Runoff coefficient: The fraction of total rainfall that will appear at the conveyance as runoff.

Sanitary Sewer: A system of underground pipes that carries sanitary waste or process wastewater to a treatment plant.

Sanitary Waste: Domestic sewage.

SARA: Superfund Amendments and Reauthorization Act.

Scour: The clearing and digging action of flowing water, especially the downward erosion caused by stream water in sweeping away mud and silt from the stream bed and outside bank of a curved channel.

Sealed Gate: A device used to control the flow of liquid materials through a valve.

Secondary Containment: Structures, usually dikes or berms, surrounding tanks or other storage containers and designed to catch spilled material from the storage containers.

Sediment Trap: A device for removing sediment from water flows; usually installed at outfall points.

Sedimentation: The process of depositing soil particles, clays, sands, or other sediments that were picked up by flowing water.

Sediments: Soil, sand, and minerals washed from land into water, usually after rain. They pile up in reservoirs, rivers, and harbors, destroying fish-nesting areas and holes of water animals and cloud the water so that needed sunlight might not reach aquatic plants. Careless farming, mining, and building activities will expose sediment materials, allowing them to be washed off the land after rainfalls.

Sheet Erosion: Erosion of thin layers of surface materials by continuous sheets of running water.

Sheetflow: Runoff which flows over the ground surface as a thin, even layer, not concentrated in a channel.

Shelf Life: The time for which chemicals and other materials can be stored before becoming unusable due to age or deterioration.

Significant materials, as defined at 122.26(b)(12) include, but are not limited to:

- Raw materials; fuels; materials such as solvents, detergents and plastic pellets; finished materials such as metallic products; raw materials used in food processing or production; hazardous substances designated under section 101(14) of the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA); any chemical the facility is required to report pursuant to section 313 of Title III of the Superfund Amendments and Reauthorization Act (SARA); fertilizers; pesticides; and waste products such as ashes, slag, and sludge that have a potential to be released with storm water discharges.

Slag: Non-metal containing waste leftover from the smelting and refining of metals.

Slide Gate: A device used to control the flow of water through storm water conveyances.

Sloughing: The movement of unstabilized soil layers down a slope due to excess water in the soils.

Sludge: A semi-solid residue from any of a number of air or water treatment processes. Sludge can be a hazardous waste.

Soil: The unconsolidated mineral and organic material on the immediate surface of the earth that serves as a natural medium for the growth of plants.

Solids Dewatering: A process for removing excess water from solids to lessen the overall weight of the wastes.

Source Control: A practice or structural measure to prevent pollutants from entering storm water runoff or other environmental media.

Spent Solvent: A liquid solution that has been used and is no longer capable of dissolving solids, gases, or liquids.

Spill Guard: A device used to prevent spills of liquid materials from storage containers.

Spill Prevention Control and Countermeasures Plan (SPCC): Plan consisting of structures, such as curbing, and action plans to prevent and respond to spills of hazardous substances as defined in the Clean Water Act.

Stopcock Valve: A small valve for stopping or controlling the flow of water or other liquid through a pipe.

Storm Drain: A slotted opening leading to an underground pipe or an open ditch for carrying surface runoff.

Storm Water: Runoff from a storm event, snow melt runoff, and surface runoff and drainage.

Storm Water Discharge Associated with Industrial Activity: The discharge from any conveyance which is used for collecting and conveying storm water and which is directly related to manufacturing, processing or raw materials storage areas at an industrial plant. The term does not include discharges from facilities or activities excluded from the NPDES program under 40 CFR Part 122. For the categories of industries identified in subparagraphs (i) through (x) of this subsection, the term includes, but is not limited to, storm water discharges from industrial plant yards; immediate access roads and rail lines used or traveled by carriers of raw materials, manufactured products, waste material, or by-products used or created by the facility; material handling sites; refuse sites; sites used for the application or disposal of process waste waters (as defined at 40 CFR 401); sites used for the storage and maintenance of material handling equipment; sites used for residual treatment, storage, or disposal; shipping and receiving areas; manufacturing buildings; storage areas (including tank farms) for raw materials, and intermediate and finished products; and areas where industrial activity has taken place in the past and significant materials remain and are exposed to storm water. For the categories of industries identified in subparagraph (xi), the term includes only storm water discharges from all the areas (except access roads and rail lines) that are listed in the previous sentence where material handling equipment or activities, raw materials, intermediate products, final products, waste material, by-products, or industrial machinery are exposed to storm water. For the purposes of this paragraph, material handling activities include the: storage, loading and unloading, transportation, or conveyance of any raw material, intermediate product, finished product, by-product or waste product. The term excludes areas located on plant lands separate from the plant's industrial activities, such as office buildings and accompanying parking lots as long as the drainage from the excluded areas is not mixed with storm water drained from the above described areas. Industrial facilities (including industrial facilities that are Federally, State, or municipally owned or operated that meet the description of the facilities listed in this paragraph (i)-(xi) include those facilities designated under the provision of 122.26(a)(1)(v). The following categories of facilities are considered to be engaging in "industrial activity" for purposes of this subsection:

(i) Facilities subject to storm water effluent limitations guidelines, new source performance standards, or toxic pollutant effluent standards under 40 CFR Subchapter N (except facilities with toxic pollutant effluent standards which are excepted under category (xi) of this paragraph);

(ii) Facilities classified as Standard Industrial Classifications 24 (except 2434), 26 (except 265 and 267), 28 (except 283 and 285) 29, 311, 32 (except 323), 33, 3441, 372;

(iii) Facilities classified as Standard Industrial Classifications 10 though 14 (mineral industry) including active or inactive mining operations (except for areas of coal mining operations no longer meeting the definition of a reclamation area under 40 CFR 434.11(l) because the performance bond issued to the facility by the appropriate SMCRA authority has been released, or except for areas of non-coal mining operations which have been released from applicable State or Federal reclamation requirements after December 17, 1990 and oil and gas exploration, production, processing, or treatment operations, or transmission facilities that discharge storm water contaminated by contact with or that has come into contact with, any overburden, raw material, intermediate products, finished products, byproducts or waste products located on the site of such operations; (inactive mining operations are mining sites that are not being actively mined, but which have an identifiable owner/operator; inactive mining sites do not include sites where mining claims are being maintained prior to disturbances associated with the extraction, beneficiation, or processing of mined materials, nor sites where minimal activities are undertaken for the sole purpose of maintaining mining claim);

(iv) Hazardous waste treatment, storage, or disposal facilities, including those that are operating under interim status or a permit under Subtitle C of RCRA;

(v) Landfills, land application sites, and open dumps that receive or have received any industrial wastes (waste that is received from any of the facilities described under this subsection) including those that are subject to regulation under Subtitle D of RCRA;

(vi) Facilities involved in the recycling of materials, including metal scrapyards, battery reclaimers, salvage yards, and automobiles junkyards, including but limited to those classified as Standard Industrial Classification 5015 and 5093;

(vii) Steam electric power generating facilities, including coal handling sites;

(viii) Transportation facilities classified as Standard Industrial Classifications 40, 41, 42 (except 4221-25), 43, 44, 45, and 5171 which have vehicle maintenance shops, equipment cleaning operations, or airport deicing operations. Only those portions of the facility that are either involved in vehicle maintenance (including vehicle rehabilitation, mechanical repairs, painting, fueling, and lubrication), equipment cleaning operations, airport deicing operations, or which

are otherwise identified under paragraphs (i)-(vii) or (ix)-(xi) of this subsection are associated with industrial activity;
(ix) Treatment works treating domestic sewage or any other sewage sludge or wastewater treatment device or system, used in the storage treatment, recycling, and reclamation of municipal or domestic sewage, including land dedicated to the disposal of sewage sludge that are located within the confines of the facility, with a design flow of 1.0 mgd or more, or required to have an approved pretreatment program under 40 CFR 403. Not included are farm lands, domestic gardens or lands used for sludge management where sludge is beneficially reused and which are not physically located in the confines of the facility, or areas that are in compliance with Section 405 of the CWA;
(x) Construction activity including clearing, grading and excavation activities except: operations that result in the disturbance of less than five acres of total land area which are not part of a larger common plan of development or sale;
(xi) Facilities under Standard Industrial Classification 20, 21, 22, 23, 2434, 25, 265, 267, 27, 283, 285, 30, 31 (except 311), 323, 34 (except 3441), 35, 36, 37 (except 373), 38, 39, 4221-25, (and which are not otherwise included within categories (ii)-(x));

Note: The Transportation Act of 1991 provides an exemption from storm water permitting requirements for certain facilities owned or operated by municipalities with a population of less than 100,000. Such municipalities must submit storm water discharge permit applications for only airports, power plants, and uncontrolled sanitary landfills that they own or operate, unless a permit is otherwise required by the permitting authority.

Subsoil: The bed or stratum of earth lying below the surface soil.

Sump: A pit or tank that catches liquid runoff for drainage or disposal.

Surface Impoundment: Treatment, storage, or disposal of liquid wastes in ponds.

Surface Water: All water naturally open to the atmosphere (rivers, lakes, reservoirs, streams, wetlands impoundments, seas, estuaries, etc.); also refers to springs, wells, or other collectors which are directly influenced by surface water.

Swale: An elongated depression in the land surface that is at least seasonally wet, is usually heavily vegetated, and is normally without flowing water. Swales direct storm water flows into primary drainage channels and allow some of the storm water to infiltrate into the ground surface.

Tarp: A sheet of waterproof canvas or other material used to cover and protect materials, equipment, or vehicles.

Topography: The physical features of a surface area including relative elevations and the position of natural and human-made features.

Toxic Pollutants: Any pollutant listed as toxic under Section 501(a)(1) or, in the case of "sludge use or disposal practices," any pollutant identified in regulations implementing Section 405(d) of the CWA. Please refer to 40 CFR Part 122 Appendix D.

Treatment: The act of applying a procedure or chemicals to a substance to remove undesirable pollutants.

Tributary: A river or stream that flows into a larger river or stream.

Underground Storage Tanks (USTs): Storage tanks with at least 10 percent or more of its storage capacity underground (the complete regulatory definition is at 40 CFR Part 280.12).

Waste: Unwanted materials left over from a manufacturing or other process.

Water Table: The depth or level below which the ground is saturated with water.

Waters of the United States:
"(a) All waters, which are currently used, were used in the past, or may be susceptible to use in interstate or foreign commerce, including all waters which are subject to the ebb and flow of the tide;
(b) All interstate waters, including interstate "wetlands;"
(c) All other waters such as intrastate lakes, rivers, streams (including intermittent streams), mudflats, sandflats, "wetlands," sloughs, prairie potholes, wet meadows, playa lakes, or natural ponds, the use, degradation, or destruction of which would affect or could affect interstate or foreign commerce including any such waters:
(1) Which are or could be used by interstate or foreign travelers for recreational or other purposes;
(2) From which fish or shellfish are or could be taken and sold in interstate or foreign commerce; or
(3) Which are used or could be used for industrial purposes by industries in interstate commerce;
(d) All impoundments of waters otherwise defined as waters of the United States under this definition;
(e) Tributaries of waters identified in paragraphs (a) through (d) of this definition;
(f) The territorial sea; and
(g) "Wetlands" adjacent to waters (other than waters that are themselves wetlands) identified in paragraphs (a) through (f) of this definition.
Waste treatment systems, including treatment ponds or lagoons designed to meet the requirements of CWA (other than cooling ponds as defined in 40 CFR 423.11(m) which also meet the criteria of this definition) are not waters of the United States. This exclusion applies only to manmade bodies of water which neither were originally created in waters of the United States (such as disposal area in wetlands) nor resulted from the impoundment of waters of the United States.

Waterway: A channel for the passage or flow of water.

Wet Well: A chamber used to collect water or other liquid and to which a pump is attached.

Wetlands: An area that is regularly saturated by surface or ground water and subsequently is characterized by a prevalence of vegetation that is adapted for life in saturated soil conditions. Examples include: swamps, bogs, fens, marshes, and estuaries.

Wind Break: Any device designed to block wind flow and intended for protection against any ill effects of wind.

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APPENDIX F

LIST OF HAZARDOUS SUBSTANCES AND REPORTABLE QUANTITIES

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LIST OF HAZARDOUS SUBSTANCES AND REPORTABLE QUANTITIES
40 CFR 302.4 and 117

Note: All comments are located at the end of this table.

Hazardous Substance	CASRN	Regulatory Synonyms	Statutory			Final RQ	
			RQ	Code†	RCRA Waste #	Category	Pounds (Kg)
Acenaphthene	83329		1*	2		B	100 (45.4)
Acenaphthylene	208968		1*	2		D	5000 (2270)
Acetaldehyde	75070	Ethanal	1000	1,4	U001	C	1000 (454)
Acetaldehyde, chloro-	107200	Chloroacetaldehyde	1*	4	P023	C	1000 (454)
Acetaldehyde, trichloro-	75876	Chloral	1*	4	U034	D	5000 (2270)
Acetamide, N-(aminothioxomethyl)-	591082	1-Acetyl-2-thiourea	1*	4	P002	C	1000 (454)
Acetamide, N-(4-ethoxyphenyl)-	62442	Phenacetin	1*	4	U187	B	100 (45.4)
Acetamide, 2-fluoro-	640197	Fluoroacetamide	1*	4	P057	B	100 (45.4)
Acetamide, N-9H-fluoren-2-yl-	53963	2-Acetylaminofluorene	1*	4	U005	X	1 (0.454)
Acetic acid	64197		1000	1		D	5000 (2270)
Acetic acid (2,4-dichlorophenoxy)-	94757	2,4-D Acid 2,4-D, salts and esters	100	1,4	U240	B	100 (45.4)
Acetic Acid, lead(2+) salt	301042	Lead acetate	5000	1,4	U144		#
Acetic acid, thallium(1+) salt	563688	Thallium(I) acetate	1*	4	U214	B	100 (45.4)
Acetic acid (2,4,5-trichlorophenoxy)-	93765	2,4,5-T 2,4,5-T acid	100	1,4	U232	C	1000 (454)
Acetic acid, ethyl ester	141786	Ethyl acetate	1*	4	U112	D	5000 (2270)
Acetic acid, fluoro-, sodium salt	62748	Fluoroacetic acid, sodium salt	1*	4	P058	A	10 (4.54)
Acetic anhydride	108247		1000	1		D	5000 (2270)
Acetone	67641	2-Propanone	1*	4	U002	D	5000 (2270)
Acetone cyanohydrin	75865	Propanenitrile, 2-hydroxy-2-methyl-2-Methyllactonitrile	10	1,4	P069	A	10 (4.54)
Acetonitrile	75058		1*	4	U003	D	5000 (2270)
Acetophenone	98862	Ethanone, 1-phenyl-	1*	4	U004	D	5000 (2270)
2-Acetylaminofluorene	53963	Acetamide, N-9H-fluoren-2-yl-	1*	4	U005	X	1 (0.454)
Acetyl bromide	506967		5000	1		D	5000 (2270)
Acetyl chloride	75365		5000	1,4	U006	D	5000 (2270)
1-Acetyl-2-thiourea	591082	Acetamide, N-(aminothioxomethyl)-	1*	4	P002	C	1000 (454)
Acrolein	107028	2-Propenal	1	1,2,4	P003	X	1 (0.454)
Acrylamide	79061	2-Propenamide	1*	4	U007	D	5000 (2270)

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Hazardous Substance	CASRN	Regulatory Synonyms	Statutory			Final RQ	
			RQ	Code†	RCRA Waste #	Category	Pounds (Kg)
Acrylic acid	79107	2-Propenoic acid	1*	4	U008	D	5000 (2270)
Acrylonitrile	107131	2-Propenenitrile	100	1,2,4	U009	B	100 (45.4)
Adipic acid	124049		5000	1		D	5000 (2270)
Aldicarb	116063	Propanal, 2-methyl-2-(methylthio)-,O-[(methylamino)carbonyl]oxime	1*	4	P070	X	1 (0.454)
Aldrin	309002	1,4,5,8-Dimethanonaphthalene, 1,2,3,4,10,10-10-hexachloro-1,4,4a,5,8,8a-hexahydro-, (1alpha,4alpha,4abeta,5alpha,8alpha,8abeta)-	1	1,2,4	P004	X	1 (0.454)
Allyl alcohol	107186	2-Propen-1-ol	100	1,4	P005	B	100 (45.4)
Allyl chloride	107051		1000	1		C	1000 (454)
Aluminum phosphide	20859738		1*	4	P006	B	100 (45.4)
Aluminum sulfate	10043013		5000	1		D	5000 (2270)
5-(Aminomethyl)-3-isoxazolol	2763964	Muscimol 3(2H)-isoxazolone, 5-(aminomethyl)-	1*	4	P007	C	1000 (454)
4-Aminopyridine	504245	4-Pyridinamine	1*	4	P008	C	1000 (454)
Amitrole	61825	1H-1,2,4-Triazol-3-amine	1*	4	U011	A	10 (4.54)
Ammonia	7664417		100	1		B	100 (45.4)
Ammonium acetate	631618		5000	1		D	5000 (2270)
Ammonium benzoate	1863634		5000	1		D	5000 (2270)
Ammonium bicarbonate	1066337		5000	1		D	5000 (2270)
Ammonium bichromate	7789095		1000	1		A	10 (4.54)
Ammonium bifluoride	1341497		5000	1		B	100 (45.4)
Ammonium bisulfite	10192300		5000	1		D	5000 (2270)
Ammonium carbamate	1111780		5000	1		D	5000 (2270)
Ammonium carbonate	506876		5000	1		D	5000 (2270)
Ammonium chloride	12125029		5000	1		D	5000 (2270)
Ammonium chromate	7788989		1000	1		A	10 (4.54)
Ammonium citrate, dibasic	3012655		5000	1		D	5000 (2270)
Ammonium fluoborate	13826830		5000	1		D	5000 (2270)
Ammonium fluoride	12125018		5000	1		B	100 (45.4)
Ammonium hydroxide	1336216		1000	1		C	1000 (454)
mmonium oxalate	6009707		5000	1		D	5000 (2270)

Hazardous Substance	CASRN	Regulatory Synonyms	Statutory			Final RQ	
			RQ	Code†	RCRA Waste #	Category	Pounds (Kg)
	5972736		5000	1		D	5000 (2270)
	14258492		5000	1		D	5000 (2270)
Ammonium picrate	131748	Phenol, 2,4,6-trinitro-, ammonium salt	1*	4	P009	A	10 (4.54)
Ammonium silicofluoride	16919190		1000	1		C	1000 (454)
Ammonium sulfamate	7773060		5000	1		D	5000 (2270)
Ammonium sulfide	12135761		5000	1		B	100 (45.4)
Ammonium sulfite	10196040		5000	1		D	5000 (2270)
Ammonium tartrate	14307438		5000	1		D	5000 (2270)
	3164292		5000	1		D	5000 (2270)
Ammonium thiocyanate	1762954		5000	1		D	5000 (2270)
Ammonium vanadate	7803556	Vanadic acid, ammonium salt	1*	4	P119	C	1000 (454)
Amyl acetate	628637		1000	1		D	5000 (2270)
iso-Amyl acetate	123922		1000	1		D	5000 (2270)
sec-Amyl acetate	626380		1000	1		D	5000 (2270)
tert-Amyl acetate	625161		1000	1		D	5000 (2270)
Aniline	62533	Benzenamine	1000	1,4	U012	D	5000 (2270)
Anthracene	120127		1*	2		D	5000 (2270)
Antimony††	7440360		1*	2		D	5000 (2270)
ANTIMONY AND COMPOUNDS	N/A		1*	2			**
Antimony pentachloride	7647189		1000	1		C	1000 (454)
Antimony potassium tartrate	28300745		1000	1		B	100 (45.4)
Antimony tribromide	7789619		1000	1		C	1000 (454)
Antimony trichloride	10025919		1000	1		C	1000 (454)
Antimony trifluoride	7783564		1000	1		C	1000 (454)
Antimony trioxide	1309644		5000	1		C	1000 (454)
Argentate(1-), bis(cyano-C)-, potassium	506616	Potassium silver cyanide	1*	4	P099	X	1 (0.454)
Aroclor 1016	12674112	POLYCHLORINATED BIPHENYLS (PCBs)	10	1,2		X	1 (0.454)
Aroclor 1221	11104282	POLYCHLORINATED BIPHENYLS (PCBs)	10	1,2		X	1 (0.454)
Aroclor 1232	11141165	POLYCHLORINATED BIPHENYLS (PCBs)	10	1,2		X	1 (0.454)

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Hazardous Substance	CASRN	Regulatory Synonyms	Statutory			Final RQ	
			RQ	Code†	RCRA Waste #	Category	Pounds (Kg)
Aroclor 1242	53469219	POLYCHLORINATED BIPHENYLS (PCBs)	10	1,2		X	1 (0.454)
Aroclor 1248	12672296	POLYCHLORINATED BIPHENYLS (PCBs)	10	1,2		X	1 (0.454)
Aroclor 1254	11097691	POLYCHLORINATED BIPHENYLS (PCBs)	10	1,2		X	1 (0.454)
Aroclor 1260	11096825	POLYCHLORINATED BIPHENYLS (PCBs)	10	1,2		X	1 (0.454)
Arsenic††	7440382		1*	2,3		X	1 (0.454)
Arsenic acid	1327522	Arsenic acid H_3AsO_4	1*	4	P010	X	1 (0.454)
	7778394						
Arsenic acid H_3AsO_4	1327522	Arsenic acid	1*	4	P010	X	1 (0.454)
	7778394		1*	4	P010	X	1(0.454)
ARSENIC AND COMPOUNDS	N/A		1*	2			**
Arsenic disulfide	1303328		5000	1		X	1 (0.454)
Arsenic oxide As_2O_3	1327533	Arsenic trioxide	5000	1,4	P012	X	1 (0.454)
Arsenic oxide As_2O_5	1303282	Arsenic pentoxide	5000	1,4	P011	X	1 (0.454)
Arsenic pentoxide	1303282	Arsenic oxide As_2O_5	5000	1,4	P011	X	1 (0.454)
Arsenic trichloride	7784341		5000	1		X	1 (0.454)
Arsenic trioxide	1327533	Arsenic oxide As_2O_3	5000	1,4	P012	X	1 (0.454)
Arsenic trisulfide	1303339		5000	1		X	1 (0.454)
Arsine, diethyl-	692422	Diethylarsine	1*	4	P038	X	1 (0.454)
Arsinic acid, dimethyl-	75605	Cacodylic acid	1*	4	U136	X	1 (0.454)
Arsonous dichloride, phenyl-	696286	Dichlorophenylarsine	1*	4	P036	X	1 (0.454)
Asbestos†††	1332214		1*	2,3		X	1 (0.454)
Auramine	492808	Benzenamine, 4,4'-carbonimidoylbis (N,N-dimethyl-	1*	4	U014	B	100 (45.4)
Azaserine	115026	L-Serine, diazoacetate (ester)	1*	4	U015	X	1 (0.454)
Aziridine	151564	Ethylenimine	1*	4	P054	X	1 (0.454)
Aziridine, 2-methyl-	75558	1,2-Propylenimine	1*	4	P067	X	1 (0.454)
Azirino[2',3':3,4]pyrrolo[1,2-a]indole-4,7-dione,6-amino-8-[[(aminocarbonyl)oxy]methyl]-1,1a,2,8,8a,8b-hexahydro-8a-methoxy-5-methyl-,[1aS-(1aalpha,8beta,8aalpha,8balpha)]-	50077	Mitomycin C	1*	4	U010	A	10 (4.54)

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Hazardous Substance	CASRN	Regulatory Synonyms	Statutory			Final RQ	
			RQ	Code†	RCRA Waste #	Category	Pounds (Kg)
Barium cyanide	542621		10	1,4	P013	A	10 (4.54)
Benz[j]aceanthrylene, 1,2-dihydro-3-methyl-	56495	3-Methylcholanthrene	1*	4	U157	A	10 (4.54)
Benz[c]acridine	225514		1*	4	U016	B	100 (45.4)
Benzal chloride	98873	Benzene, dichloromethyl-	1*	4	U017	D	5000 (2270)
Benzamide, 3,5-dichloro-N-(1,1-dimethyl-2-propynyl)-	23950585	Pronamide	1*	4	U192	D	5000 (2270)
Benz[a]anthracene	56553	Benzo[a]anthracene 1,2-Benzanthracene	1*	2,4	U018	A	10 (4.54)
1,2-Benzanthracene	56553	Benz[a]anthracene Benzo[a]anthracene	1*	2,4	U018	A	10 (4.54)
Benz[a]anthracene, 7,12-dimethyl-	57976	7,12-Dimethylbenz[a]anthracene	1*	4	U094	X	1 (0.454)
Benzenamine	62533	Aniline	1000	1,4	U012	D	5000 (2270)
Benzenamine, 4,4'-carbonimidoylbis (N,N-dimethyl-	492808	Auramine	1*	4	U014	B	100 (45.4)
Benzenamine, 4-chloro-	106478	p-Chloroaniline	1*	4	P024	C	1000 (454)
Benzenamine, 4-chloro-2-methyl-, hydrochloride	3165933	4-Chloro-o-toluidine, hydrochloride	1*	4	U049	B	100 (45.4)
Benzenamine, N,N-dimethyl-4(phenylazo-)	60117	p-Dimethylaminoazobenzene	1*	4	U093	A	10 (4.54)
Benzenamine, 2-methyl-	95534	o-Toluidine	1*	4	U328	B	100 (45.4)
Benzenamine, 4-methyl-	106490	p-Toluidine	1*	4	U353	B	100 (45.4)
Benzenamine, 4,4'-methylenebis(2-chloro-	101144	4,4'-Methylenebis(2-chloroaniline)	1*	4	U158	A	10 (4.54)
Benzenamine, 2-methyl-, hydrochloride	636215	o-Toluidine hydrochloride	1*	4	U222	B	100 (45.4)
Benzenamine, 2-methyl-5-nitro	99558	5-Nitro-o-toluidine	1*	4	U181	B	100 (45.4)
Benzenamine, 4-nitro-	100016	p-Nitroaniline	1*	4	P077	D	5000 (2270)
Benzene	71432		1000	1,2,3,4	U109	A	10 (4.54)
Benzeneacetic acid, 4-chloro-alpha-(4-chlorophenyl)-alpha-hydroxy-, ethyl ester	510156	Chlorobenzilate	1*	4	U038	A	10 (4.54)
Benzene, 1-bromo-4-phenoxy-	101553	4-Bromophenyl phenyl ether	1*	2,4	U030	B	100 (45.4)
Benzenebutanoic acid, 4-[bis(2-chloroethyl)amino]-	305033	Chlorambucil	1*	4	U035	A	10 (4.54)
Benzene, chloro-	108907	Chlorobenzene	100	1,2,4	U037	B	100 (45.4)
Benzene, chloromethyl-	100447	Benzyl chloride	100	1,4	P028	B	100 (45.4)

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Hazardous Substance	CASRN	Regulatory Synonyms	Statutory			Final RQ	
			RQ	Code†	RCRA Waste #	Category	Pounds (Kg)
Benzenediamin, ar-methyl-	95807	Toluenediamine	1*	4	U221	A	10 (4.54)
	496720		1*	4	U221	A	10 (4.54)
	823405		1*	4	U221	A	10 (4.54)
1,2-Benzenedicarboxylic acid, dioctyl ester	117840	Di-n-octyl phthalate	1*	2,4	U107	D	5000 (2270)
1,2-Benzenedicarboxylic acid, [bis(2-ethylhexyl)]-ester	117817	Bis (2-ethylhexyl)phthalate Diethylhexyl phthalate	1*	2,4	U028	B	100 (45.4)
1,2-Benzenedicarboxylic acid, dibutyl ester	84742	Di-n-butyl phthalate Dibutyl phthalate n-Butyl phthalate	100	1,2,4	U069	A	10 (4.54)
1,2-Benzenedicarboxylic acid, diethyl ester	84662	Diethyl phthalate	1*	2,4	U088	C	1000 (454)
1,2-Benzenedicarboxylic acid, dimethyl ester	131113	Dimethyl phthalate	1*	2,4	U102	D	5000 (2270)
Benzene, 1,2-dichloro-	95501	o-Dichlorobenzene 1,2-Dichlorobenzene	100	1,2,4	U070	B	100 (45.4)
Benzene, 1,3-dichloro-	541731	m-Dichlorobenzene 1,3-Dichlorobenzene	1*	2,4	U071	B	100 (45.4)
Benzene, 1,4-dichloro-	106467	p-Dichlorobenzene 1,4-Dichlorobenzene	100	1,2,4	U072	B	100 (45.4)
Benzene, 1,1'-(2,2-dichloroethylidene)bis[4-chloro-	72548	DDD TDE 4,4' DDD	1	1,2,4	U060	X	1 (0.454)
Benzene, dichloromethyl-	98873	Benzal chloride	1*	4	U017	D	5000 (2270)
Benzene, 1,3-diisocyanatomethyl-	584849	Toluene diisocyanate	1*	4	U223	B	100 (45.4)
	91087		1*	4	U223	B	100 (45.4)
	26471625		1*	4	U223	B	100 (45.4)
Benzene, dimethyl	1330207	Xylene (mixed)	1000	1,4	U239	C	1000 (454)
m-Benzene, dimethyl	108383	m-Xylene	1000	1,4	U239	C	1000 (454)
o-Benzene, dimethyl	95476	o-Xylene	1000	1,4	U239	C	1000 (454)
p-Benzene, dimethyl	106423	p-Xylene	1000	1,4	U239	C	1000 (454)
1,3-Benzenediol	108463	Resorcinol	1000	1,4	U201	D	5000 (2270)
1,2-Benzenediol,4-[1-hydroxy-2-(methylamino)ethyl]-	51434	Epinephrine	1*	4	P042	C	1000 (454)
Benzeneethanamine, alpha,alpha-dimethyl-,	122098	alpha,alpha-Dimethylphenethylamine	1*	4	P046	D	5000 (2270)
Benzene, hexachloro-	118741	Hexachlorobenzene	1*	2,4	U127	A	10 (4.54)
Benzene, hexahydro-	110827	Cyclohexane	1000	1,4	U056	C	1000 (454)

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Hazardous Substance	CASRN	Regulatory Synonyms	Statutory			Final RQ	
			RQ	Code†	RCRA Waste #	Category	Pounds (Kg)
Benzene, hydroxy-	108952	Phenol	1000	1,2,4	U188	C	1000 (454)
Benzene, methyl-	108883	Toluene	1000	1,2,4	U220	C	1000 (454)
Benzene, 2-methyl-1,3-dinitro-	606202	2,6-Dinitrotoluene	1000	1,2,4	U106	B	100 (45.4)
Benzene, 1-methyl-2,4-dinitro-	121142	2,4-Dinitrotoluene	1000	1,2,4	U105	A	10 (4.54)
Benzene, 1-methylethyl-	98828	Cumene	1*	4	U055	D	5000 (2270)
Benzene, nitro-	98953	Nitrobenzene	1000	1,2,4	U169	C	1000 (454)
Benzene, pentachloro-	608935	Pentachlorobenzene	1*	4	U183	A	10 (4.54)
Benzene, pentachloronitro-	82688	Pentachloronitrobenzene (PCNB)	1*	4	U185	B	100 (45.4)
Benzenesulfonic acid chloride	98099	Benzenesulfonyl chloride	1*	4	U020	B	100 (45.4)
Benzenesulfonyl chloride	98099	Benzenesulfonic acid chloride	1*	4	U020	B	100 (45.4)
Benzene, 1,2,4,5-tetrachloro-	95943	1,2,4,5-Tetrachlorobenzene	1*	4	U207	D	5000 (2270)
Benzenethiol	108985	Thiophenol	1*	4	P014	B	100 (45.4)
Benzene, 1,1'-(2,2,2-trichloroethylidene)bis[4-chloro-	50293	DDT 4,4'DDT	1	1,2,4	U061	X	1 (0.454)
Benzene, 1,1'-(trichloroethylidene) bis[4-methoxy-	72435	Methoxychlor	1	1,4	U247	X	1 (0.454)
Benzene, (trichloromethyl)-	98077	Benzotrichloride	1*	4	U023	A	10 (4.54)
Benzene, 1,3,5-trinitro-	99354	1,3,5-Trinitrobenzene	1*	4	U234	A	10 (4.554)
Benzidine	92875	(1,1'-Biphenyl)-4,4'diamine	1*	2,4	U021	X	1 (0.454)
1,2-Benzisothiazol-3(2H)-one, 1,1-dioxide	81072	Saccharin and salts	1*	4	U202	B	100 (45.4)
Benzo[a]anthracene	56553	Benz[a]anthracene 1,2-Benzanthracene	1*	2,4	U018	A	10 (4.54)
Benzo[b]fluoranthene	205992		1*	2		X	1 (0.454)
Benzo(k)fluoranthene	207089		1*	2		D	5000 (2270)
Benzo[j,k]fluorene	206440	Fluoranthene	1*	2,4	U120	B	100 (45.4)
1,3-Benzodioxole, 5-(1-propenyl)-	120581	Isosafrole	1*	4	U141	B	100 (45.4)
1,3-Benzodioxole, 5-(2-propenyl)-	94597	Safrole	1*	4	U203	B	100 (45.4)
1,3-Benzodioxole, 5-propyl-	94586	Dihydrosafrole	1*	4	U090	A	10 (4.54)
Benzoic acid	65850		5000	1		D	5000 (2270)
Benzonitrile	100470		1000	1		D	5000 (2270)
Benzo[rst]pentaphene	189559	Dibenz[a,i]pyrene	1*	4	U064	A	10 (4.54)
Benzo[ghi]perylene	191242		1*	2		D	5000 (2270)

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Hazardous Substance	CASRN	Regulatory Synonyms	Statutory			Final RQ	
			RQ	Code†	RCRA Waste #	Category	Pounds (Kg)
2H-1 Benzopyran-2-one, 4-hydroxy-3-(3-oxo-1-phenyl-butyl)-, & salts, when present at concentrations greater than 0.3%	81812	Warfarin, & salts, when present at concentrations greater than 0.3%	1*	4	P001	B	100 (45.4)
Benzo[a]pyrene	50328	3,4-Benzopyrene	1*	2,4	U022	X	1 (0.454)
3,4-Benzopyrene	50328	Benzo[a]pyrene	1*	2,4	U022	X	1 (0.454)
p-Benzoquinone	106514	2,5-Cyclohexadiene-1,4-dione	1*	4	U197	A	10 (4.54)
Benzotrichloride	98077	Benzene, (trichloromethyl)-	1*	4	U023	A	10 (4.54)
Benzoyl chloride	98884		1000	1		C	1000 (454)
1,2-Benzphenanthrene	218019	Chrysene	1*	2,4	U050	B	100 (45.4)
Benzyl chloride	100447	Benzene, chloromethyl-	100	1,4	P028	B	100 (45.4)
Beryllium††	7440417	Beryllium dust ††	1*	2,3,4	P015	A	10 (4.54)
BERYLLIUM AND COMPOUNDS	N/A		1*	2			**
Beryllium chloride	7787475		5000	1		X	1 (0.454)
Beryllium dust††	7440417	Beryllium††	1*	2,3,4	P015	A	10 (4.54)
Beryllium fluoride	7787497		5000	1		X	1 (0.454)
Beryllium nitrate	13597994		5000	1		X	1 (0.454)
	7787555		5000	1		X	1 (0.454)
alpha-BHC	319846		1*	2		A	10 (4.54)
beta-BHC	319857		1*	2		X	1 (0.454)
delta-BHC	319868		1*	2		X	1 (0.454)
gamma-BHC	58899	Cyclohexane, 1,2,3,4,5,6-hexachloro-,(1alpha,2alpha,3beta,4alpha,5alpha,6 beta)- Hexachlorocyclohexane (gamma isomer) Lindane	1	1,2,4	U129	X	1 (0.454)
2,2'-Bioxirane	1464535	1,2:3,4-Diepoxybutane	1*	4	U085	A	10 (4.54)
(1,1'-Biphenyl)-4,4'diamine	92875	Benzidine	1*	2,4	U021	X	1 (0.454)
(1,1'-Biphenyl)-4,4'diamine,3,3'dichloro-	91941	3,3'-Dichlorobenzidine	1*	2,4	U073	X	1 (0.454)
(1,1'-Biphenyl)-4,4'diamine,3,3'dimethoxy-	119904	3,3'-Dimethoxybenzidine	1*	4	U091	B	100 (45.4)
(1,1'-Biphenyl)-4,4'-diamine,3,3'-dimethyl-	119937	3,3'-Dimethylbenzidine	1*	4	U095	A	10 (4.54)

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Hazardous Substance	CASRN	Regulatory Synonyms	Statutory			Final RQ	
			RQ	Code†	RCRA Waste #	Category	Pounds (Kg)
Bis (2-chloroethyl) ether	111444	Dichloroethyl ether Ethane, 1,1'-oxybis[2-chloro-	1*	2,4	U025	A	10 (4.54)
Bis(2-chloroethoxy) methane	111911	Dichloromethoxy ethane Ethane, 1,1'-[methylenebis(oxy)] bis[2-chloro-	1*	2,4	U024	C	1000 (454)
Bis (2-ethylhexyl)phthalate	117817	Diethylhexyl phthalate 1,2-Benzenedicarboxylic acid, [bis(2-ethylhexyl)] ester	1*	2,4	U028	B	100 (45.4)
Bromoacetone	598312	2-Propanone, 1-bromo-	1*	4	P017	C	1000 (454)
Bromoform	75252	Methane, tribromo	1*	2,4	U225	B	100 (45.4)
4-Bromophenyl phenyl ether	101553	Benzene, 1-bromo-4-phenoxy-	1*	2,4	U030	B	100 (45.4)
Brucine	357573	Strychnidin-10-one, 2,3-dimethoxy-	1*	4	P018	B	100 (45.4)
1,3-Butadiene, 1,1,2,3,4,4-hexachloro-	87683	Hexachlorobutadiene	1*	2,4	U128	X	1 (0.454)
1-Butanamine, N-butyl-N-nitroso-	924163	N-Nitrosodi-n-butylamine	1*	4	U172	A	10 (4.54)
1-Butanol	71363	n-Butyl alcohol	1*	4	U031	D	5000 (2270)
2-Butanone	78933	Methyl ethyl ketone (MEK)	1*	4	U159	D	5000 (2270)
2-Butanone peroxide	1338234	Methyl ethyl ketone peroxide	1*	4	U160	A	10 (4.54)
2 Butanone, 3,3-dimethyl-1-(methylthio)-, O[(methylamino) carbonyl] oxime.	39196184	Thiofanox	1*	4	P045	B	100 (45.4)
2-Butenal	123739	Crotonaldehyde	100	1,4	U053	B	100 (45.4)
	4170303						
2-Butene, 1,4-dichloro-	764410	1,4-Dichloro-2-butene	1*	4	U074	X	1 (0.454)
2-Butenoic acid, 2-methyl, 7[[2,3-dihydroxy-2-(1-methoxyethyl)-3-methyl-1-oxobutoxy]methyl]-2,3,5,7a-tetrahydro-1H-pyrrolizin-1-ylester, [1S-[1alpha(Z), 7(2S*,3R*),7aalpha]]-	303344	Lasiocarpine	1*	4	U143	A	10 (4.54)
Butyl acetate	123864		5000	1		D	5000 (2270)
iso-Butyl acetate	110190		5000	1		D	5000 (2270)
sec-Butyl acetate	105464		5000	1		D	5000 (2270)
tert-Butyl acetate	540885		5000	1		D	5000 (2270)
n-Butyl alcohol	71363	1-Butanol	1*	4	U031	D	5000 (2270)
Butylamine	109739		1000	1		C	1000 (454)
iso-Butylamine	78819		1000	1		C	1000 (454)

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Hazardous Substance	CASRN	Regulatory Synonyms	Statutory			Final RQ	
			RQ	Code†	RCRA Waste #	Category	Pounds (Kg)
sec-Butylamine	513495		1000	1		C	1000 (454)
	13952846		1000	1		C	1000 (454)
tert-Butylamine	75649		1000	1		C	1000 (454)
Butyl benzyl phthalate	85687		1*	2		B	100 (45.4)
n-Butyl phthalate	84742	Di-n-butyl phthalate Dibutyl phthalate 1,2-Benzenedicarboxylic acid, dibutyl ester	100	1,2,4	U069	A	10 (4.54)
Butyric acid	107926		5000	1		D	5000 (2270)
iso-Butyric acid	79312						
Cacodylic acid	75605	Arsinic acid, dimethyl-	1*	4	U136	X	1 (0.454)
Cadmium††	7440439		1*	2		A	10 (4.54)
Cadmium acetate	543908		100	1		A	10 (4.54)
CADMIUM AND COMPOUNDS	N/A		1*	2			**
Cadmium bromide	7789426		100	1		A	10 (4.54)
Cadmium chloride	10108642		100	1		A	10 (4.54)
Calcium arsenate	7778441		1000	1		X	1 (0.454)
Calcium arsenite	52740166		1000	1		X	1 (0.454)
Calcium carbide	75207		5000	1		A	10 (4.54)
Calcium chromate	13765190	Chromic acid H2CrO4, calcium salt	1000	1,4	U032	A	10 (4.54)
Calcium cyanide	592018	Calcium cyanide Ca(CN)2	10	1,4	P021	A	10 (4.54)
Calcium cyanide Ca(CN)2	592018	Calcium cyanide	10	1,4	P021	A	10 (4.54)
Calcium dodecylbenzenesulfonate	26264062		1000	1		C	1000 (454)
Calcium hypochlorite	7778543		100	1		A	10 (4.54)
Camphene, octachloro-	8001352	Toxaphene	1	1,2,4	P123	X	1 (0.454)
Captan	133062		10	1		A	10 (4.54)
Carbamic acid, ethyl ester	51796	Ethyl carbamate (urethane)	1*	4	U238	B	100 (45.4)
Carbamic acid, methylnitroso-, ethyl ester	615532	N-Nitroso-N-methylurethane	1*	4	U178	X	1 (0.454)
Carbamic chloride, dimethyl-	79447	Dimethylcarbamoyl chloride	1*	4	U097	X	1 (0.454)
Carbamodithioic acid, 1,2-ethanediylbis, salts & esters	111546	Ethylenebisdithiocarbamic acid, salts & esters	1*	4	U114	D	5000 (2270)
Carbamothioic acid, bis(1-methylethyl)-, S-(2,3-dich-loro-2-propenyl) ester	2303164	Diallate	1*	4	U062	B	100 (45.4)

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Hazardous Substance	CASRN	Regulatory Synonyms	Statutory			Final RQ	
			RQ	Code†	RCRA Waste #	Category	Pounds (Kg)
Carbaryl	63252		100	1		B	100 (45.4)
Carbofuran	1563662		10	1		A	10 (4.54)
Carbon disulfide	75150		5000	1,4	P022	B	100 (45.4)
Carbon oxyfluoride	353504	Carbonic difluoride	1*	4	U033	C	1000 (454)
Carbon tetrachloride	56235	Methane, tetrachloro-	5000	1,2,4	U211	A	10 (4.54)
Carbonic acid, dithallium(1+) salt	6533739	Thallium(I) carbonate	1*	4	U215	B	100 (45.4)
Carbonic dichloride	75445	Phosgene	5000	1,4	P095	A	10 (4.54)
Carbonic difluoride	353504	Carbon oxyfluoride	1*	4	U033	C	1000 (454)
Carbonochloridic acid, methyl ester	79221	Methyl chlorocarbonate Methyl chloroformate	1*	4	U156	C	1000 (454)
Chloral	75876	Acetaldehyde, trichloro-	1*	4	U034	D	5000 (2270)
Chlorambucil	305033	Benzenebutanoic acid, 4-[bis(2-chloroethyl)amino]-	1*	4	U035	A	10 (4.54)
Chlordane	57749	Chlordane, alpha & gamma isomers Chlordane, technical 4,7-Methano-1H-indene, 1,2,4,5,6,7,8,8-octachloro-2,3,3a,4,7,7a-hexahydro-	1	1,2,4	U036	X	1 (0.454)
CHLORDANE (TECHNICAL MIXTURE AND METABOLITES)	N/A		1*	2			**
Chlordane, alpha & gamma isomers	57749	Chlordane Chlordane, technical 4,7-Methano-1H-indene, 1,2,4,5,6,7,8,8-octachloro-2,3,3a,4,7,7a-hexahydro-	1	1,2,4	U036	X	1 (0.454)
Chlordane, technical	57749	Chlordane Chlordane, alpha & gamma isomers 4,7-Methano-1H-indene, 1,2,4,5,6,7,8,8-octachloro-2,3,3a,4,7,7a-hexahyrdo-	1	1,2,4	U036	X	1 (0.454)
CHLORINATED BENZENES	N/A		1*	2			**
CHLORINATED ETHANES	N/A		1*	2			**
CHLORINATED NAPHTHALENE	N/A		1*	2			**
CHLORINATED PHENOLS	N/A		1*	2			**
Chlorine	7782505		10	1		A	10 (4.54)
Chlornaphazine	494031	Naphthalenamine, N,N'-bis(2-chloroethyl)-	1*	4	U026	B	100 (45.4)
Chloroacetaldehyde	107200	Acetaldehyde, chloro-	1*	4	P023	C	1000 (454)

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Hazardous Substance	CASRN	Regulatory Synonyms	Statutory			Final RQ	
			RQ	Code†	RCRA Waste #	Category	Pounds (Kg)
CHLOROALKYL ETHERS	N/A		1*	2			**
p-Chloroaniline	106478	Benzenamine, 4-chloro-	1*	4	P024	C	1000 (454)
Chlorobenzene	108907	Benzene, chloro-	100	1,2,4	U037	B	100 (45.4)
Chlorobenzilate	510156	Benzeneacetic acid, 4-chloro-alpha-(4-chloro-phenyl)-alpha-hydroxy-, ethyl ester	1*	4	U038	A	10 (4.54)
4-Chloro-m-cresol	59507	p-Chloro-m-cresol Phenol, 4-chloro-3-methyl	1*	2,4	U039	D	5000 (2270)
p-Chloro-m-cresol	59507	Phenol, 4-chloro-3-methyl- 4-Chloro-m-cresol	1*	2,4	U039	D	5000 (2270)
Chlorodibromomethane	124481		1*	2		B	100 (45.4)
Chloroethane	75003		1*	2		B	100 (45.4)
2-Chloroethyl vinyl ether	110758	Ethene, 2-chloroethoxy-	1*	2,4	U042	C	1000 (454)
Chloroform	67663	Methane, trichloro-	5000	1,2,4	U044	A	10 (4.54)
Chloromethyl methyl ether	107302	Methane, chloromethoxy-	1*	4	U046	A	10 (4.54)
beta-Chloronaphthalene	91587	Naphthalene, 2-chloro- 2-Chloronaphthalene	1*	2,4	U047	D	5000 (2270)
2-Chloronaphthalene	91587	beta-Chloronaphthalene Naphthalene, 2-chloro-	1*	2,4	U047	D	5000 (2270)
2-Chlorophenol	95578	o-Chlorophenol Phenol, 2-chloro-	1*	2,4	U048	B	100 (45.4)
o-Chlorophenol	95578	Phenol, 2-chloro- 2-Chlorophenol	1*	2,4	U048	B	100 (45.4)
4-Chlorophenyl phenyl ether	7005723		1*	2		D	5000 (2270)
1-(o-Chlorophenyl)thiourea	5344821	Thiourea, (2-chlorophenyl)-	1*	4	P026	B	100 (45.4)
3-Chloropropionitrile	542767	Propanenitrile, 3-chloro-	1*	4	P027	C	1000 (454)
Chlorosulfonic acid	7790945		1000	1		C	1000 (454)
4-Chloro-o-toluidine, hydrochloride	3165933	Benzenamine, 4-chloro-2-methyl-, hydrochloride	1*	4	U049	B	100 (45.4)
Chlorpyrifos	2921882		1	1		X	1 (0.454)
Chromic acetate	1066304		1000	1		C	1000 (454)
Chromic acid	11115745		1000	1		A	10 (4.54)
	7738945		1000	1		A	10 (4.54)
Chromic acid H2CrO4, calcium salt	13765190	Calcium chromate	1000	1,4	U032	A	10 (4.54)
Chromic sulfate	10101538		1000	1		C	1000 (454)
Chromium††	7440473		1*	2		D	5000 (2270)

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Hazardous Substance	CASRN	Regulatory Synonyms	Statutory			Final RQ	
			RQ	Code†	RCRA Waste #	Category	Pounds (Kg)
CHROMIUM AND COMPOUNDS	N/A		1*	2			**
Chromous chloride	10049055		1000	1		C	1000 (454)
Chrysene	218019	1,2-Benzphenanthrene	1*	2,4	U050	B	100 (45.4)
Cobaltous bromide	7789437		1000	1		C	1000 (454)
Cobaltous formate	544183		1000	1		C	1000 (454)
Cobaltous sulfamate	14017415		1000	1		C	1000 (454)
Coke Oven Emissions	N/A		1*	3		X	1 (0.454)
Copper cyanide CuCN	544923	Copper cyanide	1*	4	P029	A	10 (4.54)
Copper††	7440508		1*	2		D	5000 (2270)
COPPER AND COMPOUNDS	N/A		1*	2			**
Copper cyanide	544923	Copper cyanide CuCN	1*	4	P029	A	10 (4.54)
Coumaphos	56724		10	1		A	10 (4.54)
Creosote	8001589		1*	4	U051	X	1 (0.454)
Cresol(s)	1319773	Cresylic acid Phenol, methyl-	1000	1,4	U052	C	1000 (454)
m-Cresol	108394	m-Cresylic acid	1000	1,4	U052	C	1000 (454)
o-Cresol	95487	o-Cresylic acid	1000	1,4	U052	C	1000 (454)
p-Cresol	106445	p-Cresylic acid	1000	1,4	U052	C	1000 (454)
Cresylic acid	1319773	Cresol(s) Phenol, methyl-	1000	1,4	U052	C	1000 (454)
m-Cresol	108394	m-Cresylic acid	1000	1,4	U052	C	1000 (454)
o-Cresol	95487	o-Cresylic acid	1000	1,4	U052	C	1000 (454)
p-Cresol	106445	p-Cresylic acid	1000	1,4	U052	C	1000 (454)
Crotonaldehyde	123739	2-Butenal	100	1,4	U053	B	100 (45.4)
	4170303						
Cumene	98828	Benzene, 1-methylethyl-	1*	4	U055	D	5000 (2270)
Cupric acetate	142712		100	1		B	100 (45.4)
Cupric acetoarsenite	12002038		100	1		X	1 (0.454)
Cupric chloride	7447394		10	1		A	10 (4.54)
Cupric nitrate	3251238		100	1		B	100 (45.4)
Cupric oxalate	5893663		100	1		B	100 (45.4)
Cupric sulfate	7758987		10	1		A	10 (4.54)
Cupric sulfate, ammoniated	10380297		100	1		B	100 (45.4)

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Hazardous Substance	CASRN	Regulatory Synonyms	Statutory			Final RQ	
			RQ	Code†	RCRA Waste #	Category	Pounds (Kg)
Cupric tartrate	815827		100	1		B	100 (45.4)
CYANIDES	N/A		1*	2			**
Cyanides (soluble salts and complexes) not otherwise specified	57125		1*	4	P030	A	10 (4.54)
Cyanogen	460195	Ethanedinitrile	1*	4	P031	B	100 (45.4)
Cyanogen bromide	506683	Cyanogen bromide (CN)Br	1*	4	U246	C	1000 (454)
Cyanogen bromide (CN)Br	506683	Cyanogen bromide	1*	4	U246	C	1000 (454)
Cyanogen chloride	506774	Cyanogen chloride (CN)Cl	10	1,4	P033	A	10 (4.54)
Cyanogen chloride (CN)Cl	506774	Cyanogen chloride	10	1,4	P033	A	10 (4.54)
2,5-Cyclohexadiene-1,4-dione	106514	p-Benzoquinone	1*	4	U197	A	10 (4.54)
Cyclohexane	110827	Benzene, hexahydro-	1000	1,4	U056	C	1000 (454)
Cyclohexane, 1,2,3,4,5,6-hexachloro-,(1alpha, 2alpha, 3beta,4alpha,5alpha,6,beta)-	58899	gamma—BHC	1	1,2,4	U129	X	1 (0.454)
Cyclohexanone	108941		1*	4	U057	D	5000 (2270)
2-Cyclohexyl-4,6-dinitrophenol	131895	Phenol, 2-cyclohexyl-4,6-dinitro-	1*	4	P034	B	100 (45.4)
1,3-Cyclopentadiene, 1,2,3,4,5,5-hexachloro-	77474	Hexachlorocyclopentadiene	1	1,2,4	U130	A	10 (4.54)
Cyclophosphamide	50180	2H-1,3,2-Oxazaphosphorin-2-amine, N,N-bis(2-chloroethyl) tetrahydro-,2-oxide	1*	4	U058	A	10 (4.54)
2,4-D Acid	94757	Acetic acid (2,4-dichlorophenoxy)-2,4-D, salts and esters	100	1,4	U240	B	100 (45.4)
2,4-D Ester	94111		100	1		B	100 (45.4)
	94791		100	1		B	100 (45.4)
	94804		100	1		B	100 (45.4)
	1320189		100	1		B	100 (45.4)
	1928387		100	1		B	100 (45.4)
	1928616		100	1		B	100 (45.4)
	1929733		100	1		B	100 (45.4)
	2971382		100	1		B	100 (45.4)
	25168267		100	1		B	100 (45.4)
	53467111		100	1		B	100 (45.4)
2,4-D, salts and esters	94757	Acetic acid (2,4-dichlorophenoxy)-2,4-D Acid	100	1,4	U240	B	100 (45.4)

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Hazardous Substance	CASRN	Regulatory Synonyms	Statutory			Final RQ	
			RQ	Code†	RCRA Waste #	Category	Pounds (Kg)
Daunomycin	20830813	5,12-Naphthacenedione, 8-acetyl-10-[3-amino-2,3,6- trideoxy-alpha-L-lyxo-hexo-pyranosyl)oxy]-7,8,9,10-tetrahydro-6,8,11-trihydroxy-1-methoxy-, (8S-cis)-	1*	4	U059	A	10 (4.54)
DDD	72548	Benzene, 1,1'-(2,2-dichloroethylidene)bis[4-chloro- TDE 4,4' DDD	1	1,2,4	U060	X	1 (0.454)
4,4' DDD	72548	Benzene, 1,1'-(2,2-dichloroethylidene)bis[4-chloro- DDD TDE	1	1,2,4	U060	X	1 (0.454)
DDE	72559	4,4' DDE	1*	2		X	1 (0.454)
4,4' DDE	72559	DDE	1*	2		X	1 (0.454)
DDT	50293	Benzene, 1,1'-(2,2,2-trichloroethylidene)bis[4-chloro- 4,4'DDT	1	1,2,4	U061	X	1 (0.454)
4,4' DDT	50293	Benzene, 1,1'-(2,2,2-trichloroethylidene)bis[4-chloro- DDT	1	1,2,4	U061	X	1 (0.454)
DDT AND METABOLITES	N/A		1*	2			**
Diallate	2303164	Carbamothioic acid, bis(1-methylethyl)-, S-(2,3,-dich-loro-2-propenyl) ester	1*	4	U062	B	100 (45.4)
Diazinon	333415		1	1		X	1 (0.454)
Dibenz[a,h]anthracene	53703	Dibenzo[a,h]anthracene 1,2:5,6-Dibenzanthracene	1*	2,4	U063	X	1 (0.454)
1,2:5,6-Dibenzanthracene	53703	Dibenz[a,h]anthracene Dibenzo[a,h]anthracene	1*	2,4	U063	X	1 (0.454)
Dibenzo[a,h]anthracene	53703	Dibenz[a,h]anthracene 1,2:5,6-Dibenzanthracene	1*	2,4	U063	X	1 (0.454)
Dibenz[a,i]pyrene	189559	Benzo[rst]pentaphene	1*	4	U064	A	10 (4.54)
1,2-Dibromo-3-chloropropane	96128	Propane, 1,2-dibromo-3-chloro-	1*	4	U066	X	1 (0.454)
Dibutyl phthalate	84742	Dibutyl phthalate n-Butyl phthalate 1,2-Benzenedicarboxylic acid, dibutyl ester	100	1,2,4	U069	A	10 (4.54)
Di-n-butyl phthalate	84742	Dibutyl phthalate n-Butyl phthalate 1,2-Benzenedicarboxylic acid, dibutyl ester	100	1,2,4	U069	A	10 (4.54)
Dicamba	1918009		1000	1		C	1000 (454)

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Hazardous Substance	CASRN	Regulatory Synonyms	Statutory			Final RQ	
			RQ	Code†	RCRA Waste #	Category	Pounds (Kg)
Dichlobenil	1194656		1000	1		B	100 (45.4)
Dichlone	117806		1	1		X	1 (0.454)
Dichlorobenzene	25321226		100	1		B	100 (45.4)
1,2-Dichlorobenzene	95501	Benzene, 1,2-dichloro- o-Dichlorobenzene	100	1,2,4	U070	B	100 (45.4)
1,3-Dichlorobenzene	541731	Benzene, 1,3-dichloro m-Dichlorobenzene	1*	2,4	U071	B	100 (45.4)
1,4-Dichlorobenzene	106467	Benzene, 1,4-dichloro p-Dichlorobenzene	100	1,2,4	U072	B	100 (45.4)
m-Dichlorobenzene	541731	Benzene, 1,3-dichloro 1,3-Dichlorobenzene	1*	2,4	U071	B	100 (45.4)
o-Dichlorobenzene	95501	Benzene, 1,2-dichloro 1,2-Dichlorobenzene	100	1,2,4	U070	B	100 (45.4)
p-Dichlorobenzene	106467	Benzene, 1,4-dichloro 1,4-Dichlorobenzene	100	1,2,4	U072	B	100 (45.4)
DICHLOROBENZIDINE	N/A		1*	2			**
3,3'-Dichlorobenzidine	91941	[1,1'-Biphenyl]-4,4'diamine,3,3'dichloro-	1*	2,4	U073	X	1 (0.454)
Dichlorobromomethane	75274		1*	2		D	5000 (2270)
1,4-Dichloro-2-butene	764410	2-Butene, 1,4-dichloro-	1*	4	U074	X	1 (0.454)
Dichlorodifluoromethane	75718	Methane, dichlorodifluoro-	1*	4	U075	D	5000 (2270)
1,1-Dichloroethane	75343	Ethane, 1,1-dichloro- Ethylidene dichloride	1*	2,4	U076	C	1000 (454)
1,2-Dichloroethane	107062	Ethane, 1,2-dichloro- Ethylene dichloride	5000	1,2,4	U077	B	100 (45.4)
1,1-Dichloroethylene	75354	Ethene, 1,1-dichloro- Vinylidene chloride	5000	1,2,4	U078	B	100 (45.4)
1,2-Dichloroethylene	156605	Ethene 1,2-dichloro- (E)	1*	2,4	U079	C	1000 (454)
Dichloroethyl ether	111444	Bis (2-chloroethyl) ether Ethane, 1,1'-oxybis[2-chloro-	1*	2,4	U025	A	10 (4.54)
Dichloroisopropyl ether	108601	Propane, 2,2'-oxybis[2-chloro-	1*	2,4	U027	C	1000 (454)
Dichloromethoxy ethane	111911	Bis(2-chloroethoxy) methane Ethane, 1,1'-[methylenebis(oxy)] bis[2-chloro-	1*	2,4	U024	C	1000 (454)
Dichloromethyl ether	542881	Methane, oxybis[chloro-	1*	4	P016	A	10 (4.54)
2,4-Dichlorophenol	120832	Phenol, 2,4-dichloro-	1*	2,4	U081	B	100 (45.4)
2,6-Dichlorophenol	87650	Phenol, 2,6-dichloro-	1*	4	U082	B	100 (45.4)
Dichlorophenylarsine	696286	Arsonous dichloride, phenyl-	1*	4	P036	X	1 (0.454)

Hazardous Substance	CASRN	Regulatory Synonyms	Statutory			Final RQ	
			RQ	Code†	RCRA Waste #	Category	Pounds (Kg)
Dichloropropane	26638197		5000	1		C	1000 (454)
1,1-Dichloropropane	78999		5000	1		C	1000 (454)
1,3-Dichloropropane	142289		5000	1		C	1000 (454)
1,2-Dichloropropane	78875	Propane, 1,2-dichloro- Propylene dichloride	5000	1,2,4	U083	C	1000 (454)
Dichloropropane—Dichloropropene (mixture)	8003198		5000	1		B	100 (45.4)
Dichloropropene	26952238		5000	1		B	100 (45.4)
2,3-Dichloropropene	78886		5000	1		B	100 (45.4)
1,3-Dichloropropene	542756	1-Propene, 1,3-dichloro-	5000	1,2,4	U084	B	100 (45.4)
2,2-Dichloropropionic acid	75990		5000	1		D	5000 (2270)
Dichlorvos	62737		10	1		A	10 (4.54)
Dicofol	115322		5000	1		A	5000 (2270)
Dieldrin	60571	2,7:3,6-Dimethanonaphth[2,3-b]oxirene,3,4,5,6,9,9-hexachloro-1a,2,2a,3,6,6a,7,7a-octahydro-, (1aalpha,2beta,2aalpha,3beta, 6beta,6aalpha,7beta, 7aalpha)-	1	1,2,4	P037	X	1 (0.454)
1,2:3,4-Diepoxybutane	1464535	2,2'-Bioxirane	1*	4	U085	A	10 (4.54)
Diethylamine	109897		1000	1		B	100 (454.4)
Diethylarsine	692422	Arsine, diethyl-	1*	4	P038	X	1 (0.454)
1,4-Diethylenedioxide	123911	1,4-Dioxane	1*	4	U108	B	100 (45.4)
Diethylhexyl phthalate	117817	Bis (2-ethylhexyl)phthalate 1,2,-Benzenedicarboxylic acid, [bis(2-ethylhexyl)] ester	1*	2,4	U028	B	100 (45.4)
N,N-'Diethylhydrazine	1615801	Hydrazine, 1,2-diethyl-	1*	4	U086	A	10 (4.54)
O,O-Diethyl S-methyl dithiophosphate	3288582	Phosphorodithioic acid, O,O-diethyl S-methyl ester	1*	4	U087	D	5000 (2270)
Diethyl-p-nitrophenyl phosphate	311455	Phosphoric acid, diethyl 4-nitrophenyl ester	1*	4	P041	B	100 (45.4)
Diethyl phthalate	84662	1,2-Benzenedicarboxylic acid, diethyl ester	1*	2,4	U088	C	1000 (454)
O,O-Diethyl O-pyrazinyl phosphorothioate	297972	Phosphorothioic acid, O,O-diethyl O-pyrazinyl ester	1*	4	P040	B	100 (45.4)
Diethylstilbestrol	56531	Phenol, 4,4'-(1,2-diethyl-1,2-ethenediyl)bis-, (E)	1*	4	U089	X	1 (0.454)
Dihydrosafrole	94586	1,3-Benzodioxole, 5-propyl-	1*	4	U090	A	10 (4.54)

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Hazardous Substance	CASRN	Regulatory Synonyms	Statutory RQ	Statutory Code†	Statutory RCRA Waste #	Final RQ Category	Final RQ Pounds (Kg)
Diisopropylfluorophosphate	55914	Phosphorofluoridic acid, bis(1-methylethyl) ester	1*	4	P043	B	100 (45.4)
1,4,5,8-Dimethanonaphthalene, 1,2,3,4,10,10-,10-hexachloro-1,4,4a,5,8,8a-hexahydro-, (1alpha,4alpha,4abeta,5alpha,' 8alpha,	309002	Aldrin	1	1,2,4	P004	X	1 (0.454)
8abeta)-1,4,5,8-Dimenthanonaphthalene, 1,2,3,4,10,10-hexachloro-1,4,4a,5,8,8a-hexahydro,(1alpha,4alpha,4abeta, 5abeta,8beta,	465736	Isodrin	1*	4	P060	X	1 (0.454)
8abeta)-2,7:3,6-Dimethanonaphth[2,3-b]oxirene, 3,4,5,6,9,9-hexachloro-1a,2,2a,3, 6,6a,7,7a-octahydro-, (1aalpha, 2beta,2aalpha,3beta,6beta,	60571	Dieldrin	1	1,2,4	P037	X	1 (0.454)
6aalpha,7beta,7aalpha)-2,7:3,6-Dimethanonaphth[2,3-b]oxirene, 3,4,5,6,9,9-hexachloro-1a,2,2a,3, 6,6a,7,7a-octa-hydro-,(1aalpha, 2beta,2abeta,3alpha,6alpha,	72208	Endrin Endrin & metabolites	1	1,2,4	P051	X	1 (0.454)
6abeta,7beta,7aalpha)-Dimethoate	60515	Phosphorodithioic acid, O,O-dimethyl S-[2(methyla-mino)-2-oxoethyl] ester	1*	4	P044	A	10 (4.54)
3,3'-Dimethoxybenzidine	119904	[1,1'-Biphenyl]-4,4'diamine,3, 3'dimethyoxy-	1*	4	U091	B	100 (45.4)
Dimethylamine	124403	methanamine, N-methyl	1000	1,4	U092	C	1000 (454)
p-Dimethylaminoazobenzene	60117	Benzenamine, N,N-dimethyl-4-(phenylazo-)	1*	4	U093	A	10 (4.54)
7,12-Dimethylbenz[a]anthracene	57976	Benz[a]anthracene, 7,12-dimethyl-	1*	4	U094	X	1 (0.454)
3,3'-Dimethylbenzidine	119937	[1,1'Biphynyl]-4,4'diamine,3,3'-dimethyl-	1*	4	U095	A	10 (4.54)
alpha,alpha-Dimethylbenzylhydroperoxide	80159	Hydroperoxide, 1-mehtyl-1-phenylethyl-	1*	4	U096	A	10 (4.54)
Dimethylcarbamoyl chloride	79447	Carbamic chloride, dimethyl-	1*	4	U097	X	1 (0.454)
1,1-Dimethylhydrazine	57147	Hydrazine, 1,1-dimethyl-	1*	4	U098	A	10 (4.54)
1,2-Dimethylhydrazine	540738	Hydrazine, 1,2-dimethyl-	1*	4	U099	X	1 (0.454)
alpha,alpha-Dimethylphenethylamine	122098	Benzeneethanamine, alpha,alpha-dimethyl-	1*	4	P046	D	5000 (2270)
2,4-Dimethylphenol	105679	Phenol, 2,4-dimethyl-	1*	2,4	U101	B	100 (45.4)

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Hazardous Substance	CASRN	Regulatory Synonyms	Statutory			Final RQ	
			RQ	Code†	RCRA Waste #	Category	Pounds (Kg)
Dimethyl phthalate	131113	1,2-Benzenedicarboxylic acid, dimethyl ester	1*	2,4	U102	D	5000 (2270)
Dimethyl sulfate	77781	Sulfuric acid, dimethyl ester	1*	4	U103	B	100 (45.4)
Dinitrobenzene (mixed)	25154545		1000	1		B	100 (45.4)
m-Dinitrobenzene	99650		1000	1		B	100 (45.4)
o-Dinitrobenzene	528290		1000	1		B	100 (45.4)
p-Dinitrobenzene	100254		1000	1		B	100 (45.4)
4,6-Dinitro-o-cresol and salts	534521	Phenol, 2-methyl-4,6-dinitro-	1*	2,4	P047	A	10 (4.54)
Dinitrophenol	25550587		1000	1		A	10 (4.54)
2,5-Dinitrophenol	329715		1000	1		A	10 (4.54)
2,6-Dinitrophenol	573568		1000	1		A	10 (4.54)
2,4-Dinitrophenol	51285	Phenol, 2,4-dinitro-	1000	1,2,4	P048	A	10 (4.54)
Dinitrotoluene	25321146		1000	1,2		A	10 (4.54)
3,4-Dinitrotoluene	610399						
2,4-Dinitrotoluene	121142	Benzene, 1-methyl-2,4-dinitro-	1000	1,2,4	U105	A	10 (4.54)
2,6-Dinitrotoluene	606202	Benzene, 2-methyl-1,3-dinitro-	1000	1,2,4	U106	B	100 (45.4)
Dinoseb	88857	Phenol, 2-(1-methylpropyl)-4,6-dinitro	1*	4	P020	C	1000 (454)
Di-n-octyl phthalate	117840	1,2-Benzenedicarboxylic acid, dioctyl ester	1*	2,4	U107	D	5000 (2270)
1,4-Dioxane	123911	1,4-Diethylenedioxide	1*	4	U108	B	100 (45.4)
DIPHENYLHYDRAZINE	N/A		1*	2			**
1,2-Diphenylhydrazine	122667	Hydrazine, 1,2-diphenyl	1*	2,4	U109	A	10 (4.54)
Diphosphoramide, octamethyl-	152169	Octamethylpyrophosphoramide	1*	4	P085	B	100 (45.4)
Diphosphoric acid, tetraethyl ester	107493	Tetraethyl pyrophosphate	100	1,4	P111	A	10 (4.54)
Dipropylamine	142847	1-Propanamine, N-propyl-	1*	4	U110	D	5000 (2270)
Di-n-propylnitrosamine	621647	1-Propanamine, N-nitroso-N-propyl-	1*	2,4	U111	A	10 (4.54)
Diquat	85007		1000	1		C	1000 (454)
	2764729		1000	1		C	1000 (454)
Disulfoton	298044	Phosphorodithioic acid, o,o-diethyl S-[2-(ethylthio)ethyl]ester	1	1,4	P039	X	1 (0.454)
Dithiobiuret	541537	Thiomidodicarbonic diamide [(H2N)C(S)]2NH	1*	4	P049	B	100 (45.4)
Diuron	330541		100	1		B	100 (45.4)

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Hazardous Substance	CASRN	Regulatory Synonyms	Statutory RQ	Code†	Statutory RCRA Waste #	Final RQ Category	Final RQ Pounds (Kg)
Dodecylbenzenesulfonic acid	27176870		1000	1		C	1000 (454)
Endosulfan	115297	6,9-Methano-2,4,3-benzodioxathiepin, 6,7,8,9,10,10-hexachloro-1,5,5a,6,9,9a-hexahydro-, 3-oxide	1	1,2,4	P050	X	1 (0.454)
alpha - Endosulfan	959988		1*	2		X	1 (0.454)
beta - Endosulfan	33213659		1*	2		X	1 (0.454)
ENDOSALFAN AND METABOLITES	N/A		1*	2			**
Endosulfan sulfate	1031078		1*	2		X	1 (0.454)
Endothall	145733	7-Oxabicyclo[2.2.1]heptane-2,3-dicarboxylic acid	1*	4	P088	C	1000 (454)
Endrin	72208	Endrin, & metabolites 2,7:3,6-Dimethanonaphth[2,3-b]oxirene,3,4,5,6,9,9 -hexachloro-1a,2,2a,3,6,6a,7,7a-octa-hydro-, (1 aalpha, 2beta,2abeta,3alpha, 6alpha,6abeta,7beta, 7aalpha)-	1	1,2,4	P051	X	1 (0.454)
Endrin aldehyde	7421934		1*	2		X	1 (0.454)
ENDRIN AND METABOLITES	N/A		1*	2			**
Endrin, & metablites	72208	Endrin 2,7:3,6-Dimethanonaphth[2,3-b] oxirene, 3,4,5,6,9,9-hexachloro-1a,2,2a,3,6,6a,7,7a-octa-hydro-, (1 aalpha,2beta, 2abeta,3alpha, 6alpha, ... 6abeta,7beta, 7aalpha)-	1	1,2,4	P051	X	1 (0.454)
Epichlorohydrin	106898	Oxirane, (chloromethyl)-	1000	1,4	U041	B	100 (45.4)
Epinephrine	51434	1,2-Benzenediol,4-[1-hydroxy-2-(methylamino)ethyl]-	1*	4	P042	C	1000 (454)
Ethanal	75070	Acetaldehyde	1000	1,4	U001	C	1000 (454)
Ethanamine, N-ethyl-N-nitroso-	55185	N-Nitrosodiethylamine	1*	4	U174	X	1 (0.454)
1,2-Ethanediamine, N,N-dimethyl-N'-2-pyridinyl-N'-(2-thienylmethyl)-	91805	Methapyrilene	1*	4	U155	D	5000 (2270)
Ethane, 1,2-dibromo-	106934	Ethylene dibromide	1000	1,4	U067	X	1 (0.454)
Ethane, 1,1-dichloro-	75343	Ethylidene dichloride 1,1-Dichloroethane	1*	2,4	U076	C	1000 (454)
Ethane, 1,2-dichloro-	107062	Ethylene dichloride 1,2-Dichloroethane	5000	1,2,4	U077	B	100 (45.4)
Ethanedinitrile	460195	Cyanogen	1*	4	P031	B	100 (45.4)

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Hazardous Substance	CASRN	Regulatory Synonyms	Statutory			Final RQ	
			RQ	Code†	RCRA Waste #	Category	Pounds (Kg)
Ethane, hexachloro-	67721	Hexachloroethane	1*	2,4	U131	B	100 (45.4)
Ethane, 1,1'-[methylenebis(oxy)]bis[2-chloro-	111911	Bis(2-chloroethoxy) methane Dichloromethoxy ethane	1*	2,4	U024	C	1000 (454)
Ethane, 1,1'-oxybis-	60297	Ethyl ether	1*	4	U117	B	100 (45.4)
Ethane, 1,1'-oxybis[2-chloro-	111444	Bis (2-chloroethyl) ether Dichloroethyl ether	1*	2,4	U025	A	10 (4.54)
Ethane, pentachloro-	76017	Pentachloroethane	1*	4	U184	A	10 (4.54)
Ethane, 1,1,1,2-tetrachloro	630206	1,1,1,2-Tetrachloroethane	1*	4	U208	B	100 (45.4)
Ethane, 1,1,2,2-tetrachloro	79345	1,1,2,2-Tetrachloroethane	1*	2,4	U209	B	100 (45.4)
Ethanethioamide	62555	Thioacetamide	1*	4	U218	A	10 (4.54)
Ethane, 1,1,1-trichloro	71556	Methyl chloroform 1,1,1-Trichloroethane	1*	2,4	U226	C	1000 (454)
Ethane, 1,1,2-trichloro-	79005	1,1,2-Trichloroethane	1*	2,4	U227	B	100 (45.4)
Ethanimidothioic acid, N-[[(methylamino)carbonyl]oxy]-, methyl ester	16752775	Methomyl	1*	4	P066	B	100 (45.4)
Ethanol, 2-ethoxy-	110805	Ethylene glycol monoethyl ether	1*	4	U359	C	1000 (454)
Ethanol, 2,2'-(nitrosoimino)bis-	1116547	N-Nitrosodiethanolamine	1*	4	U173	X	1 (0.454)
Ethanone, 1-phenyl-	98862	Acetophenone	1*	4	U004	D	5000 (2270)
Ethene, chloro-	75014	Vinyl chloride	1*	2,3,4	U043	X	1 (0.454)
Ethene, 2-Cloroethoxy-	110758	2-Chloroethyl vinyl ether	1*	2,4	U042	C	1000 (454)
Ethene, 1,1-dichloro-	75354	Vinylidene chloride 1,1-Dichloroethylene	5000	1,2,4	U078	B	100 (45.4)
Ethene, 1,2-dichloro-	156605	1,2-Dichloroethylene	1*	2,4	U079	C	1000 (45.4)
Ethene, tetrachloro-	127184	Perchloroethylene Tetrachlorethene Tetrachloroethylene	1*	2,4	U210	B	100 (45.4)
Ethene, trichloro-	79016	Trichloroethene Trichloroethylene	1000	1,2,4	U228	B	100 (45.4)
Ethion	563122		10	1		A	10 (4.54)
Ethyl acetate	141786	Acetic acid, ethyl ester	1*	4	U112	D	5000 (2270)
Ethyl acrylate	140885	2-Propenoic acid, ethyl ester	1*	4	U113	C	1000 (454)
Ethylbenzene	100414		1000	1,2		C	1000 (454)
Ethyl carbamate (urethane)	51796	Carbamic acid, ethyl ester	1*	4	U238	B	100 (45.4)
Ethyl cyanide	107120	Propanenitril	1*	4	P101	A	10 (4.54)

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Hazardous Substance	CASRN	Regulatory Synonyms	Statutory			Final RQ	
			RQ	Code†	RCRA Waste #	Category	Pounds (Kg)
Ethylenebisdithiocarbamic acid, salts & esters	111546	Carbamodithioic acid, 1,2-ethanedrylbis, salts & esters	1*	4	U114	D	5000 (2270)
Ethylenediamine	107153		1000	1		D	5000 (2270)
Ethylenediamine-tetraacetic acid (EDTA)	60004		5000	1		D	5000 (2270)
Ethylene dibromide	106934	Ethane, 1,2-dibromo-	1000	1,4	U067	X	1 (0.454)
Ethylene dichloride	107062	Ethane, 1,2-dichloro- 1,2-Dichlornethane	5000	1,2,4	U077	B	100 (45.4)
Ethylene glycol monoethy ether	110805	Ethanol, 2-ethoxy-	1*	4	U359	C	1000 (454)
Ethylene oxide	75218	Oxirane	1*	4	U115	A	10 (4.54)
Ethylenethiourea	96457	2-Imidazolidinethione	1*	4	U116	A	10 (4.54)
Ethylenimine	151564	Aziridine	1*	4	P054	X	1 (0.454)
Ethyl ether	60297	Ethane, 1,1'-oxybis	1*	4	U117	B	100 (45.4)
Ethylidene dichloride	75343	Ethane, 1,1'-dichloro- 1,1-Dichloroethane	1*	2,4	U076	C	1000 (454)
Ethyl methacrylate	97632	2-Propenoic acid, 2-methyl-, ethyl ester	1*	4	U118	C	1000 (454)
Ethyl methanesulfonate	62500	Methanesulfonic acid, ethyl ester	1*	4	U119	X	1 (0.454)
Famphur	52857	Phosphorothioic acid, O,[4-[(dimethylamino) sulfonyl] phenyl] O,O-dimethyl ester	1*	4	P097	C	1000 (454)
Ferric ammonium citrate	1185575		1000	1		C	1000 (454)
Ferric ammonium oxalate	2944674		1000	1		C	1000 (454)
	55488874		1000	1		C	1000 (454)
Ferric chloride	7705080		1000	1		C	1000 (454)
Ferric flouride	7783508		100	1		B	100 (45.4)
Ferric nitrate	10421484		1000	1		C	1000 (454)
Ferric sulfate	10028225		1000	1		C	1000 (454)
Ferrous ammonium sulfate	10045893		1000	1		C	1000 (454)
Ferrous chloride	7758943		100	1		B	100 (45.4)
Ferrous sulfate	7720787		1000	1		C	1000 (454)
	7782630		1000	1		C	1000 (454)
Flouranthene	206440	Benzo[j,k]flourene	1*	2,4	U120	B	100 (45.4)
Flourene	86737		1*	2		D	5000 (2270)
Flourine	7782414		1*	4	P056	A	10 (4.54)

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Hazardous Substance	CASRN	Regulatory Synonyms	Statutory RQ	Statutory Code†	Statutory RCRA Waste #	Final RQ Category	Final RQ Pounds (Kg)
Flouroacetamide	640197	Acetamide, 2-fluoro-	1*	4	P057	B	100 (45.4)
Flouracetic acid, sodium salt	62748	Acetic acid, fluoro-, sodium salt	1*	4	P058	A	10 (4.54)
Formaldehyde	50000		1000	1,4	U122	B	100 (45.4)
Formic acid	64186		5000	1,4	U123	D	5000 (2270)
Fulminic acid, mercury(2+)salt	628864	Mercury fulminate	1*	4	P065	A	10 (4.54)
Fumaric acid	110178		5000	1		D	5000 (2270)
Furan	110009	Furfuran	1*	4	U124	B	100 (45.4)
Furan, tetrahydro-	109999	Tetrahydrofuran	1*	4	U213	C	1000 (454)
2-Furancarboxaldehyde	98011	Furfural	1000	1,4	U125	D	5000 (2270)
2,5-Furandione	108316	Maleic anhydride	5000	1,4	U147	D	5000 (2270)
Furfural	98011	2-Furancarboxaldehyde	1000	1,4	U125	D	5000 (2270)
Furfuran	110009	Furan	1*	4	U124	B	100 (45.4)
Glucopyranose, 2-deoxy-2-(3-methyl-3-nitrosoureido)-	18883664	D-Glucose, 2-deoxy-2-[[(methylnitrosoamino)-carbonyl]amino] Streptozotocin	1*	4	U206	X	1 (0.454)
D-Glucose, 2-deoxy-2-[[(methylnitrosoamino)-carbonyl]amino]-	18883664	Glucopyranose, 2-deoxy-2-(3-methyl-3-nitrosoureido)-	1*	4	U206	X	1 (0.45)
Glycidylaldehyde	765344	Oxiranecarboxyaldehyde	1*	4	U126	A	10 (4.54)
Guanidien, N-methyl-N'-nitro-N-nitroso-	70257	MNNG	1*	4	U163	A	10 (4.54)
Guthion	865500		1	1		X	1 (0.454)
HALOETHERS	N/A		1*	2			**
HALOMETHANES	N/A		1*	2			**
Heptachlor	76448	4,7-Methano-1H-indene, 1,4,5,6,7,8,8-heptachloro-3a,4,7,7a-tetrahydro-	1	1,2,4	P059	X	1 (0.454)
HEPTACHLOR AND METABOLITES	N/A		1*	2			**
Heptachlor epoxide	1024573		1*	2		X	1 (0.454)
Hexachlorobenzene	118741	Benzene, hexachloro-	1*	2,4	U127	A	10 (4.54)
Hexachlorobutadiene	87683	1,3-Butadiene, 1,1,2,3,4,5-hexachloro-	1*	2,4	U128	X	1 (0.454)
HEXACHLOROCYCLOHEXANE (all isomers)	608731		1*	2			**

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R0043607

Hazardous Substance	CASRN	Regulatory Synonyms	Statutory			Final RQ	
			RQ	Code†	RCRA Waste #	Category	Pounds (Kg)
Hexachlorocyclohexane (gamma isomer)	58899	Cyclohexane, 1,2,3,4,5,6-hexachloro-,(1alpha,2alpha,3beta,4alpha,5alpha,6beta)-gamma-BHC Lindane	1	1,2,4	U129	X	1 (0.454)
Hexachlorocyclopentadiene	77474	1,3-Cyclopentadiene,1,2,3,4,5,5-hexachloro-	1	1,2,4	U130	A	10 (4.54)
Hexachloroethane	67721	Ethane, hexachloro-	1*	2,4	U131	B	100 (45.4)
Hexachlorophene	70304	Phenol, 2,2'-methylenebis[3,4,6-trichloro-	1*	4	U132	B	100 (45.4)
Hexachloropropene	1888717	1-Propene, 1,1,2,3,3,3-hexachloro-	1*	4	U243	C	1000 (454)
Hexaethyl tetraphosphate	757584	Tetraphosphoric acid, hexaethyl ester	1*	4	P062	B	100 (45.4)
Hydrazine	302012		1*	4	U133	X	1 (0.454)
Hydrazine, 1,2-diethyl-	1615801	N,N'-Diethylhydrazine	1*	4	U086	A	10 (4.54)
Hydrazine, 1,1-dimethyl-	57147	1,1-Dimethylhydrazine	1*	4	U098	A	10 (4.54)
Hydrazine, 1,2-dimethyl-	540738	1,2-Dimethylhydrazine	1*	4	U099	X	1 (0.454)
Hydrazine, 1,2-diphenyl-	122667	1,2-Diphenylhydrazine	1*	2,4	U109	A	10 (4.54)
Hydrazine, methyl-	60344	Methyl hydrazine	1*	4	P068	A	10 (4.54)
Hydrazinecarbothioamide	79196	Thiosemicarbazide	1*	4	P116	B	100 (45.4)
Hydrochloric acid	7647010	Hydrogen chloride	5000	1		D	5000 (2270)
Hydrocyanic acid	74908	Hydrogen cyanide	10	1,4	P063	A	10 (4.54)
Hydrofluoric acid	7664393	Hydrogen flouride	5000	1,4	U134	B	100 (45.4)
Hydrogen chloride	7647010	Hydrochloric acid	5000	1		D	5000 (2270)
Hydrogen cyanide	74908	Hydrocyanic acid	10	1,4	P063	A	10 (4.54)
Hydrogen fluoride	7664393	Hydrofluoric acid	5000	1,4	U134	B	100 (45.4)
Hydrogen sulfide	7783064	Hydrogen sulfide H2S	100	1,4	U135	B	100 (45.4)
Hydrogen sulfide H2S	7783064	Hydrogen sulfide	100	1,4	U135	B	100 (45.4)
Hydroperoxide, 1-methyl-1-phenylethyl-	80159	alpha,alpha-Dimethylbenzylhydroperoxide	1*	4	U096	A	10 (4.54)
2-Imidazolidinethione	96457	Ethylenethiourea	1*	4	U116	A	10 (4.54)
Indeno(1,2,3-cd)pyrene	193395	1,10-(1,2-Phenylene)pyrene	1*	2,4	U137	B	100 (45.4)
1,3-Isobenzofurandione	85449	Phthalic anhydride	1*	4	U190	D	5000 (2270)
Isobutyl alcohol	78831	1-Propanol, 2-methyl-	1*	4	U140	D	5000 (2270)

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1 0302

Hazardous Substance	CASRN	Regulatory Synonyms	Statutory			Final RQ	
			RQ	Code†	RCRA Waste #	Category	Pounds (Kg)
Isodrin	465736	1,4,5,8-Dimethanonaphthalene, 1,2,3,4,10,10-hexachloro-1,4,4a,5,8,8a-hexahydro,(1alpha,4alpha,4abeta,5beta,8beta,8abeta)-	1*	4	P060	X	1 (0.454)
Isophorone	78591		1*	2		D	5000 (2270)
Isoprene	78795		1000	1		B	100 (45.4)
Isopropanolamine dodecylbenzenesulfonate	42504461		1000	1		C	1000 (454)
Isosafrole	120581	1,3-Benzodioxole,5-)1-propenly)-	1*	4	U141	B	100 (45.4)
3(2H)-Isoxazolone, 5-(aminomethyl)-	2763964	Muscimol 5-(Aminomethyl)-3-isoxazolol	1*	4	P007	C	1000 (454)
Kepone	143500	1,2,4-Metheno-2H-cyclobuta[cd] pentalen-2-one,1,1a,3,3a,4,5,5,5a,5b,6-decachlorooctahydro-	1	1,4	U142	X	1 (0.454)
Lasiocarpine	303344	2-Butenoic acid, 2-methyl-, 7[[2,3-dihydroxy-2-(1-methoxyethyl)-3-methyl-1-oxobutoxy]methyl]-2,3,5,7a-tetrahydro-1H-pyrrolizin-1-yl ester, [1S-[1alpha(Z), 7(2S*,3R*),7aalpha]]-	1*	4	U143	A	10 (4.54)
Lead††	7439921		1*	2	U143	A	10 (4.54)
Lead acetate	301042	Acetic acid, lead(2+) salt	5000	1,4	U144		#
LEAD AND COMPOUNDS	N/A		1*	2			**
Lead arsenate	7784409		5000	1		X	1 (0.454)
	7645252		5000	1		X	1 (0.454)
	10102484		5000	1		X	1 (0.454)
Lead, bis(acetato-O)tetrahydroxytri	1335326	Lead subacetate	1*	4	U146	B	100 (45.4)
Lead chloride	7758954		5000	1		B	100 (45.4)
Lead fluoborate	13814965		5000	1		B	100 (45.4)
Lead fluoride	7783462		1000	1		B	100 (45.4)
Lead iodide	10101630		5000	1		B	100 (45.4)
Lead nitrate	10099748		5000	1		B	100 (45.4)
Lead phosphate	7446277	Phosphoric acid, lead(2+) salt (2:3)	1*	4	U145		#
Lead stearate	7428480		5000	1		D	# 5000 (2270)
	1072351		5000	1		D	# 5000 (2270)

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R0043609

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10304

Hazardous Substance	CASRN	Regulatory Synonyms	Statutory			Final RQ	
			RQ	Code†	RCRA Waste #	Category	Pounds (Kg)
	52652592		5000	1		D	# 5000 (2270)
	56189094		5000	1		D	# 5000 (2270)
Lead subacetate	1335326	Lead, bis(acetato-O)tetrahydroxytri	1*	4	U146	B	100 (45.4)
Lead sulfate	15739807		5000	1		B	100 (45.4)
	7446142		5000	1		B	100 (45.4)
			5000	1		B	100 (45.4)
Lead sulfide	1314870		5000	1		D	# 5000 (2270)
Lead thiocyanate	592870		5000	1		B	100 (45.4)
Lindane	58899	Cyclohexane, 1,2,3,4,5,6-hexachloro-,(1alpha,2alpha,3beta,4alpha,5alpha,6beta)-gamma-BHC Hexachlorocyclohexane (gamma isomer)	1	1,2,4	U129	X	1 (0.454)
Lithium Chromate	14307358		1000	1		A	10 (4.54)
Malathion	121755		10	1		B	100 (45.4)
Maleic acid	110167		5000	1		D	5000 (2270)
Maleic anhydride	108316	2,5-Furandione	5000	1,4	U147	D	5000 (2270)
Maleic hydrazide	123331	3,6-Pyridazinedione, 1,2-dihydro-	1*	4	U148	D	5000 (2270)
Malononitrile	109773	Propanedinitrile	1*	4	U149	C	1000 (454)
Melphalan	148823	L-Phenylalanine, 4-[bis(2-chloroethyl)amino]	1*	4	U150	X	1 (0.454)
Mercaptodimethur	2032657		100	1		A	10 (4.54)
Mercuric cyanide	592041		1	1		X	1 (0.454)
Mercuric nitrate	10045940		10	1		A	10 (4.54)
Mercuric sulfate	7783359		10	1		A	10 (4.54)
Mercuric thiocyanate	592858		10	1		A	10 (4.54)
Mercurous nitrate	10415755		10	1		A	10 (4.54)
	7782867		10	1		A	10 (4.54)
Mercury	7439976		1*	2,3,4	U151	X	1 (0.454)
MERCURY AND COMPOUNDS	N/A		1*	2		-	**
Mercury, (acetato-O)phenyl	62384	Phenylmercury acetate	1*	4	P092	B	100 (45.4)
Mercury fulminate	628864	Fulminic acid, mercury(2+)salt	1*	4	P065	A	10 (4.54)

Hazardous Substance	CASRN	Regulatory Synonyms	Statutory			Final RQ	
			RQ	Code†	RCRA Waste #	Category	Pounds (Kg)
Methacrylonitrile	126987	2-Propenenitrile, 2-methyl-	1*	4	U152	C	1000 (454)
Methanamine, N-methyl-	124403	Dimethylamine	1000	1,4	U092	C	1000 (454)
Methanamine, N-methyl-N-nitroso-	62759	N-Nitrosodimethylamine	1*	2,4	P082	A	10 (4.54)
Methane, bromo-	74839	Methyl bromide	1*	2,4	U029	C	1000 (454)
Methane, chloro-	74873	Methyl chloride	1*	2,4	U045	B	100 (45.4)
Methane, chloromethoxy-	107302	Chloromethyl methyl ether	1*	4	U046	A	10 (4.54)
Methane, dibromo-	74953	Methylene bromide	1*	4	U068	C	1000 (454)
Methane, dichloro-	75092	Methylene chloride	1*	2,4	U080	C	1000 (454)
Methane, dichlorodifluoro-	75718	Dichlorodifluoromethane	1*	4	U075	D	5000 (2270)
Methane, iodo-	74884	Methyl iodide	1*	4	U138	B	100 (45.4)
Methane, isocyanato-	624839	Methyl isocyanate	1*	4	P064		##
Methane, oxybis(chloro-	542881	Dichloromethyl ether	1*	4	P016	A	10 (4.54)
Methanesulfenyl chloride, trichloro-	594423	Trichloromethanesulfenyl chloride	1*	4	P118	B	100 (45.4)
Methanesulfonic acid, ethyl ester	62500	Ethyl methanesulfonate	1*	4	U119	X	1 (0.454)
Methane, tetrachloro-	56235	Carbon tetrachloride	5000	1,2,4	U211	A	10 (4.54)
Methane, tetranitro-	509148	Tetranitromethane	1*	4	P112	A	10 (4.54)
Methane, tribromo-	75252	Bromoform	1*	2,4	U225	B	100 (45.4)
Methane, trichloro-	67663	Chloroform	5000	1,2,4	U044	A	10 (4.54)
Methane, trichlorofluoro	75694	Trichloromonofluoromethane	1*	4	U121	D	5000 (2270)
Methanethiol	74931	Methylmercaptan Thiomethanol	100	1,4	U153	B	100 (45.4)
6,9-Methano-2,4,3-benzodioxathiepin, 6,7,8,9,10,10-hexachloro-1,5,5a,6,9,9a-hexahydro-, 3-oxide	115297	Endosulfan	1	1,2,4	P050	X	1 (0.454)
1,3,4-Metheno-2H-cyclobuta[cd] pentalen-2-one, 1,1a,3,3a,4,5,5,5a,5b,6-decachlorooctahydro-	143500	Kepone	1	1,4	U142	X	1 (0.454)
4,7-Methano-1H-indene, 1,4,5,6,7,8,8-heptachloro-3a,4,7,7a-tetrahydro-	76448	Heptachlor	1	1,2,4	P059	X	1 (0.454)
4,7-Methano-1H-indene, 1,2,3,4,5,6,8,8-octachloro-2,3,3a,4,5,6a-hexahydro-	57749	Chlordane Chlordane, alpha & gamma isomers Chlordane, technical	1	1,2,4	U036	X	1 (0.454)
Methanol	67561	Methyl alcohol	1*	4	U154	D	5000 (2270)

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1 0305

R0043611

Hazardous Substance	CASRN	Regulatory Synonyms	Statutory RQ	Statutory Code†	Statutory RCRA Waste #	Final RQ Category	Final RQ Pounds (Kg)
Methapyrilene	91805	1,2-Ethanediamine, N,N-dimethyl-N'-2-pyridinyl-N'-(2-thienylmethyl)-	1*	4	U155	D	5000 (2270)
Methomyl	16752775	Ethanimidothioic acid, N-[[(methylamino)carbonyl]oxy]-, methyl ester	1*	4	P066	B	100 (45.4)
Methoxychlor	72435	Benzene, 1,1'-(2,2,2-trichloroethylidene)bis[4-methoxy-	1	1,4	U247	X	1 (0.454)
Methyl alchohol	67561	Methanol	1*	4	U154	D	5000 (2270)
Methyl bromide	74839	Methane, bromo-	1*	2,4	U029	C	1000 (454)
1-Methylbutadiene	504609	1,3-Pentadiene	1*	4	U186	B	100 (45.4)
Methyl chloride	74873	Methane, chloro-	1*	2,4	U045	B	100 (45.4)
Methyl chlorocarbonate	79221	Carbonochloridic acid, methyl ester Methyl chloroformate	1*	4	U156	C	1000 (454)
Methyl chloroform	71556	Ethane, 1,1,1-trichloro- 1,1,1-Trichloroethane	1*	2,4	U226	C	1000 (454)
Methyl chloroformate	79221	Carbonochloridic acid, methyl ester Methyl chlorocarbonate	1*	4	U156	C	[illegible]00 (454)
3-Methylcholanthrene	56495	Benz[j]aceanthrylene, 1,2-dihydro-3-methyl-	1*	4	U157	A	10 (4.54)
4,4'-Methylenebis(2-chloroaniline)	101144	Benzenamine, 4,4'-methylenebis(2-chloro-	1*	4	[illegible]158	A	10 (4.54)
Methylene bromide	74953	Methane, dibromo-	1*	4	U068	C	1000 (454)
Methylene chloride	75092	Methane, dichloro-	1*	2,4	U080	C	1000 (454)
Methyl ethyl ketone (MEK)	78933	2-Butanone	1*	4	U159	D	5000 (2270)
Methyl ethyl ketone peroxide	1338234	2-Butanone peroxide	1*	4	U160	A	10 (4.54)
Methyl hydrazine	60344	Hydrazine, methyl-	1*	4	P068	A	10 (4.54)
Methyl iodide	74884	Methane, iodo-	1*	4	U138	B	100 (45.4)
Methly isobutyl ketone	108101	4-Methyl-2-pentanone	1*	4	U161	D	5000 (2270)
Methyl isocyanate	624839	Methane, isocyanato-	1*	4	P064		##
2-Methyllactonitrile	75865	Acetone cyanohydrin Propanenitrile, 2-hydroxy-2-methyl-	10	1,4	P069	A	10 (4.54)
Methylmercaptan	74931	Methanethiol Thiomethanol	100	1,4	U153	B	100 (45.4)
Methyl methacrylate	80626	2-Propenoic acid, 2-methyl, methyl ester	5000	1,4	U162	C	1000 (454)
Methyl parathion	298000	Phosphorotioic acid,),)-dimethyl O-(4-nitro-phenyl) ester	100	1,4	P071	B	100 (45.4)
4-Methyl-2-pentanone	108101	Methyl isobutyl ketone	1*	4	U161	D	5000 (2270)

Hazardous Substance	CASRN	Regulatory Synonyms	Statutory RQ	Statutory Code†	Statutory RCRA Waste #	Final RQ Category	Final RQ Pounds (Kg)
Methylthiouracil	56042	4(1H)-Pyrimidinone, 2,3-dihydro-6-methyl-2-thioxo-	1*	4	U164	A	10 (4.54)
Mevinphos	7786347		1	1		A	10 (4.54)
Mexacarbate	315184		1000	1		C	1000 (454)
Mitomycin C	50077	Azirino[2',3':3,4]pyrrolo[1,2-a]indole-4,7-dione,6-amino-8-[[(aminocarbonyl)oxy]methyl]-1,1a,2,8,8a,8b-hexahydro-8a-methoxy-5-methyl, [1aS-(1aalpha, 8beta,8aalpha, 8balpha)]-	1*	4	U010	A	10 (4.54)
MNNG	70257	Guanidine, N-methyl-N'-nitro-N-nitroso-	1*	4	U163	A	10 (4.54)
Monoethylamine	75047		1000	1		B	100 (45.4)
Monomethylamine	74895		1000	1		B	100 (45.4)
Multi Source Leachate			1*	4	F039	X	1 (0.454)
Muscimol	2763964	3(2H)-Isoxazolone, 5-(aminomethyl)- 5-(Amino-methyl)-3-isoxazolol	1*	4	P007	C	1000 (454)
Naled	300765		10	1		A	10 (4.54)
5,12-Naphthacenedione, 8-acetyl-10-[3-amino-2,3,6-trideoxy-alpha-L-lyxo-hexopyranosyl)oxy]-7,8,9,10-tetrahydro-6,8,11-trihydroxy-1-methoxy, (8S-cis)-	20830813	Daunomycin	1*	4	U059	A	10 (4.54)
1-Naphthalenamine	134327	alpha-Naphthylamine	1*	4	U167	B	100 (45.4)
2-Naphthalenamine	91598	beta-Naphthylamine	1*	4	U168	A	10 (4.54)
Naphthalenamine,N,N'-bis(2-chloroethyl)-	494031	Chlornaphazine	1*	4	U026	B	100 (45.4)
Naphthalene	91203		5000	1,2,4	U165	B	100 (45.4)
Naphthalene, 2-chloro-	91587	beta-Chloronaphthalene 2-Chloronaphthalene	1*	2,4	U047	D	5000 (2270)
1,4-Naphthalenedione	130154	1,4-Naphthoquinone	1*	4	U166	D	5000 (2270)
2,7-Naphthalenedisulfonic acid, 3,3'-[(3,3'-dimethyl-(1,1'-byphenyl)-4,4'-diyl)-bis(azo)]bis(5-amino-4-hydroxy)tetrasodium salt	72571	Trypan blue	1*	4	U236	A	10 (4.54)
Naphthenic acid	1338245		100	1		B	100 (45.4)
1,4-Naphthoquinone	130154	1,4-Naphthalenedione	1*	4	U166	D	5000 (2270)
alpha-Naphthylamine	134327	1,-Naphthalenamine	1*	4	U167	B	100 (45.4)
beta-Naphthylamine	91598	2,-Naphthalenamine	1*	4	U168	A	10 (4.54)

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Hazardous Substance	CASRN	Regulatory Synonyms	Statutory			Final RQ	
			RQ	Code†	RCRA Waste #	Category	Pounds (Kg)
alpha-Naphthylthiourea	86884	Thiourea, 1-naphthalenyl-	1*	4	P072	B	100 (45.4)
Nickel††	7440020		1*	2		B	100 (45.4)
Nickel ammonium sulfate	15699180		5000	1		B	100 (45.4)
NICKEL AND COMPOUNDS	N/A		1*	2			
Nickel carbonyl	13463393	Nickel carbonyl Ni(CO)4, (T-4)-	1*	4	P073	A	10 (4.54)
Nickel carbonyl Ni(CO)4, (T-4)-	13463393	Nickel carbonyl	1*	4	P073	A	10 (4.54)
Nickel chloride	7718549		5000	1		B	100 (45.4)
	37211055		5000	1		B	100 (45.4)
Nickel cyanide	557197	Nickel cyanide Ni(CN)2	1*	4	P074	A	10 (4.54)
Nickel cyanide Ni(CN)2	557197	Nickel cyanide	1*	4	P074	A	10 (4.54)
Nickel hydroxide	12054487		1000	1		A	10 (4.54)
Nickel nitrate	14216752		5000	1		B	100 (45.4)
Nickel sulfate	7786814		5000	1		B	100 (45.4)
Nicotine, & salts	54115	Pyridine, 3-(1-methyl-2-pyrrolidinyl)-, (S)-	1*	4	P075	B	100 (45.4)
Nitric acid	7697372		1000	1		C	1000 (454)
Nitric acid, thallium (1+) salt	10102451	Thallium (I) nitrate	1*	4	U217	B	100 (45.4)
Nitric oxide	10102439	Nitrogen oxide NO	1*	4	P076	A	10 (4.54)
p-Nitroaniline	100016	Benzenamine, 4-nitro-	1*	4	P077	D	5000 (2270)
Nitrobenzene	98953	Benzene, nitro-	1000	1,2,4	U169	C	1000 (454)
Nitrogen dioxide	10102440	Nitrogen oxide NO2	1000	1,4	P078	A	10 (4.54)
	10544726		1000	1,4	P078	A	10 (4.54)
Nitrogen oxide NO	10102439	Nitric oxide	1*	4	P076	A	10 (4.54)
Nitrogen oxide NO2	10102440	Nitrogen dioxide	1000	1,4	P078	A	10 (4.54)
	10544726						
Nitroglycerine	55630	1,2,3-Propanetriol, trinitrate-	1*	4	P081	A	10 (4.54)
Nitrophenol (mixed)	25154556		1000	1		B	100 (45.4)
m-Nitrophenol	554847					B	100 (45.4)
o-Nitrophenol	88755	2-Nitrophenol					
p-Nitrophenol	100027	Phenol, 4-nitro- 4-Nitrophenol					
o-Nitrophenol	88755	2-Nitrophenol	1000	1,2		B	100 (45.4)
p-Nitrophenol	100027	Phenol, 4-nitro- 4-Nitrophenol	1000	1,2,4	U170	B	100 (45.4)

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Hazardous Substance	CASRN	Regulatory Synonyms	Statutory RQ	Statutory Code†	Statutory RCRA Waste #	Final RQ Category	Final RQ Pounds (Kg)
2-Nitrophenol	88755	o-Nitrophenol	1000	1,2		B	100 (45.4)
4-Nitrophenol	100027	p-Nitrophenol Phenol, 4-nitro-	1000	1,2,4	U170	B	100 (45.4)
NITROPHENOLS	N/A		1*	2			**
2-Nitropropane	79469	Propane, 2-nitro-	1*	4	U171	A	10 (4.54)
NITROSAMINES	N/A		1*	2			**
N-Nitrosodi-n-butylamine	924163	1-Butanamine, N-butyl-N-nitroso-	1*	4	U172	A	10 (4.54)
N-Nitrosodiethanolamine	1116547	Ethanol, 2,2'-(nitrosoimino)bis-	1*	4	U173	X	1 (0.454)
N-Nitrosodiethylamine	55185	Ethanamine, N-ethyl-N-nitroso-	1*	4	U174	X	1 (0.454)
N-Nitrosodimethylamine	62759	Methanamine, N-methyl-N-nitroso-	1*	2,4	P082	A	10 (4.54)
N-Nitrosodiphenylamine	86306		1*	2		B	100 (45.4)
N-Nitroso-N-ethylurea	759739	Urea, N-ethyl-N-nitroso-	1*	4	U176	X	1 (0.454)
N-Nitroso-N-methylurea	684935	Urea, N-methyl-N-nitroso	1*	4	U177	X	1 (0.454)
N-Nitroso-N-methylurethane	615532	Carbamic acid, methylnitroso-, ethyl ester	1*	4	U178	X	1 (0.454)
N-Nitrosomethylvinylamine	4549400	Vinylamine, N-methyl-N-nitroso-	1*	4	P084	A	10 (4.54)
N-Nitrosopiperidine	100754	Piperidine, 1-nitroso-	1*	4	U179	A	10 (4.54)
N-Nitrosopyrrolidine	930552	Pyrrolidine, 1-nitroso-	1*	4	U180	X	1 (0.454)
Nitrotoluene	1321126		1000	1		C	1000 (454)
m-Nitrotoluene	99081						
o-Nitrotoluene	88722						
p-Nitrotoluene	99990						
5-Nitro-o-toluidine	99558	Benzenamine, 2-methyl-5-nitro-	1*	4	U181	B	100 (45.4)
Octamethylpyrophosphoramide	152169	Diphosphoramide, octamethyl-	1*	4	P085	B	100 (45.4)
Osmium oxide OsO4 (T-4)-	20816120	Osmium tetroxide	1*	4	P087	C	1000 (454)
Osmium tetroxide	20816120	Osmium oxide OsO4 (T-4)-	1*	4	P087	C	1000 (454)
7-Oxabicyclo[2.2.1]heptane-2,3-dicarboxylic acid	145733	Endothall	1*	4	P088	C	1000 (454)
1,2-Oxathiolane, 2,2-dioxide	1120714	1,3-Propane sultone	1*	4	U193	A	10 (4.54)
2H-1,3,2-Oxazaphosphorin-2-amine, N,N-bis(2-chloroethyl) tetrahydro-, 2-oxide	50180	Cyclophosphamide	1*	4	U058	A	10 (4.54)
Oxirane	75218	Ethylene oxide	1*	4	U115	A	10 (4.54)
Oxiranecarboxyaldehyde	765344	Glycidylaldehyde	1*	4	U126	A	10 (4.54)

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Hazardous Substance	CASRN	Regulatory Synonyms	Statutory			Final RQ	
			RQ	Code†	RCRA Waste #	Category	Pounds (Kg)
Oxirene, (chloromethyl)-	106898	Epichlorohydrin	1000	1,4	U041	B	100 (45.4)
Paraformaldehyde	30525894		1000	1		C	1000 (454)
Paraldehyde	123637	1,3,5-Trioxane, 2,4,6-trimethyl-	1*	4	U182	C	1000 (454)
Parathion	56382	Phosphorothioic acid, O,O-diethyl O-(4-nitrophenyl) ester	1	1,4	P089	A	10 (4.54)
Pentachlorobenzene	608935	Benzene, pentachloro-	1*	4	U183	A	10 (4.54)
Pentachloroethane	76017	Ethane, pentachloro-	1*	4	U184	A	10 (4.54)
Pentachloronitrobenzene (PCNB)	82688	Benzene, pentachloronitro-	1*	4	U185	B	100 (45.4)
Pentachlorophenol	87865	Phenol, pentachloro-	10	1,2,4	U242	A	10 (4.54)
1,3-Pentadiene	504609	1-Methylbutadiene	1*	4	U186	B	100 (45.4)
Perchloroethylene	127184	Ethene, tetrachloro- Tetrachloroethene Tetrachlor-oethylene	1*	2,4	U210	B	100 (45.4)
Phenacetin	62442	Acetamide, N-(4-ethoxyphenyl)-	1*	4	U187	B	100 (45.4)
Phenanthrene	85018		1*	2		D	5000 (2270)
Phenol	108952	Benzene, hydroxy-	1000	1,2,4	U188	C	1000 (454)
Phenol, 2-chloro-	95578	o-Chlorophenol 2-Chlorophenol	1*	2,4	U048	B	100 (45.4)
Phenol, 4-chloro-3-methyl-	59507	p-Chloro-m-cresol 4-Chloro-m-cresol	1*	2,4	U039	D	5000 (2270)
Phenol, 2-cyclohexyl-4,6-dinitro-	131895	2-Cyclohexyl-4,6-dinitrophenol	1*	4	P034	B	100 (45.4)
Phenol, 2,4-dichloro-	120832	2,4-Dichlorophenol	1*	2,4	U081	B	100 (45.4)
Phenol, 2,6-dichloro	87650	2,6-Dichlorophenol	1*	4	U082	B	100 (45.4)
Phenol, 4,4'-(1,2-diethyl-1,2-ethenediyl)bis-, (E)	56531	Diethylstilbestrol	1*	4	U089	X	1 (0.454)
Phenol, 2,4-dimethyl-	105679	2,4-Dimethylphenol	1*	2,4	U101	B	100 (45.4)
Phenol, 2,4-dinitro-	51285	2,4-Dinitrophenol	1000	1,2,4	P048	A	10 (4.54)
Phenol, methyl-	1319773	Cresol(s) Cresylic acid	1000	1,4	U052	C	1000 (454)
m-Cresol	108394	m-Cresylic acid	1000	1,4	U052	C	1000 (454)
o-Cresol	95487	o-Cresylic acid	1000	1,4	U052	C	1000 (454)
p-Cresol	106445	p-Cresylic acid	1000	1,4	U052	C	1000 (454)
Phenol, 2-methyl-4,6-dinitro-	534521	4,6-Dinitro-o-cresol and salts	1*	2,4	P047	A	10 (4.54)
Phenol, 2,2'-methylenebis[3,4,6-trichloro-	70304	Hexachlorophene	1*	4	U132	B	100 (45.4)
Phenol, 2-(1-methylpropyl)-4,6-dinitro	88857	Dinoseb	1*	4	P020	C	1000 (454)

Hazardous Substance	CASRN	Regulatory Synonyms	Statutory RQ	Statutory Code†	Statutory RCRA Waste #	Final RQ Category	Final RQ Pounds (Kg)
Phenol, 4-nitro-	100027	p-Nitrophenol 4-Nitrophenol	1000	1,2,4	U170	B	100 (45.4)
Phenol, pentachloro-	87865	Pentachlorophenol	10	1,2,4	U242	A	10 (4.54)
Phenol, 2,3,4,6-tetrachloro-	58902	2,3,4,6-Tetrachlorophenol	1*	4	U212	A	10 (4.54)
Phenol, 2,4,5-trichloro-	95954	2,4,5-Trichlorophenol	10	1,4	U230	A	10 (4.54)
Phenol, 2,4,6-trichloro-	88062	2,4,6-Trichlorophenol	10	1,2,4	U231	A	10 (4.54)
Phenol, 2,4,6-trinitro-, ammonium salt	131748	Ammonium picrate	1*	4	P009	A	10 (4.54)
L-Phenylalanine, 4-[bis(2-chloroethyl) amino]-	148823	Melphalan	1*	4	U150	X	1 (0.454)
1,10-(1,2-Phenylene)pyrene	193395	Indeno(1,2,3-cd)pyrene	1*	2,4	U137	B	100 (45.4)
Phenylmercury acetate	62384	Mercury, (acetato-O)phenyl-	1*	4	P092	B	100 (45.4)
Phenylthiourea	103855	Thiourea, phenyl-	1*	4	P093	B	100 (45.4)
Phorate	298022	Phosphorodithioic acid, O,O-diethyl S-(ethylthio), methyl ester	1*	4	P094	A	10 (4.54)
Phosgene	75445	Carbonic dichloride	5000	1,4	P095	A	10 (4.54)
Phosphine	7803512		1*	4	P096	B	100 (45.4)
Phosphoric acid	7664382		5000	1		D	5000 (2270)
Phosphoric acid, diethyl 4-nitrophenyl ester	311455	Diethyl-p-nitrophenyl phosphate	1*	4	P041	B	100 (45.4)
Phosphoric acid, lead(2+) salt (2:3)	7446277	Lead phosphate	1*	4	U145		#
Phosphorodithioic acid, O,O-diethyl S-[2-(ethylthio)ethyl]ester	298044	Disulfoton	1	1,4	P039	X	1 (0.454)
Phosphorodithioic acid, O,O-diethyl S-(ethylthio), methyl ester	298022	Phorate	1*	4	P094	A	10 (4.54)
Phosphorodithioic acid, O,O-diethyl S-methyl ester	3288582	O,O-Diethyl S-methyl dithiophosphate	1*	4	U087	D	5000 (2270)
Phosphorodithioic acid, O,O-dimethyl S-[2(methylamino)-2-oxoethyl] ester	60515	Dimethoate	1*	4	P044	A	10 (4.54)
Phosphorofluoridic acid, bis(1-methylethyl) ester	55914	Diisopropylfluorophosphate	1*	4	P043	B	100 (45.4)
Phosphorothioic acid, O,O-diethyl O-(4-nitrophenyl) ester	56382	Parathion	1	1,4	P089	A	10 (4.54)
Phosphorothioic acid, O,[4-[(dimethylamino)sulfonyl] phenyl]O,O-dimethyl ester	52857	Famphur	1*	4	P097	C	1000 (454)

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Hazardous Substance	CASRN	Regulatory Synonyms	Statutory			Final RQ	
			RQ	Code†	RCRA Waste #	Category	Pounds (Kg)
Phosphorothioic acid, O,O-dimethyl O-(4-nitrophenyl) ester	298000	Methyl parathion	100	1,4	P071	B	100 (45.4)
Phosphorothioic acid, O,O-diethyl O-pyrazinyl ester	297972	O,O-Diethyl O-pyrazinyl phosphorothioate	1*	4	P040	B	100 (45.4)
Phosphorus	7723140		1	1		X	1 (0.454)
Phosphorus oxycloride	10025873		5000	1		C	1000 (454)
Phosphorus pentasulfide	1314803	Phosphorus sulfide Sulfur phosphide	100	1,4	U189	B	100 (45.4)
Phosphorus sulfide	1314803	Phosphorus pentasulfide Sulfur phosphide	100	1,4	U189	B	100 (45.4)
Phosophorus trichloride	7719122		5000	1		C	1000 (454)
PHTHALATE ESTERS	N/A		1*	2			**
Phthalic anhydride	85449	1,3-Isobenzofurandione	1*	4	U190	D	5000 (2270)
2-Picoline	109068	Pyridine, 2-methyl-	1*	4	U191	D	5000 (2270)
Piperidine, 1-nitroso-	100754	N-Nitrosopiperidine	1*	4	U179	A	10 (4.54)
Plumbane, tetraethyl-	78002	Tetraethyl lead	100	1,4	P110	A	10 (4.54)
POLYCHLORINATED BIPHENYLS (PCBs)	1336363		10	1,2		X	1 (0.454)
Aroclor 1016	12674112	POLYCHLORINATED BIPHENYLS (PCBs)					
Aroclor 1221	11104282	POLYCHLORINATED BIPHENYLS (PCBs)					
Aroclor 1232	11141165	POLYCHLORINATED BIPHENYLS (PCBs)					
Aroclor 1242	53469219	POLYCHLORINATED BIPHENYLS (PCBs)					
Aroclor 1248	12672296	POLYCHLORINATED BIPHENYLS (PCBs)					
Aroclor 1254	11097691	POLYCHLORINATED BIPHENYLS (PCBs)					
Aroclor 1260	11096825	POLYCHLORINATED BIPHENYLS (PCBs)					
POLYNUCLEAR AROMATIC HYDROCARBONS	N/A		1*	2			**
Potassium arsenate	7784410		1000	1		X	1 (0.454)
Potassium arsenite	10124502		1000	1		X	1 (0.454)
Potassium bichromate	7778509		1000	1		A	10 (4.54)
otassium chromate	7789006		1000	1		A	10 (4.54)

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Hazardous Substance	CASRN	Regulatory Synonyms	Statutory			Final RQ	
			RQ	Code†	RCRA Waste #	Category	Pounds (Kg)
Potassium cyanide	151508	Potassium cyanide K (CN)	10	1,4	P098	A	10 (4.54)
Potassium cyanide K(CN)	151508	Potassium cyanide	10	1,4	P098	A	10 (4.54)
Potassium hydroxide	1310583		1000	1		C	1000 (454)
Potassium permanganate	7722647		100	1		B	100 (45.4)
Potassium silver cyanide	506616	Argentate (1-), bis(cyano-C)-, potassium	1*	4	P099	X	1 (0.454)
Pronamide	23950585	Benzamide, 3,5-dichloro-N-(1,1-dimethyl-2-propynyl)-	1*	4	U192	D	5000 (2270)
Propanal, 2-methyl-2-(methylthio)-, O-[(methylamino)carbonyl]oxime	116063	Aldicarb	1*	4	P070	X	1 (0.454)
1-Propanamine	107108	n-Propylamine	1*	4	U194	D	5000 (2270)
1-Propanamine, N-propyl-	142847	Dipropylamine	1*	4	U110	D	5000 (2270)
1-Propanamine, N-nitroso-N-propyl-	621647	Di-n-propylnitrosamine	1*	2,4	U111	A	10 (4.54)
Propane, 1,2-dibromo-3-chloro-	96128	1,2-Dibromo-3-chloropropane	1*	4	U066	X	1 (0.454)
Propane, 2-nitro-	79469	2-Nitropropane	1*	4	U171	A	10 (4.54)
1,3-Propane sultone	1120714	1,2-Oxathiolane, 2,2-dioxide	1*	4	U193	A	10 (4.54)
Propane, 1,2-dichloro-	78875	Propylene dichloride 1,2-Dichloropropane	5000	1,2,4	U083	C	1000 (454)
Propanedinitrile	109773	Malononitrile	1*	4	U149	C	1000 (454)
Propanenitrile	107120	Ethyl cynide	1*	4	P101	A	10 (4.54)
Propanenitrile, 3-chloro-	542767	3-Chloropropionitrile	1*	4	P027	C	1000 (454)
Propanenitrile, 2-hydroxy-2-methyl-	75865	Acetone cyanohydrin 2-Methyllactonitrile	10	1,4	P069	A	10 (4.54)
Propane, 2,2'-oxybis[2-chloro-	108601	Dichloroisopropyl ether	1*	2,4	U027	C	1000 (454)
1,2,3-Propanetriol, trinitrate-	55630	Nitroglycerine	1*	4	P081	A	10 (4.54)
1-Propanol, 2,3-dibromo-, phosphate (3:1)	126727	Tris(2,3-dibromopropyl) phosphate	1*	4	U235	A	10 (4.54)
1-Propanol, 2-methyl-	78831	Isobutyl alcohol	1*	4	U140	D	5000 (2270)
2-Propanone	67641	Acetone	1*	4	U002	D	5000 (2270)
2-Propanone, 1-bromo-	598312	Bromoacetone	1*	4	P017	C	1000 (454)
Propargite	2312358		10	1		A	10 (4.54)
Propargyl alcohol	107197	2-Propyn-1-ol	1*	4	P102	C	1000 (454)
2-Propenal	107028	Acrolein	1	1,2,4	P003	X	1 (0.454)
2-Propenamide	79061	Acrylamide	1*	4	U007	D	5000 (2270)

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Hazardous Substance	CASRN	Regulatory Synonyms	Statutory			Final RQ	
			RQ	Code†	RCRA Waste #	Category	Pounds (Kg)
1-Propene, 1,1,2,3,3,3-hexachloro-	1888717	Hexachloropropene	1*	4	U243	C	1000 (454)
1-Propene, 1,3-dichloro-	542756	1,3-Dichloropropene	5000	1,2,4	U084	B	100 (45.4)
2-Propenenitrile	107131	Acrylonitrile	100	1,2,4	U009	B	100 (45.4)
2-Propenenitrile, 2-methyl-	126987	Methacrylonitrile	1*	4	U152	C	1000 (454)
2-Propenoic acid	79107	Acrylic acid	1*	4	U008	D	5000 (2270)
2-Propenoic acid, ethyl ester	140885	Ethyl acrylate	1*	4	U113	C	1000 (454)
2-Propenoic acid, 2-methyl-, ethyl ester	97632	Ethyl methacrylate	1*	4	U118	C	1000 (454)
2-Propenoic acid, 2-methyl-, methyl ester	80626	Methyl methacrylate	5000	1,4	U162	C	1000 (454)
2-Propen-1-ol	107186	Allyl alcohol	100	1,4	P005	B	100 (45.4)
Propionic acid	79094		5000	1		D	5000 (2270)
Propionic acid, 2-(2,4,5-trichlorophenoxy)-	93721	Silvex (2,4,5-TP) 2,4,5-TP acid	100	1,4	U233	B	100 (45.4)
Propionic anhydride	123626		5000	1		D	5000 (2270)
n-Propylamine	107108	1-Propanamine	1*	4	U194	D	5000 (2270)
Propylene dichloride	78875	Propane, 1,2-dichloro- 1,2-Dichloropropane	5000	1,2,4	U083	C	1000 (454)
Propylene oxide	75569		5000	1		B	100 (45.4)
1,2-Propylenimine	75558	Aziridine, 2-methyl-	1*	4	P067	X	1 (0.454)
2-Propyn-1-ol	107197	Propargyl alcohol	1*	4	P102	C	1000 (454)
Pyrene	129000		1*	2		D	5000 (2270)
Pyrethrins	121299		1000	1		X	1 (0.454)
	121211		1000	1		X	1 (0.454)
	8003347		1000	1		X	1 (0.454)
3,6-Pyridazinedione, 1,2-dihydro-	123331	Maleic hydrazide	1*	4	U148	D	5000 (2270)
4-Pyridinamine	504245	4-Aminopyridine	1*	4	P008	C	1000 (454)
Pyridine	110861		1*	4	U196	C	1000 (454)
Pyridine, 2-methyl-	109068	2-Picoline	1*	4	U191	D	5000 (2270)
Pyridine, 3-(1-methyl-2-pyrrolidinyl)-, (S)	54115	Nicotine, & salts	1*	4	P075	B	100 (45.4)
2,4-(1H,3H)-Pyrimidinedione, 5-[bis(2-chloroethyl)amino]-	66751	Uracil mustard	1*	4	U237	A	10 (4.54)
4(1H)-Pyrimidinone, 2,3-dihydro-6-methyl-2-thioxo-	56042	Methylthiouracil	1*	4	U164	A	10 (4.54)

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Hazardous Substance	CASRN	Regulatory Synonyms	Statutory			Final RQ	
			RQ	Code†	RCRA Waste #	Category	Pounds (Kg)
Pyrrolidine, 1-nitroso-	930552	N-Nitrosopyrrolidine	1*	4	U180	X	1 (0.454)
Quinoline	91225		1000	1		D	5000 (2270)
RADIONUCLIDES	N/A		1*	3			§
Reserpine	50555	Yohimban-16-carboxylic acid, 11,17-dimethoxy-18-[(3,4,5-trimethoxybenzoyl)oxy-, methyl ester (3beta, 16beta, 17alpha, 18beta, 20alpha)-	1*	4	U200	D	5000 (2270)
Resorcinol	108463	1,3-Benzenediol	1000	1,4	U201	D	5000 (2270)
Saccharin and salts	81072	1,2-Benzisothiazol-3(2H)-one, 1,1-dioxide	1*	4	U202	B	100 (45.4)
Safrole	94597	1,3-Benzodioxole, 5-(2-propenyl)-	1*	4	U203	B	100 (45.4)
Selenious acid	7783008		1*	4	U204	A	10 (4.54)
Selenious acid, dithallium (1+) salt	12039520	Thallium selenite	1*	4	P114	C	1000 (454)
Selenium††	7782492		1*	2		B	100 (45.4)
SELENIUM AND COMPOUNDS	N/A		1*	2			**
Selenium dioxide	7446084	Selenium oxide	1000	1,4	U204	A	10 (4.54)
Selenium oxide	7446084	Selenium dioxide	1000	1,4	U204	A	10 (4.54)
Selenium sulfide	7488564	Selenium sulfide SeS2	1*	4	U205	A	10 (4.54)
Selenium sulfide SeS2	7488564	Selenium sulfide	1*	4	U205	A	10 (4.54)
Selenourea	630104		1*	4	P103	C	1000 (454)
L-Serine, diazoacetate (ester)	115026	Azaserine	1*	4	U015	X	1 (0.454)
Silver††	7440224		1*	2		C	1000 (454)
SILVER AND COMPOUNDS	N/A		1*	2			**
Silver cyanide	506649	Silver cyanide Ag(CN)	1*	4	P104	X	1 (0.454)
Silver cyanide Ag (CN)	506649	Silver cyanide	1*	4	P104	X	1 (0.454)
Silver nitrate	7761888		1	1		X	1 (0.454)
Silvex (2,4,5-TP)	93721	Propionic acid, 2-(2,4,5-trichlorophenoxy)- 2,4,5-TP acid	100	1,4	U233	B	100 (45.4)
Sodium	7440235		1000	1		A	10 (4.54)
Sodium arsenate	7631892		1000	1		X	1 (0.454)
Sodium arsenite	7784465		1000	1		X	1 (0.454)
Sodium azide	26628228		1*	4	P105	C	1000 (454)
Sodium bichromate	10588019		1000	1		A	10 (4.54)

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Hazardous Substance	CASRN	Regulatory Synonyms	Statutory			Final RQ	
			RQ	Code†	RCRA Waste #	Category	Pounds (Kg)
Sodium bifluoride	1333831		5000	1		B	100 (45.4)
Sodium bisulfite	7631905		5000	1		D	5000 (2270)
Sodium chromate	7775113		1000	1		A	10 (4.54)
Sodium cyanide	143339	Sodium cyanide Na(CN)	10	1,4	P106	A	10 (4.54)
Sodium cyanide Na (CN)	143339	Sodium cyanide	10	1,4	P106	A	10 (4.54)
Sodium dodecylbenzenesulfonate	25155300		1000	1		C	1000 (454)
Sodium fluoride	7681494		5000	1		C	1000 (454)
Sodium hydrosulfide	16721805		5000	1		D	5000 (2270)
Sodium hydroxide	1310732		1000	1		C	1000 (454)
Sodium hypochlorite	7681529		100	1		B	100 (45.4)
	10022705		100	1		B	100 (45.4)
Sodium methylate	124414		1000	1		C	1000 (454)
Sodium nitrite	7632000		100	1		B	100 (45.4)
Sodium phosphate, dibasic	7558794		5000	1		D	5000 (2270)
	10039324		5000	1		D	5000 (2270)
	10140655		5000	1		D	5000 (2270)
Sodium phosphate, tribasic	7601549		5000	1		D	5000 (2270)
	7758294		5000	1		D	5000 (2270)
	7785844		5000	1		D	5000 (2270)
	10101890		5000	1		D	5000 (2270)
	10124568		5000	1		D	5000 (2270)
	10361894		5000	1		D	5000 (2270)
Sodium selenite	10102188		1000	1		B	100 (45.4)
	7782823						
Streptozotocin	18883664	D-Glucose, 2-deoxy-2-[[(methylnitrosoamino)-carbonyl]amino]- Glucopyranose, 2-deoxy-2-(3-methyl-3-nitrosoureido)-	1*	4	U206	X	1 (0.454)
Strontium chromate	7789062		1000	1		A	10 (4.54)
Strychnidin-10-one	57249	Strychnine, & salts	10	1,4	P108	A	10 (4.54)
Strychnidin-10-one, 2,3-dimethoxy-	357573	Brucine	1*	4	P018	B	100 (45.4)
Strychnine, & salts	57249	Strychnidin-10-one	10	1,4	P108	A	10 (4.54)

Hazardous Substance	CASRN	Regulatory Synonyms	Statutory RQ	Statutory Code†	Statutory RCRA Waste #	Final RQ Category	Final RQ Pounds (Kg)
Styrene	100425		1000	1		C	1000 (454)
Sulfur monochloride	12771083		1000	1		C	1000 (454)
Sulfur phosphide	1314803	Phosphorus pentasulfide Phosphorus sulfide	100	1,4	U189	B	100 (45.4)
Sulfuric acid	7664939		1000	1		C	1000 (454)
	8014957		1000	1		C	1000 (454)
Sulfuric acid, dithallium (1+) salt	7446186	Thallium (I) sulfate	1000	1,4	P115	B	100 (45.4)
	10031591		1000	1,4	P115	B	100 (45.4)
Sulfuric acid, dimethyl ester	77781	Dimethyl sulfate	1*	4	U103	B	100 (45.4)
2,4,5-T acid	93765	Acetic acid, (2,4,5-trichlorophenoxy) 2,4,5-T	100	1,4	U232	C	1000 (454)
2,4,5-T amines	2008460		100	1		D	5000 (2270)
	1319728		100	1		D	5000 (2270)
	3813147		100	1		D	5000 (2270)
	6369966		100	1		D	5000 (2270)
	6369977		100	1		D	5000 (2270)
2,4,5-T esters	93798		100	1		C	1000 (454)
	1928478		100	1		C	1000 (454)
	2545597		100	1		C	1000 (454)
	25168154		100	1		C	1000 (454)
	61792072		100	1		C	1000 (454)
2,4,5-T salts	13560991		100	1		C	1000 (454)
2,4,5-T	93765	Acetic acid, (2,4,5-trichlorophenoxy) 2,4,5-T acid	100	1,4	U232	C	1000 (454)
TDE	72548	Benzene, 1,1'-(2,2-dichloroethylidene)bis[4-chloro- DDD 4,4' DDD	1	1,2,4	U060	X	1 (0.454)
1,2,4,5-Tetrachlorobenzene	95943	Benzene, 1,2,4,5-tetrachloro-	1*	4	U207	D	5000 (2270)
2,3,7,8-Tetrachlorodibenzo-p-dioxin (TCDD)	1746016		1*	2		X	1 (0.454)
1,1,1,2-Tetrachloroethane	630206	Ethane, 1,1,1,2-tetrachloro-	1*	4	U208	B	100 (45.4)
1,1,2,2-Tetrachloroethane	79345	Ethane, 1,1,2,2-tetrachloro-	1*	2,4	U209	B	100 (45.4)

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Hazardous Substance	CASRN	Regulatory Synonyms	Statutory			Final RQ	
			RQ	Code†	RCRA Waste #	Category	Pounds (Kg)
Tetrachloroethene	127184	Ethene, tetrachloro- Perchloroethylene Tetrachloroethylene	1*	2,4	U210	B	100 (45.4)
Tetrachloroethylene	127184	Ethene, tetrachloro- Perchloroethylene Tetrachloroethene	1*	2,4	U210	B	100 (45.4)
2,3,4,6-Tetrachlorophenol	58902	Phenol, 2,3,4,6-tetrachloro-	1*	4	U212	A	10 (4.54)
Tetraethyl lead	78002	Plumbane, tetraethyl-	100	1,4	P110	A	10 (4.54)
Tetraethyl pyrophosphate	107493	Diphosphoric acid, tetraethyl ester	100	1,4	P111	A	10 (4.54)
Tetraethyldithiopyrophosphate	3689245	Thiodiphosphoric acid, tetraethyl ester	1*	4	P109	B	100 (45.4)
Tetrahydrofuran	109999	Furan, tetrahydro-	1*	4	U213	C	1000 (454)
Tetranitromethane	509148	Methane, tetranitro-	1*	4	P112	A	10 (4.54)
Tetraphosphoric acid, hexaethyl ester	757584	Hexaethyl tetraphosphate	1*	4	P062	B	100 (45.4)
Thallic oxide	1314325	Thallium oxide Tl203	1*	4	P113	B	100 (45.4)
Thallium††	7440280		1*	2		C	1000 (454)
Thallium and compounds	N/A		1*	2			**
Thallium (I) acetate	563688	Acetic acid, thallium (1+) salt	1*	4	U214	B	100 (45.4)
Thallium (I) carbonate	6533739	Carbonic acid, dithallium (1+) salt	1*	4	U215	B	100 (45.4)
Thallium (I) chloride	7791120	Thallium chloride TlCl	1*	4	U216	B	100 (45.4)
Thallium chloride TlCl	7791120	Thallium (I) chloride	1*	4	U216	B	100 (45.4)
Thallium (I) nitrate	10102451	Nitric acid, thallium (1+) salt	1*	4	U217	B	100 (45.4)
Thallium oxide Tl203	1314325	Thallic oxide	1*	4	P113	B	100 (45.4)
Thallium selenite	12039520	Selenious acid, dithallium (1+) salt	1*	4	P114	C	1000 (454)
Thallium (I) sulfate	7446186	Sulfuric acid, dithallium (1+) salt	1000	1,4	P115	B	100 (45.4)
	10031591		1000	1,4	P115	B	100 (45.4)
Thioacetamide	62555	Ethanethioamide	1*	4	U218	A	10 (4.54)
Thiodiphosphoric acid, tetraethyl ester	3689245	Tetraethyldithiopyrophosphate	1*	4	P109	B	100 (45.4)
Thiofanox	39196184	2-Butanone, 3,3-dimethyl-1-(methylthio)-, O[(methylamino) carbonyl] oxime	1*	4	P045	B	100 (45.4)
Thioimidodicarbonic diamide [(H2N)C(S)] 2NH	541537	Dithiobiuret	1*	4	P049	B	100 (45.4)
Thiomethanol	74931	Methanethiol Methylmercaptan	100	1,4	U153	B	100 (45.4)

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Hazardous Substance	CASRN	Regulatory Synonyms	Statutory			Final RQ	
			RQ	Code†	RCRA Waste #	Category	Pounds (Kg)
Thioperoxydicarbonic diamide [(H2N)C(S)]2S2, tetramethyl-	137268	Thiram	1*	4	U244	A	10 (4.54)
Thiophenol	108985	Benzenethiol	1*	4	P014	B	100 (45.4)
Thiosemicarbazide	79196	Hydrazinecarbothioamide	1*	4	P116	B	100 (45.4)
Thiourea	62566		1*	4	U219	A	10 (4.54)
Thiourea, (2-chlorophenyl)-	5344821	1-(o-Chlorophenyl)thiourea	1*	4	P026	B	100 (45.4)
Thiourea, 1-naphthalenyl-	86884	alpha-Naphthylthiourea	1*	4	P072	B	100 (45.4)
Thiourea, phenyl-	103855	Phenylthiourea	1*	4	P093	B	100 (45.4)
Thiram	137268	Thioperoxydicarbonic diamide [(H2N)C(S)]2S2, tetramethyl-	1*	4	U244	A	10 (4.54)
Toluene	108883	Benzene, methyl-	1000	1,2,4	U220	C	1000 (454)
Toluenediamine	95807	Benzenediamine, ar-methyl-	1*	4	U221	A	10 (4.54)
	496720		1*	4	U221	A	10 (4.54)
	823405		1*	4	U221	A	10 (4.54)
	25376458		1*	4	U221	A	10 (4.54)
Toluene diisocyanate	584849	Benzene, 1,3-diisocyanatomethyl-	1*	4	U223	B	100 (45.4)
	91087		1*	4	U223	B	100 (45.4)
	26471625		1*	4	U223	B	100 (45.4)
o-Toluidine	95534	Benzenamine, 2-methyl-	1*	4	U328	B	100 (45.4)
p-Toluidine	106490	Benzenamine, 4-methyl-	1*	4	U353	B	100 (45.4)
o-Toluidine hydrochloride	636215	Benzenamine, 2-methyl-, hydrochloride	1*	4	U222	B	100 (45.4)
Toxaphene	8001352	Camphene, octachloro-	1*	1,2,4	P123	X	1 (0.454)
2,4,5-TP acid	93721	Propionic acid 2-(2,4,5-trichlorophenoxy)- Silvex (2,4,5-TP)	100	1,4	U233	B	100 (45.4)
2,4,5-TP esters	32534955		100	1		B	100 (45.4)
1H-1,2,4-Triazol-3-amine	61825	Amitrole	1*	4	U011	A	10 (4.54)
Trichlorfon	52686		1000	1		B	100 (45.4)
1,2,4-Trichlorobenzene	120821		1*	2		B	100 (45.4)
1,1,1-Trichloroethane	71556	Ethane, 1,1,1-trichloro- Methyl chloroform	1*	2,4	U226	C	1000 (454)
1,1,2-Trichloroethane	79005	Ethane, 1,1,2-trichloro-	1*	2,4	U227	B	100 (45.4)
Trichloroethene	79016	Ethene, trichloro- Trichloroethylene	1000	1,2,4	U228	B	100 (45.4)

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Hazardous Substance	CASRN	Regulatory Synonyms	Statutory RQ	Statutory Code†	Statutory RCRA Waste #	Final RQ Category	Final RQ Pounds (Kg)
Trichloroethylene	79016	Ethene, trichloro- Trichloroethene	1000	1,2,4	U228	B	100 (45.4)
Trichloromethanesulfenyl chloride	594423	Methanesulfenyl chloride, trichloro-	1*	4	P118	B	100 (45.4)
Trichloromonofluoromethane	75694	Methane, trichlorofluoro-	1*	4	U121	D	5000 (2270)
Trichlorophenol	25167822		10	1		A	10 (4.54)
2,3,4-Trichlorophenol	15950660		10	1		A	10 (4.54)
2,3,5-Trichlorophenol	933788		10	1		A	10 (4.54)
2,3,6-Trichlorophenol	933755		10	1		A	10 (4.54)
2,4,5-Trichlorophenol	95954	Phenol, 2,4,5-trichloro-	10*	1,4	U230	A	10 (4.54)
2,4,6-Trichlorophenol	88062	Phenol, 2,4,6-trichloro-	10*	1,2,4	U231	A	10 (4.54)
3,4,5-Trichlorophenol	609198						
2,4,5-Trichlorophenol	95954	Phenol, 2,4,5-trichloro-	10*	1,4	U230	A	10 (4.54)
2,4,6-Trichlorophenol	88062	Phenol, 2,4,6-trichloro-	10	1,2,4	U231	A	10 (4.54)
Triethanolamine dodecylbenzenesulfonate	27323417		1000	1		C	1000 (454)
Triethylamine	121448		5000	1		D	5000 (2270)
Trimethylamine	75503		1000	1		B	100 (45.4)
1,3,5-Trinitrobenzene	99354	Benzene, 1,3,5-trinitro-	1*	4	U234	A	10 (4.54)
1,3,5-Trioxane, 2,4,6-trimethyl-	123637	Paraldehyde	1*	4	U182	C	1000 (454)
Tris(2,3-dibromopropyl) phosphate	126727	1-Propanol, 2,3-dibromo-, phosphate (3:1)	1*	4	U235	A	10 (4.54)
Trypan blue	72571	2,7-Naphthalenedisulfonic acid, 3,3'-3,3'-dimethyl-(1,1'-biphenyl)-4,4'-diyl)-bis(azo))bis(5-amino-4-hydroxy)-tetrasodium salt	1*	4	U236	A	10 (4.54)
Unlisted Hazardous Wastes Characteristic of Corrosivity	N/A		1*	4	D002	B	100 (45.4)
Unlisted Hazardous Wastes Characteristics: Characteristic of Toxicity:	N/A		1*	4			
Arsenic (D004)	N/A		*1	4	D004	X	1 (0.454)
Barium (D005)	N/A		*1	4	D005	C	1000 (454)
Benzene (D018)	N/A		1000	1,2,3,4	D018	A	10 (4.54)
Cadmium (D006)	N/A		*1	4	D006	A	10 (4.54)
Carbon tetrachloride (D019)	N/A		5000	1,2,4	D019	A	10 (4.54)

Hazardous Substance	CASRN	Regulatory Synonyms	Statutory			Final RQ	
			RQ	Code†	RCRA Waste #	Category	Pounds (Kg)
Chlordane (D020)	N/A		1	1,2,4	D020	X	1 (0.454)
Chlorobenzene (D021)	N/A		100	1,2,4	D021	B	100 (45.4)
Chloroform (D022)	N/A		5000	1,2,4	D022	A	10 (4.54)
Chromium (D007)	N/A		*1	4	D007	A	10 (4.54)
o-Cresol (D023)	N/A		1000	1,4	D023	C	1000 (454)
m-Cresol (D024)	N/A		1000	1,4	D024	C	1000 (454)
p-Cresol (D025)	N/A		1000	1,4	D025	C	1000 (454)
Cresol (D026)	N/A		1000	1,4	D026	C	1000 (454)
2,4-D (D016)	N/A		100	1,4	D016	B	100 (45.4)
1,4-Dichlorobenzene (D027)	N/A		100	1,2,4	D027	B	100 (45.4)
1,2-Dichloroethane (D028)	N/A		5000	1,2,4	D028	B	100 (45.4)
1,1-Dichloroethylene (D029)	N/A		5000	1,2,4	D029	B	100 (45.4)
2,4-Dinitrotoluene (D030)	N/A		1000	1,2,4	D030	A	10 (4.54)
Endrin (D012)	N/A		1	1,4	D012	X	1 (0.454)
Heptachlor (and epoxide) (D031)	N/A		1	1,2,4	D031	X	1 (0.454)
Hexachlorobenzene (D032)	N/A		*1	2,4	D032	A	10 (4.54)
Hexachlorobutadiene (D033)	N/A		*1	2,4	D033	X	1 (0.454)
Hexachloroethane (D034)	N/A		*1	2,4	D034	B	100 (45.4)
Lead (D008)	N/A		*1	4	D008		(#)
Lindane (D013)	N/A		1	1,4	D013	X	1 (0.454)
Mercury (D009)	N/A		*1	4	D009	X	1 (0.454)
Methoxychlor (D014)	N/A		1	1,4	D014	X	1 (0.454)
Methyl ethyl ketone (D035)	N/A		*1	4	D035	D	5000 (2270)
Nitrobenzene (D036)	N/A		1000	1,2,4	D036	C	1000 (454)
Pentachlorophenol (D037)	N/A		10	1,2,4	D037	A	10 (4.54)
Pyridine (D038)	N/A		*1	4	D038	C	1000 (454)
Selenium (D010)	N/A		*1	4	D010	A	10 (4.54)
Silver (D011)	N/A		*1	4	D011	X	1 (0.454)
Tetrachloroethylene (D039)	N/A		*1	2,4	D039	B	100 (45.4)
Toxaphene (D015)	N/A		1	1,4	D015	X	1 (0.454)
Trichloroethylene (D040)	N/A		1000	1,2,4	D040	B	100 (45.4)
2,4,5-Trichlorophenol (D041)	N/A		10	1,4	D041	A	10 (4.54)

Hazardous Substance	CASRN	Regulatory Synonyms	Statutory			Final RQ	
			RQ	Code†	RCRA Waste #	Category	Pounds (Kg)
2,4,6-Trichlorophenol (D042)	N/A		10	1,2,4	D042	A	10 (4.54)
2,4,5-TP (D017)	N/A		100	1,4	D017	B	100 (45.4)
Vinyl chloride (D043)	N/A		*1	2,3,4	D043	X	1 (0.454)
Unlisted Hazardous Wastes Characteristic of Ignitability	N/A		1*	4	D001	B	100 (45.4)
Unlisted Hazardous Wastes Characteristic of Reactivity	N/A		1*	4	D003	B	100 (45.4)
Uracil mustard	66751	2,4-(1H,3H)-Pyrimidinedione, 5-[bis(2-chloroethyl)amino]-	1*	4	U237	A	10 (4.54)
Uranyl acetate	5411093		5000	1		B	100 (45.4)
Uranyl nitrate	10102064		5000	1		B	100 (45.4)
	36478769					B	
Urea, N-ethyl-N-nitroso-	759739	N-Nitroso-N-ethylurea	1*	4	U176	X	1 (0.454)
Urea, N-methyl-N-nitroso	684935	N-Nitroso-N-methylurea	1*	4	U177	X	1 (0.454)
Vanadic acid, ammonium salt	7803556	Ammonium vanadate	1*	4	P119	C	1000 (454)
Vanadium oxide V205	1314621	Vanadium pentoxide	1000	1,4	P120	C	1000 (454)
Vanadium pentoxide	1314621	Vanadium oxide V205	1000	1,4	P120	C	1000 (454)
Vanadyl sulfate	27774136		1000	1		C	1000 (454)
Vinyl chloride	75014	Ethene, chloro-	1*	2,3,4	U043	X	1 (0.454)
Vinyl acetate	108054	Vinyl acetate monomer	1000	1		D	5000 (2270)
Vinyl acetate monomer	108054	Vinyl acetate	1000	1		D	5000 (2270)
Vinylamine, N-methyl-N-nitroso-	4549400	N-Nitrosomethylvinylamine	1*	4	P084	A	10 (4.54)
Vinylidene chloride	75354	Ethene, 1,1-dichloro- 1,1-Dichloroethylene	5000	1,2,4	U078	B	100 (45.4)
Warfarin, & salts, when present at concentrations greater than 0.3%	81812	2H-1-Benzopyran-2-one, 4-hydroxy-3-(3-oxo-1-phenyl-butyl)-, & salts, when present at concentrations greater than 0.3%	1*	4	P001	B	100 (45.4)
Xylene (mixed)	1330207	Benzene, dimethyl	1000	1,4	U239	C	1000 (454)
m-Benzene, dimethyl	108383	m-Xylene	1000	1,4	U239	C	1000 (454)
o-Benzene, dimethyl	95476	o-Xylene	1000	1,4	U239	C	1000 (454)
p-Benzene, dimethyl	106423	p-Xylene	1000	1,4	U239	C	1000 (454)

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Hazardous Substance	CASRN	Regulatory Synonyms	Statutory			Final RQ	
			RQ	Code†	RCRA Waste #	Category	Pounds (Kg)
Xylenol	1300716		1000	1		C	1000 (454)
Yohimban-16-carboxylic acid, 11,17-dimethoxy-18-[(3,4,5-trimethoxybenzoyl)oxy]-, methyl ester (3beta,16beta,17alpha, 18beta,20alpha)-	50555	Reserpine	1*	4	U200	D	5000 (2270)
Zinc††	7440666		1*	2		C	1000 (454)
ZINC AND COMPOUNDS	N/A		1*	2			**
Zinc acetate	557346		1000	1		C	1000 (454)
Zinc ammonium chloride	52628258		5000	1		C	1000 (454)
	14639975		5000	1		C	1000 (454)
	14639986		5000	1		C	1000 (454)
Zinc borate	1332076		1000	1		C	1000 (454)
Zinc bromide	7699458		5000	1		C	1000 (454)
Zinc carbonate	3486359		1000	1		C	1000 (454)
Zinc chloride	7646857		5000	1		C	1000 (454)
Zinc cyanide	557211	Zinc cyanide Zn(CN)2	10	1,4	P121	A	10 (4.54)
Zinc cyanide Zn(CN)2	557211	Zinc cyanide	10	1,4	P121	A	10 (4.54)
Zinc fluoride	7783495		1000	1		C	1000 (454)
Zinc formate	557415		1000	1		C	1000 (454)
Zinc hydrosulfite	7779864		1000	1		C	1000 (454)
Zinc nitrate	7779886		5000	1		C	1000 (454)
Zinc phenolsulfonate	127822		5000	1		D	5000 (2270)
Zinc phosphide	1314847	Zinc phosphide Zn3P2, when present at concentrations greater than 10%	1000	1,4	P122	B	100 (45.4)
Zinc phosphide Zn3P2, when present at concentrations greater than 10%	1314847	Zinc phosphide	1000	1,4	P122	B	100 (45.4)
Zinc silicofluoride	16871719		5000	1		D	5000 (2270)
Zinc sulfate	7733020		1000	1		C	1000 (454)
Zirconium nitrate	13746899		5000	1		D	5000 (2270)
Zirconium potassium fluoride	16923958		5000	1		C	1000 (454)
Zirconium sulfate	14644612		5000	1		D	5000 (2270)
Zirconium tetrachloride	10026116		5000	1		D	5000 (2270)

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Hazardous Substance	CASRN	Regulatory Synonyms	Statutory RQ	Statutory Code†	Statutory RCRA Waste #	Final RQ Category	Final RQ Pounds (Kg)
F001			1*	4	F001	A	10 (4.54)
The following spent halogenated solvents used in degreasing: all spent solvent mixtures/blends used in degreasing containing, before use, a total of ten percent or more (by volume) of one or more of the above halogenated solvents or those solvents listed in F002, F004, and F005; and still bottoms from the recovery of these spent solvents and spent solvent mixtures.							
(a) Tetrachloroethylene	127184		1*	2,4	U210	B	100 (45.4)
(b) Trichloroethylene	79016		1000	1,2,4	U228	B	100 (45.4)
(c) Methylene chloride	75092		1*	2,4	U080	C	1000 (454)
(d) 1,1,1-Trichloroethane	71556		1*	2,4	U226	C	1000 (454)
(e) Carbon tetrachloride	56235		5000	1,2,4	U211	A	10 (4.54)
(f) Chlorinated fluorocarbons	N/A					D	5000 (2270)
F002			1*	2,4	F002	A	10 (4.54)
The following spent halogenated solvents; all spent solvent mixtures/blends containing, before use, a total of ten percent or more (by volume) of one or more of the above halogenated solvents or those solvents listed in F002,F004, and F005; and still bottoms from the recovery of these spent solvents and spent solvent mixtures.							
(a) Tetracholoroethylene	127184		1*	4	U210	B	100 (45.4)
(b) Methylene chloride	75092		1*	2,4	U080	C	1000
(c) Trichloroethylene	79016		1000	1,2,4	U228	B	100 (4[illegible]
(d) 1,1,1-Trichloroethane	71556		1*	2,4	U226	C	1000 (454)
(e) Chlorobenzene	108907		100	1,2,4	U037	B	100 (45.4)
(f) 1,1,2-Trichloro-1,2,2-trifluoroethane	76131					D	5000 (2270)
(g) o-Dichlorobenzene	95501		100	1,2,4	U070	B	100 (45.4)
(h) Trichlorofluoromethane	75694		1*	4	U121	D	5000 (2270)
(i) 1,1,2-Trichloroethane	79005		1*	2,4	U227	B	100 (45.4)
F003			1*	4	F003	B	100 (45.4)

Hazardous Substance	CASRN	Regulatory Synonyms	Statutory			Final RQ	
			RQ	Code†	RCRA Waste #	Category	Pounds (Kg)
The following spent non-halogenated solvents and the still bottoms from the recovery of these solvents:							
(a) Xylene	1330207					C	1000 (454)
(b) Acetone	67641					D	5000 (2270)
(c) Ethyl acetate	141786					D	5000 (2270)
(d) Ethylbenzene	100414					C	1000 (454)
(e) Ethyl ether	60297					B	100 (45.4)
(f) Methyl isobutyl ketone	108101					D	5000 (2270)
(g) n-Butyl alcohol	71363					D	5000 (2270)
(h) Cyclohexanone	108941					D	5000 (2270)
(i) Methanol	67561					D	5000 (2270)
F004			1*	4	F004	C	1000 (454)
The following spent non-halogenated solvents and the still bottoms from the recovery of these solvents:							
(a) Cresols/Cresylic acid	1319773		1000	1,4	U052	C	1000 (454)
(b) Nitrobenzene	98953		1000	1,2,4	U169	C	1000 (454)
F005			1*	4	F005	B	100 (45.4)
The following spent non-halogenated solvents and the still bottoms from the recovery of these solvents:							
(a) Toluene	108883		1000	1,2,4	U220	C	1000 (454)
(b) Methyl ethyl ketone	78933		1*	4	U159	D	5000 (2270)
(c) Carbon disulfide	75150		5000	1,4	P022	B	100 (45.4)
(d) Isobutanol	78831		1*	4	U140	D	5000 (2270)
(e) Pyridine	110861		1*	4	U196	C	1000 (454)
F006			1*	4	F006	A	10 (4.54)

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Hazardous Substance	CASRN	Regulatory Synonyms	Statutory RQ	Statutory Code†	Statutory RCRA Waste #	Final RQ Category	Final RQ Pounds (Kg)
Wastewater treatment sludges from electroplating operations except from the following processes: (1) sulfuric acid anodizing of aluminum, (2) tin plating on carbon steel, (3) zinc plating (segregated basis) on carbon steel, (4) aluminum or zinc-aluminum plating on carbon steel, (5) cleaning/stripping associated with tin, zinc and aluminum plating on carbon steel, and (6) chemical etching and milling of aluminum.							
F007			1*	4	F007	A	10 (4.54)
Spent cyanide plating bath solutions from electroplating operations.							
F008			1*	4	F008	A	10 (4.54)
Plating bath residues from the bottom of plating baths from electroplating operations where cyanides are used in the process.							
F009			1*	4	F009	A	10 (4.54)
Spent stripping and cleaning bath solutions from electroplating operations where cyanides are used in the process.							
F010			1*	4	F010	A	10 (4.54)
Quenching bath residues from oil baths from metal heat treating operations where cyanides are used in the process.							
F011			1*	4	F011	A	10 (4.54)
Spent cyanide solution from salt bath pot cleaning from metal heat treating operations.							
F012			1*	4	F012	A	10 (4.54)
Quenching wastewater treatment sludges from metal heat treating operations where cyanides are used in the process.							
F019			1	4	F019	A	10 (4.54)

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R0043632

VOL 12

Hazardous Substance	CASRN	Regulatory Synonyms	Statutory RQ	Statutory Code†	Statutory RCRA Waste #	Final RQ Category	Final RQ Pounds (Kg)
Wastewater treatment sludges from the chemical conversion coating of aluminum except from zirconium phosphating in aluminum can washing when such phosphating is an exclusive conversion coating process.							
F020			1*	4	F020	X	1 (0.454)
Wastes (except wastewater and spent carbon from hydrogen chloride purification) from the production or manufacturing use (as a reactant, chemical intermediate, or component in a formulating process) of tri-or-tetrachlorophenol, or of intermediates used to produce their pesticide derivatives. (This listing does not include wastes from the production of hexachlorophene from highly purified 2,4,5-trichlorophenol.)							
·021			1*	4	F021	X	1 (0.454)
Wastes (except wastewater and spent carbon from hydrogen chloride purification) from the production or manufacturing use (as a reactant, chemical intermediate, or component in a formulating process) of pentachlorophenol, or of intermediates used to produce its derivatives.							
F022			1*	4	F022	X	1 (0.454)
Wastes (except wastewater and spent carbon from hydrogen chloride purification) from the manufacturing use (as a reactant, chemical intermediate, or component in a formulating process) of tetra-, penta-, or hexachlorobenzenes under alkaline conditions.							
F023			1*	4	F023	X	1 (0.454)

10327

Hazardous Substance	CASRN	Regulatory Synonyms	Statutory			Final RQ	
			RQ	Code†	RCRA Waste #	Category	Pounds (Kg)
Wastes (except wastewater and spent carbon from hydrogen chloride purification) from the production of materials on equipment previously used for the production or manufacturing use (as a reactant, chemical intermediate, or component in a formulating process) of tri- and tetrachlorophenols. (This listing does not include wastes from equipment used only for the production or use of hexachlorophene from highly purified 2,4,5-tri-chlorophenol.)							
F024			1*	4	F024	X	1 (0.454)
Wastes, including but not limited to distillation residues, heavy ends, tars, and reactor cleanout wastes, from the production of chlorinated aliphatic hydrocarbons, having carbon content from one to five, utilizing free radical catalyzed processes. (This listing does not include light ends, spent filters and filter aids, spent dessicants(sic), wastewater, wastewater treatment sludges, spent catalysts, and wastes listed in Section 261.32.)							
F025			1*	4	F025	X	##1 (0.454)
Condensed light ends, spent filters and filter aids, and spent dessicant wastes from the production of certain chlorinated aliphatic hydrocarbons, by free radical catalyzed processes. These chlorinated aliphatic hydrocarbons are those having carbon chain lengths ranging from one to and including five, with varying amounts and positions of chlorine substitution.							

Hazardous Substance	CASRN	Regulatory Synonyms	Statutory			Final RQ	
			RQ	Code†	RCRA Waste #	Category	Pounds (Kg)
F026			1*	4	F026	X	1 (0.454)
Wastes (except wastewater and spent carbon from hydrogen chloride purification) from the production of materials on equipment previously used for the manufacturing use (as a reactant, chemical intermediate, or component in a formulating process) of tetra-, penta-, or hexachlorobenzene under alkaline conditions.							
F027			1*	4	F027	X	1 (0.454)
Discarded unused formulations containing tri-, tetra-, or pentachlorophenol or discarded unused formulations containing compounds derived from these chlorophenols. (This listing does not include formulations containing hexachlorophene synthesized from prepurified 2,4,5-tri-chlorophenol as the sole component.)							
F028			1*	4	F028	X	1 (0.454)
Residues resulting from the incineration or thermal treatment of soil contaminated with EPA Hazardous Waste Nos. F020, F021, F022, F023, F026, and F027.							
F032			1*	4	F032	X	1 (0.454)
Wastewaters, process residuals, preservative drippage, and spent formulations from wood preserving processes generated at plants that currently use or have previously used chlorophenolic formulations (except wastes from processes that have had the F032 waste code deleted in accordance with §261.35 and do not resume or initiate use of chlorophenolic formulations). This listing does not include K001 bottom sediment sludge from the treatment of wastewater from wood preserving processes that use creosote and/or pentachlorophenol.							
F034			1*	4	F034	X	1 (0.454)

Hazardous Substance	CASRN	Regulatory Synonyms	Statutory			Final RQ	
			RQ	Code†	RCRA Waste #	Category	Pounds (Kg)
Wastewaters, process residuals, preservative drippage, and spent formulations from wood preserving processes generated at plants that use creosote formulations. This listing does not include K001 bottom sediment sludge from the treatment of wastewater from wood preserving processes that use creosote and/or pentachlorophenol.							
F035			1*	4	F035	X	1 (0.454)
Wastewaters, process residuals, preservative drippage, and spent formulations from wood preserving processes generated at plants that use inorganic preservatives containing arsenic or chromium. This listing does not include K001 bottom sediment sludge from the treatment of wastewater from wood preserving processes that use creosote and/or penetachlorophenol.							
F037			1*	4	F037	X	1 (0.454)

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1 0330

R0043636

VOL 12

Hazardous Substance	CASRN	Regulatory Synonyms	Statutory RQ	Statutory Code†	Statutory RCRA Waste #	Final RQ Category	Final RQ Pounds (Kg)
Petroleum refinery primary oil/water/solids separation sludge--Any sludge generated from the gravitational separation of oil/water/solids during the storage or treatment of process wastewaters and oily cooling wastewaters from petroleum refineries. Such sludges include, but are not limited to, those generated in: oil/water/solids separators; tanks and impoundments; ditches and other conveyances; sumps; and stormwater units receiving dry weather flow. Sludge generated in stormwater units that do not receive dry weather flow, sludges generated from non-contact once-through cooling waters segregated for treatment from other process or oily cooling waters, sludges generated in aggressive biological treatment units as defined in §261.31(b)(2) (including sludges generated in one or more additional units after wastewaters have been treated in aggressive biological treatment units) and K051 wastes are not included in this listing.							
F038			1*	4	F038	X	1 (0.454)

1 0331

R0043637

Hazardous Substance	CASRN	Regulatory Synonyms	Statutory			Final RQ	
			RQ	Code†	RCRA Waste #	Category	Pounds (Kg)
Petroleum refinery secondary (emulsified) oil/water/solids separation sludge--Any sludge and/or float generated from the physical and/or chemical separation of oil/water/solids in process wastewaters and oily cooling wastewaters from petroleum refineries. Such wastes include, but are not limited to, all sludges and floats generated in: induced air flotation (IAF) units, tanks and impoundments, and all sludges generated in DAF units. Sludges generated in stormwater units that do not receive dry weather flow, sludges generated from once-through non-contact cooling waters segregated for treatment from other process or oil cooling wastes, sludges and floats generated in aggressive biological treatment units as defined in §261.31(b)(2) (including sludges and floats generated in one or more additional units after wastewaters have been treated in aggressive biological treatment units) and F037, K048, and K051 wastes are not included in this listing.							
K001			1*	4	K001	X	1 (0.454)
Bottom sediment sludge from the treatment of wastewaters from wood preserving processes that use creosote and/or pentachlorophenol.							
K002			1*	4	K002		#
Wastewater treatment sludge from the production of chrome yellow and orange pigments.							
K003			1*	4	K003		#
Wastewater treatment sludge from the production of molybdate orange pigments.							
K004			1*	4	K004	A	10 (4.54)
Wastewater treatment sludge from the production of zinc yellow pigments.							
K005			1*	4	K005		#

Hazardous Substance	CASRN	Regulatory Synonyms	Statutory			Final RQ	
			RQ	Code†	RCRA Waste #	Category	Pounds (Kg)
Wastewater treatment sludge from the production of chrome green pigments.							
K006			1*	4	K006	A	10 (4.54)
Wastewater treatment sludge from the production of chrome oxide green pigments (anhydrous and hydrated).							
K007			1*	4	K007	A	10 (4.54)
Wastewater treatment sludge from the production or iron blue pigments.							
K008			1*	4	K008	A	10 (4.54)
Oven residue from the production of chrome oxide green pigments.							
K009			1*	4	K009	A	10 (4.54)
Distillation bottoms from the production of acetaldehyde from ethylene.							
K010			1*	4	K010	A	10 (4.54)
Distillation side cuts from the production of acetaldehyde from ethylene.							
K011			1*	4	K011	A	10 (4.54)
Bottom stream from the wastewater stripper inthe production of acrylonitrile.							
K013			1*	4	K013	A	10 (4.54)
Bottom stream from the acetonitrile column in the production of acrylonitrile.							
K014			1*	4	K014	D	5000 (2270)
Bottoms from the acetonitrile purification column in the production of acrylonitrile.							
K015			1*	4	K015	A	10 (4.54)
Still bottoms from the distillation of benzyl chloride.							
K016			1*	4	K016	X	1 (0.454)

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1 0333

R0043639

Hazardous Substance	CASRN	Regulatory Synonyms	Statutory			Final RQ	
			RQ	Code†	RCRA Waste #	Category	Pounds (Kg)
Heavy ends or distillation residues from the production of carbon tetrachloride.							
K017			1*	4	K017	A	10 (4.54)
Heavy ends (still bottoms) from the purification column in the production of epi-chlorohydrin.							
K018			1*	4	K018	X	1 (0.454)
Heavy ends from the fractionation column in ethyl chloride production.							
K019			1*	4	K019	X	1 (0.454)
Heavy ends from the distillation of ethylene dichloride in ethylene dichloride production.							
K020			1*	4	K020	X	1 (0.454)
Heavy ends from the distillation of vinyl chloride in vinyl chloride monomer production.							
K021			1*	4	K021	A	10 (4.54)
Aqueous spent antimony catalyst waste from fluoromethanes production.							
K022			1*	4	K022	X	1 (0.454)
Distillation bottom tars from the production of phenol/acetone from cumene.							
K023			1*	4	K023	D	5000 (2270)
Distillation light ends from the production of phthalic anhydride from naphthalene.							
K024			1*	4	K024	D	5000 (2270)
Distillation bottoms from the production of phthalic anhydride from naphthalene.							
K025			1*	4	K025	A	10 (4.54)
Distillation bottoms from the production of nitrobenzene by the nitration of benzene.							
K026			1*	4	K026	C	1000 (454)

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Hazardous Substance	CASRN	Regulatory Synonyms	Statutory RQ	Statutory Code†	Statutory RCRA Waste #	Final RQ Category	Final RQ Pounds (Kg)
Stripping still tails from the production of methyl ethyl pyridines.							
K027			1*	4	K027	A	10 (4.54)
Centrifuge and distillation residues from toluene diisocyanate production.							
K028			1*	4	K028	X	1 (0.454)
Spent catalyst from the hydrochlorinator reactor in the production of 1,1,1-trichloroethane.							
K029			1*	4	K029	X	1 (0.454)
Waste from the product steam stripper in the production of 1,1,1-trichloroethane.							
K030			1*	4	K030	X	1 (0.454)
Column bottoms or heavy ends from the combined production of trichloroethylene and perchloroethylene.							
K031			1*	4	K031	X	1 (0.454)
By-product salts generated in the production of MSMA and cacodylic acid.							
K032			1*	4	K032	A	10 (4.54)
Wastewater treatment sludge from the production of chlordane.							
K033			1*	4	K033	A	10 (4.54)
Wastewater and scrub water from the chlorination of cyclopentadiene in the production of chlordane.							
K034			1*	4	K034	A	10 (4.54)
Filter solids from the filtration of hexachlorocyclo-pentadiene in the production of chlordane.							
K035			1*	4	K035	X	1 (0.454)
Wastewater treatment sludges generated in the production of creosote.							
K036			1*	4	K036	X	1 (0.454)

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1 0335

Hazardous Substance	CASRN	Regulatory Synonyms	Statutory RQ	Statutory Code†	Statutory RCRA Waste #	Final RQ Category	Final RQ Pounds (Kg)
Still bottoms from toluene reclamation distillation in the production of disulfoton.							
K037			1*	4	K037	X	1 (0.454)
Wastewater treatment sludges from the production of disulfoton.							
K038			1*	4	K038	A	10 (4.54)
Wastewater from the washing and stripping of phorate production.							
K039			1*	4	K039	A	10 (4.54)
Filter cake from the filtration of diethylphosphorodithioic acid in the production of phorate.							
K040			1*	4	K040	A	10 (4.54)
Wastewater treatment sludge from the production of phorate.							
K041			1*	4	K041	X	1 (0.454)
Wastewater treatment sludge from the production of toxaphene.							
K042			1*	4	K042	A	10 (4.54)
Heavy ends or distillation residues from the distillation of tetrachlorobenzene in the production of 2,4,5-T.							
K043			1*	4	K043	A	10 (4.54)
2,6-Dichlorophenol waste from the production of 2,4-D.							
K044			1*	4	K044	A	10 (4.54)
Wastewater treatment sludges from the manufacturing and processing of explosives.							
K045			1*	4	K045	A	10 (4.54)
Spent carbon from the treatment of wastewater containing explosives.							
K046			1*	4	K046	B	100 (45.4)
Wastewater treatment sludges from the manufacturing, formulation and loading of lead-based initiating compounds.							

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Hazardous Substance	CASRN	Regulatory Synonyms	Statutory			Final RQ	
			RQ	Code†	RCRA Waste #	Category	Pounds (Kg)
K047							
Pink/red water from TNT operations.			1*	4	K047	A	10 (4.54)
K048							
Dissolved air flotation (DAF) float from the petroleum refining industry.			1*	4	K048		#
K049							
Slop oil emulsion solids from the petroleum refining industry.			1*	4	K049		#
K050							
Heat exchanger bundle cleaning sludge from the petroleum refining industry.			1*	4	K050	A	10 (4.54)
K051							
API separator sludge from the petroleum refining industry.			1*	4	K051		#
K052							
Tank bottoms (leaded) from the petroleum refining industry.			1*	4	K052	A	10 (4.54)
K060							
Ammonia still lime sludge coking operations.			1*	4	K060	X	1 (0.454)
K061							
Emission control dust/sludge from the primary production of steel in electric furnaces.			1*	4	K061		#
K062							
Spent pickle liquor generated by steel finishing operations of facilities within the iron and steel industry (SIC Codes 331 and 332).			1*	4	K062		#
K064							
Acid plant blowdown slurry/sludge resulting from thickening of blowdown slurry from primary copper production.			1*	4	K064		##
K065			1*	4	K065		##

1 0337

R0043643

Hazardous Substance	CASRN	Regulatory Synonyms	Statutory			Final RQ	
			RQ	Code†	RCRA Waste #	Category	Pounds (Kg)
Surace impoundment solids contained in and dredged from surface impoundments at primary lead smelting facilities.							
K066			1*	4	K066		##
Sludge from treatment of process wastewater and/or acid plant blowdown from primary zinc production.							
K069			1*	4	K069		#
Emission control dust/sludge from secondary lead smelting.							
K071			1*	4	K071	X	1 (0.454)
Brine purification muds from the mercury cell process in chlorine production, where separately prepurified brine is not used.							
K073			1*	4	K073	A	10 (4.54)
Chlorinated hydrocarbon waste from the purification step of the diaphragm cell process using graphite anodes in chlorine production.							
K083			1*	4	K083	B	100 (45.4)
Distillatin bottoms from aniline extraction.							
K084			1*	4	K084	X	1 (0.454)
Wastewater treatment sludges generated during the production of veterinary pharmaceuticals from arsenic or organo-arsenic compounds.							
K085			1*	4	K085	A	10 (4.54)
Distillation or fractionation column bottoms from the production of chlorobenzenes.							
K086			1*	4	K086		#

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Hazardous Substance	CASRN	Regulatory Synonyms	Statutory			Final RQ	
			RQ	Code†	RCRA Waste #	Category	Pounds (Kg)
Solvent washes and sludges, caustic washes and sludges, or water washes and sludges from cleaning tubs and equipment used in the formulation of ink from pigments, driers, soaps, and stabilizers containing chromium and lead.							
K087			1*	4	K087	B	100 (45.4)
Decanter tank tar sludge from coking operations.							
K088			1*	4	K088		
Spent potliners from primary aluminum reduction.							
K090			1*	4	K090		
Emission control dust or sludge from ferrochromiumsilicon production.							
K091			1	4	K091		
Emission control dust or sludge from ferrochromium production.							
K093			1*	4	K093	D	5000 (2270)
Distillation light ends from the production of phthalic anhydride from ortho-xylene.							
K094			1*	4	K094	D	5000 (2270)
Distillation bottoms from the production of phthalic anhydride from ortho-xylene.							
K095			1*	4	K095	B	100 (45.4)
Distillation bottoms from the production of 1,1,1-trichloroethane.							
K096			1*	4	K096	B	100 (45.4)
Heavy ends from the heavy ends column from the production of 1,1,1-trichloroethane.							
K097			1*	4	K097	X	1 (0.454)
Vacuum stripper discharge from the chlordane chlorinator in the production of chlordane.							
K098			1*	4	K098	X	1 (0.454)

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Hazardous Substance	CASRN	Regulatory Synonyms	Statutory			Final RQ	
			RQ	Code†	RCRA Waste #	Category	Pounds (Kg)
Untreated process wastewater from the production of toxaphene.							
K099			1*	4	K099	A	10 (4.54)
Untreated wastewater from the production of 2,4-D.							
K100			1*	4	K100		#
Waste leaching solution from acid leaching of emission control dust/sludge from secondary lead smelting.							
K101			1*	4	K101	X	1 (0.454)
Distillation tar residues from the distillation of aniline-based compounds in the production of veterinary pharmaceuticals from arsenic or organo-arsenic compounds.							
K102			1*	4	K102	X	1 (0.454)
Residue from the use of activated carbon for decolorization in the production of veterinary pharmaceuticals from arsenic or organo-arsenic compounds.							
K103			1*	4	K103	B	100 (45.4)
Process residues from aniline extraction from the production of aniline.							
K104			1*	4	K104	A	10 (4.54)
Combined wastewater streams generated from nitrobenzene/aniline production.							
K105			1*	4	K105	A	10 (4.54)
Separated aqueous stereem from the reactor product washing step in the production of chlorobenzenes.							
K106			1*	4	K106	X	1 (0.454)
Wastewater treatment sludge from the mercury cell process in chlorine production.							
K107			10	4	K107	X	10 (4.54)

Hazardous Substance	CASRN	Regulatory Synonyms	Statutory			Final RQ	
			RQ	Code†	RCRA Waste #	Category	Pounds (Kg)
Column bottoms from product separation from the production of 1,1-dimethylhydrazine (UDMH) from carboxylic acid hydrazines.							
K108			10	4	K108	X	10 (4.54)
Condensed column overheads from product separation and condensed reactor vent gases from the production of 1,1-dimethylhydrazine (UDMH) from carboxylic acid hydrazides.							
K109			10	4	K109	X	10 (4.54)
Spent filter cartridges from product purification from the production of 1,1-dimethylhydrazine (UDMH) from carboxylic acid hydrazides.							
K110			10	4	K110	X	10 (4.54)
Condensed column overheads from intermediate separation from the production of 1,1-dimethylhydrazine (UDMH) from carboxylic acid hydrazides.							
K111			1*	4	K111	A	10 (4.54)
Product washwaters from the production of dinitrotoluene via nitration of toluene.							
K112			1*	4	K112	A	10 (4.54)
Reaction by-product water from the drying column in the production of toluenediamine via hydrogenation of dinitrotoluene.							
K113			1*	4	K113	A	10 (4.54)
Condensed liquid light ends from the purification of toluenediamine in the production of toluenediamine via hydrogenation of dinitrotoluene.							
K114			1*	4	K114	A	10 (4.54)
Vicinals from the purification of toluenediamine in the production of toluenediamine via hydrogenation of dinitrotoluene.							
K115			1*	4	K115	A	10 (4.54)

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Hazardous Substance	CASRN	Regulatory Synonyms	Statutory			Final RQ	
			RQ	Code†	RCRA Waste #	Category	Pounds (Kg)
Heavy ends from the purification of toluenediamine in the production of toluenediamine via hydrogenation of dinitrotoluene.							
K116			1*	4	K116	A	10 (4.54)
Organic condensate from the solvent recovery column in the production of toluene diisocyanate via phosgenation of toluenediamine.							
K117			1*	4	K117	X	1 (0.454)
Wastewater from the reaction vent gas scrubber in the production of ethylene bromide via bromination of ethene.							
K118			1*	4	K118	X	1 (0.454)
Spent absorbent solids from purification of ethylene dibromide in the production of ethylene dibromide.							
K123			1*	4	K123	A	10 (4.54)
Process wastewater (including supernates, filtrates, and washwaters) from the production of ethylene-bisdithiocarbamic acid and its salts.							
K124			1*	4	K124	A	10 (4.54)
Reactor vent scrubber water from the production of ethylenebisdithiocarbamic acid and its salts.							
K125			1*	4	K125	A	10 (4.54)
Filtration, evaporation, and centrifugation solids from the production of ethylenebisdithiocarbamic acid and its salts.							
K126			1*	4	K126	A	10 (4.54)
Baghouse dust and floor sweepings in milling and packaging operations from the production or formulation of ethylenebisdithiocarbamic acid and its salts.							
K131			100	4	K131	X	100 (45.4)

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Hazardous Substance	CASRN	Regulatory Synonyms	Statutory RQ	Statutory Code†	Statutory RCRA Waste #	Final RQ Category	Final RQ Pounds (Kg)
Wastewater from the reactor and spent sulfuric acid from the acid dryer in the production of methyl bromide.							
K132			1000	4	K132	X	1000 (454)
Spent absorbent and wastewater solids from the production of methyl bromide.							
K136			1*	4	K136	X	1 (0.454)
Still bottoms from the purification of ethylene dibromide in the production of ethylene dibromide via bromination of ethene.							

†Indicates the statutory source as defined by 1,2,3, and 4 below.
††No reporting of releases of this hazardous substance is required if the diameter of the pieces of the solid metal released is equal to or exceeds 100 micrometers (0.004 inches).
†††The RQ for asbestos is limited to friable forms only.
1--Indicates that the statutory source for designation of this hazardous substance under CERCLA is CWA Section 311(b)(4).
2--Indicates that the statutory source for designation of this hazardous substance under CERCLA is CWA Section 307(a).
3--Indicates that the statutory source for designation of this hazardous substance under CERCLA is CAA Section 112.
4--Indicates that the statutory source for designation of this hazardous substance under CERCLA is RCRA Section 3001.
1*--Indicates that the 1-pound RQ is a CERCLA statutory RQ.
#Indicates that the RQ is subject to change when the assessment of potential carcinogenicity is completed.
##The Agency may adjust the statutory RQ for this hazardous substance in a future rulemaking; until then the statutory RQ applies.
§--The adjusted RQs for radionuclides may be found in Appendix B to this table.
**--Indicates that no RQ is being assigned to the generic or broad class.

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APPENDIX G

RAIN DATA REFERENCES

Rainfall data sources

This section lists the most current 24-hour rainfall data published by the National Weather Service (NWS) for various parts of the country. Because NWS Technical Paper 40 (TP-40) is out of print, the 24-hour rainfall maps for areas east of the 105th meridian are included here as figures B-3 through B-8. For the area generally west of the 105th meridian, TP-40 has been superseded by NOAA Atlas 2, the Precipitation-Frequency Atlas of the Western United States, published by the National Oceanic and Atmospheric Administration.

East of 105th meridian

Hershfield, D.M. 1961. Rainfall frequency atlas of the United States for durations from 30 minutes to 24 hours and return periods from 1 to 100 years. U.S. Dep. Commerce, Weather Bur. Tech. Pap. No. 40. Washington, DC. 115 p.

West of 105th meridian

Miller, J.F., R.H. Frederick, and R.J. Tracey. 1973. Precipitation-frequency atlas of the Western United States. Vol. I, Montana; Vol. II, Wyoming; Vol. III, Colorado; Vol. IV, New Mexico; Vol. V, Idaho; Vol. VI, Utah; Vol. VII, Nevada; Vol. VIII, Arizona; Vol. IX, Washington; Vol. X, Oregon; Vol. XI, California. U.S. Dep. Commerce, National Weather Service, NOAA Atlas 2. Silver Spring, MD.

Alaska

Miller, John F. 1963. Probable maximum precipitation and rainfall-frequency data for Alaska for areas to 400 square miles, durations to 24 hours and return periods from 1 to 100 years. U.S. Dep. Commerce, Weather Bur. Tech. Pap. No. 47. Washington, DC. 69 p.

Hawaii

Weather Bureau. 1962. Rainfall-frequency atlas of the Hawaiian Islands for areas to 200 square miles, durations to 24 hours and return periods from 1 to 100 years. U.S. Dep. Commerce, Weather Bur. Tech. Pap. No. 43. Washington, DC. 60 p.

Puerto Rico and Virgin Islands

Weather Bureau. 1961. Generalized estimates of probable maximum precipitation and rainfall-frequency data for Puerto Rico and Virgin Islands for areas to 400 square miles, durations to 24 hours, and return periods from 1 to 100 years. U.S. Dep. Commerce, Weather Bur. Tech. Pap. No. 42. Washington, DC. 94 p.

Source: Urban Hydrology for Small Watersheds (TR55 Manual) - U.S. Department of Agriculture, Soil Conservation Service, June 1986

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APPENDIX H

THE POLLUTANT REMOVAL CAPACITY OF POND AND WETLAND SYSTEMS: A REVIEW

THE POLLUTANT REMOVAL CAPACITY OF POND AND WETLAND SYSTEMS: A REVIEW

	Site	State	No. of Storms	Watershed Area (Acres)	Treatment Vol. (In./Acre)	TSS	TP	SP	TN	NO3	COD	Pb	Zn
Dry Extended Detention													
1	Lakeridge	VA	28	88.0	0.00	0-20%	20-40%	Insufficient Knowledge	0-20%	0-20%	80-100%	60-80%	80-100%
2	London Commons	VA	27	11.4	0.22	20-40%	40-60%	Insufficient Knowledge	20-40%	Insufficient Knowledge	0-20%	20-40%	20-40%
						60-80%	40-60%	Insufficient Knowledge	60-80%	Insufficient Knowledge	40-60%	20-40%	20-40%
3	Stedwick	MD	25	34.0	0.30	60-80%	0-20%	Insufficient Knowledge	20-40%	Insufficient Knowledge	20-40%	60-80%	40-60%
4	Maple Run III	TX	17	28.0	0.50	20-40%	0-20%	60-80%	20-40%	40-60%	20-40%	20-40%	80-100%
5	Oakhampton	MD	16.8		0.50*	60-80%	20-40%	80-100%	60-80%	Insufficient Knowledge	60-80%	60-80%	80-100%
6	None Given	KS	19	12.3	3.42	0-20%	0-20%	0-20%	60-80%	0-20%	0-20%	60-80%	60-80%
Wet Ponds													
7	Seattle	WA	5	0.75		80-100%	60-80%	80-100%	80-100%	80-100%	60-80%	60-80%	60-80%
8	Boynton Beach	FL	6			80-100%	80-100%	60-80%	80-100%	80-100%	80-100%	80-100%	80-100%
9	Grace Street	MI	18		** 0.52	20-40%	0-20%	80-100%	0-20%	80-100%	80-100%	20-40%	80-100%
10	Pitt-AA	MI	6	4872.0	** 0.52	20-40%	0-20%	80-100%	80-100%	0-20%	20-40%	60-80%	0-20%
11	UnquaNY		8		**10.70	40-60%	40-60%	60-80%	60-80%	60-80%	60-80%	60-80%	80-100%
12	Waverly Hills	MI	29		** 7.57	80-100%	60-80%	80-100%	60-80%	60-80%	60-80%	80-100%	80-100%
13	Lake Ellyn	IL	23		**10.70	80-100%	20-40%	80-100%	80-100%	80-100%	80-100%	60-80%	60-80%
14	Lake Ridge	MN	20	315.0	0.08	80-100%	60-80%	0-20%	40-60%	0-20%	80-100%	60-80%	80-100%
						80-100%	20-40%	0-20%	20-40%	0-20%	80-100%	40-60%	60-80%
15	West Pond	MN	8	76.0	0.15	60-80%	20-40%	80-100%	80-100%	60-80%	80-100%	40-60%	60-80%

Key:
- 0 to 20% Removal
- 20 to 40% Removal
- 40 to 60% Removal
- 60 to 80% Removal
- 80 to 100% Removal
- Insufficient Knowledge

Key:
- TSS Total Suspended Solids
- TP Total Phosphorus
- SP Soluble Phosphorus
- TN Total Nitrogen
- NO3 Nitrate
- COD Chemical Oxygen Demand
- Pb Lead
- Zn Zinc

Note: An Asterisk (*) denotes an inferred value
Note: (**)Denotes Volume of Basin/Volume of Runoff

Note: The table above provides summary data on the pollutant removal capability of nearly sixty stormwater pond and wetland systems. Each study differs with respect to pond design, number of storms monitored, pollutant removal calculation technique, and monitoring technique, so exact comparisons between studies are not appropriate.

Note: The information in the above table was taken from: A Current Assessment of Urban Best Management Practices - Techniques for Reducing Non-Point Source Pollution in the Coastal Zone, prepared by: Metropolitan Washington Council of Governments, March 1992.

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THE POLLUTANT REMOVAL CAPACITY OF POND AND WETLAND SYSTEMS: A REVIEW

Wet Ponds (Cont'd)			No. of Storms	Watershed Area (Acres)	Treatment Vol. (In/Acre)	TSS	TP	SP	TN	NO3	COD	Pb	Zn
16	McCarrons	MN	21	608.0	0.19	●	◕	●	●	●	●	●	●
17	McKnight Basin	MN	20	725.0	0.22	●	◑	○	◔	◔	●	◕	●
						●	◔	○	○	○	●	◕	●
18	Monroe Street	WI		238.0	0.26	●	◕	◕	●	●	◕	◕	◕
19	Runaway Bay	NC	5	437.0	0.33	◑	◔	●	●	●	●	●	◑
20	Buckland	CT	7	20.0	0.40	◕	◑	●	●	◔	●	◔	◑
21	Highway Site	FL	13	41.6	0.55	◕	○	●	◔	●	○	◑	◔
22	Woodhollow	TX	14	381.0	0.55	◑	◑	●	◔	◑	◑	◕	◕
23	SR 204	WA	5	1.8	0.60	●	●	●	●	●	◕	●	●
24	Farm Pond	VA		51.4	1.13	●	●	◕	◔	●	●	●	●
25	Burke	VA	29	27.1	1.22	●	◔	◕	◔	●	◔	●	◔
26	Westleigh	MD	32	48.0	1.27	●	◑	◕	◔	●	◔	●	◔
27	Mercer	WA	5	7.8	1.72	◕	◕	●	●	●	◕	◔	◔
28	I-4	FL	6	26.3	2.35	◑	◕	●	●	●	●	◕	◕
29	Timber Creek	FL	9	122.0	3.11*	◕	◑	●	○	◕	●	●	●
30	Maitland	FL	30-40	49.0	3.65	●	●	●	●	●	●	●	●
31	Lakeside	NC	5	65.0	7.16	●	◔	●	●	●	●	●	●

Key:
- ○ 0 to 20% Removal
- ◔ 20 to 40% Removal
- ◑ 40 to 60% Removal
- ◕ 60 to 80% Removal
- ● 80 to 100% Removal
- ⊕ Insufficient Knowledge

Key:
- TSS Total Suspended Solids
- TP Total Phosphorus
- SP Soluble Phosphorus
- TN Total Nitrogen
- NO3 Nitrate
- COD Chemical Oxygen Demand
- Pb Lead
- Zn Zinc

Note: An Asterisk (*) denotes an inferred value
Note: (**)Denotes Volume of Basin/Volume of Runoff

Note: The information in the above table was taken from: A Current Assessment of Urban Best Management Practices - Techniques for Reducing Non-Point Source Pollution in the Coastal Zone, prepared by: Metropolitan Washington Council of Governments, March 1992.

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THE POLLUTANT REMOVAL CAPACITY OF POND AND WETLAND SYSTEMS: A REVIEW

			No. of Storms	Watershed Area (Acres)	Treatment Vol. (In./Acre)	TSS	TP	SP	TN	NO3	COD	Pb	Zn
Wet Extended Detention													
32	Uplands	ONT	6	860.0		●	◕	⊛	⊛	⊛	◕	◕	◕
33	East Barrhaven	ONT		2139.0	0.12	◑	◑	⊛	⊛	⊛	⊛	⊛	⊛
34	Kennedy-Burnett	ONT	6	395.0	0.62	●	◕	⊛	◑	⊛	◕	◔	◔
Stormwater Wetlands													
35	EWA3	IL				◕	◑	◕	●	◕	⊛	◕	◔
36	EWA4	IL				◕	◑	◕	◕	◑	◕	◕	⊛
37	EWA5	IL				●	◕	⊛	●	◕	◕	●	◕
38	EWA6	IL				●	●	⊛	⊛	●	●	●	◕
39	B31	WA	13	461.7	0.01	○	◕	◕	◕	○	◕	●	◕
40	PC12	WA	13	214.0	0.03	◑	◕	⊛	◕	◔	⊛	◕	◕
41	McCarrons	MN	21	608.0	0.31	◕	◔	⊛	◔	●	◕	◕	◕
42	Queen Anne's	MD			0.50*	◕	◔	◑	◔	◑	◕	●	●
43	Swift Run	MI	6	1207.0	0.60	●	○	◔	●	◕	○	●	◕
44	Tampa Office Pond	FL	3-8	6.3	0.61	◕	◑	◕	⊛	◕	○	●	◕
45	Highway Site	FL	13	41.6	0.61	◕	○	◕	◔	◕	○	◕	◑
46	Palm Beach PGA	FL		2340.0	2.00*	◑	◑	⊛	⊛	◔	●	●	●

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R0043655

THE POLLUTANT REMOVAL CAPACITY OF POND AND WETLAND SYSTEMS: A REVIEW

			No. of Storms	Watershed Area (Acres)	Treatment Vol. (In/Acre)	TSS	TP	SP	TN	NO3	COD	Pb	Zn
Extented Detention Wetlands													
47	Benjamin Franklin	VA		40.0	0.06	◕	○	◔	⊗	◑	⊗	⊗	⊗
48	Tanners's Lake	MN	10	413.0	0.10	◕	◔	○	◔	◔	⊗	◕	⊗
						◕	○	⊗	○	○	⊗	◑	⊗
49	Mays Chapel	MD		97.0	0.10*	◔	○	◔	⊗	◔	⊗	⊗	⊗
50	Clear Lake	MN		1070.0	0.15*	◕	◑	◔	⊗	⊗	⊗	⊗	◕
Natural Wetlands													
51	Hidden Lake	FL		55.4	1.06*	●	○	⊗	◕	◕	⊗	◑	◔
52	Wayzata	MN		73.0	1.25*	●	◕	◕	⊗	⊗	⊗	●	◕
Pond/Wetland Systems													
53	Lake Munson	FL	3	23393.0		●	◕	⊗	○	○	◔	◑	◑
54	Carver Ravine	MN	15	170.0	0.30*	◑	◔	◔	○	○	⊗	◑	◕
						◔	○	○	⊗	○	⊗	○	⊗
55	McCarrons	MN	21	606.0	>0.50	●	◕	◕	●	⊗	●	●	⊗
56	Lake Jackson	FL		2230.0	0.88*	●	●	⊗	◕	◕	⊗	⊗	⊗
57	Highway Site	FL	13	41.9	>1.35	●	◔	◕	◑	⊗	◕	●	◕
58	Long Lake	ME	11	18.0	2.0*	●	●	◕	⊗	⊗	⊗	⊗	⊗

Key:
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- ◑ 40 to 60% Removal
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United States
Environmental Protection
Agency

Office Of
Water
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April 1991

Urrunaga

EPA

Guidance Manual For The Preparation Of NPDES Permit Applications For Storm Water Discharges Associated With Industrial Activity

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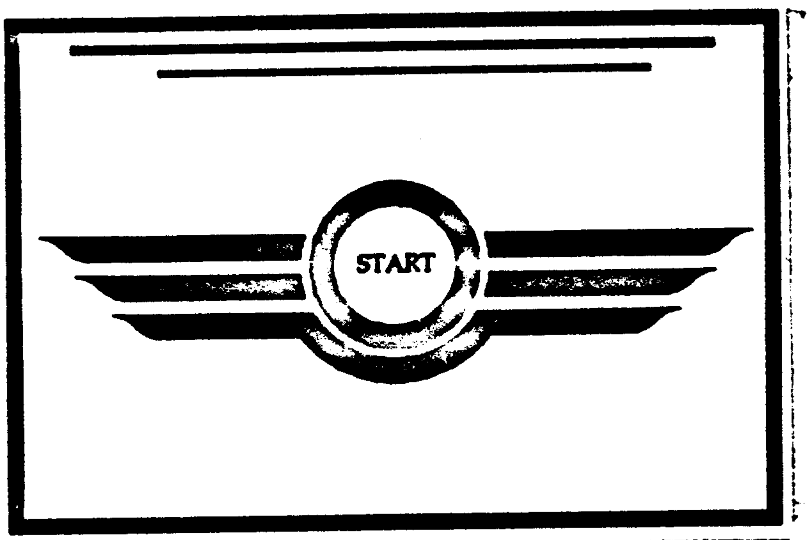

R0043657

GUIDANCE MANUAL
FOR THE PREPARATION OF
NPDES PERMIT APPLICATIONS
FOR STORM WATER DISCHARGES
ASSOCIATED WITH INDUSTRIAL ACTIVITY

April 1991

U.S. Environmental Protection Agency
Office of Wastewater Enforcement and Compliance
401 M Street, S.W.
Washington, D.C. 20460

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PREFACE

Water quality problems have occupied an increasingly prominent role in the public's awareness over the past several decades. In 1972, Congress passed significant amendments to the Federal Water Pollution Control Act (commonly referred to as the Clean Water Act or CWA) to prohibit the discharge of any pollutant to waters of the United States from a point source unless the discharge was authorized by a National Pollutant Discharge Elimination System (NPDES) permit. NPDES permits specify monitoring, reporting and control requirements, including allowable levels of pollutants in discharges.

Efforts to improve water quality under the NPDES program have traditionally focused on reducing pollutants in discharges of industrial process wastewater and municipal sewage. Industrial process discharges and sewage outfalls were easily identified as responsible for poor, often drastically degraded water quality conditions. However, as pollution control measures were installed for these discharges, it became evident that more diffuse sources (occurring over a wide area) of water pollution were also major causes of water quality problems.

For many years, most of the environmental law makers and the public alike assumed that runoff from urban and other areas subjected to man's activities was essentially "clean"water. However, during the past twenty years or so, this view has changed. It is now recognized that rainfall picks up a multitude of pollutants from falling on and draining off streets and parking lots, construction and industrial sites, and mining, logging and agricultural areas. The pollutants are dissolved into and are carried off by the rainfall as it drains from these surfaces and areas. Through natural or manmade conveyances, the runoff is channeled into and transported by gravity flow through a wide variety of drainage facilities. Once in these facilities, the runoff may scour accumulated pollutants out of gutters, catchbasins, storm sewers, and drainage channels. The runoff eventually ends up in surface water bodies such as creeks, rivers, estuaries, bays, and oceans.

Many recent studies have shown that runoff from urban and industrial areas typically contains significant quantities of the same general types of pollutants that are found in wastewaters and industrial discharges and cause similar water quality problems. These pollutants include heavy metals (e.g., chromium, cadmium, copper, lead, nickel, zinc), pesticides, herbicides, and organic compounds such as fuels, waste oils, solvents, lubricants, and grease. These pollutants may cause problems for both human health and aquatic organisms.

In general, assessments of water quality are difficult to perform and verify. However, several national assessments have been made. For the purposes of these assessments, runoff from urban and industrial areas has been considered as a diffuse source or "nonpoint"source of pollution. Legally, however, most urban runoff is discharged through conveyances such as separate storm sewers or other conveyances which are point sources under the CWA and are, therefore, subject to the NPDES program.

To provide a better understanding of the nature of storm water runoff from residential, commercial, and light industrial areas (collectively referred to as urban), the U.S. Environmental Protection Agency (EPA) provided funding and guidance to the Nationwide Urban Runoff Program (NURP), which was conducted from 1978 through 1983. The NURP study provided insight on what can be considered background levels of pollutants for urban runoff. NURP also concluded that the quality of urban runoff can be adversely impacted by several sources of pollutants that were not directly evaluated in the study, including illicit connections, construction and industrial site runoff, and illegal dumping.

Other studies have shown that storm sewers contain illicit discharges of non-storm water, and that wastes, particularly used oils, are improperly disposed of in storm sewers. Removal of non-storm water discharges to storm sewers presents opportunities for dramatic improvements in the quality of storm water discharges.

In 1987, the Clean Water Act was revised by adding Section 402(p) to address storm water. In summary, Section 402(p) states that prior to October 1, 1992, the NPDES program cannot require permits for discharges composed entirely of storm water unless one of the following conditions apply:

1) The discharge has been permitted prior to February 4, 1987 (in this case, the operator is required to maintain the existing permit).

2) The discharge is associated with industrial activity.

3) The discharge is from a large (population greater than 250,000) or medium (population greater than 100,000 but less than 250,000) municipal separate storm sewer system.

4) The permitting authority determines that the discharge contributes to a violation of a water quality standard or is a significant contributor of pollutants to the waters of the United States.

Section 402(p) of the CWA requires EPA to establish NPDES permit application requirements for storm water discharges associated with industrial activity; discharges from large municipal separate storm water systems (systems serving a population of 250,000 or more); and discharges from medium municipal separate storm water systems (systems serving a population of 100,000 or more, but less than 250,000). In response to this requirement, EPA published permit application requirements on November 16, 1990 (55 FR 47990). This manual provides guidance to facility operators discharging storm water associated with industrial activity on how to comply with the permit application requirements.

SECTION 1.0 INTRODUCTION

1.1 What Is The Purpose Of This Guidance Manual?

The Federal Water Pollution Control Act (also known as the Clean Water Act (CWA)), as amended in 1987, requires National Pollutant Discharge Elimination System (NPDES) permits for storm water discharges associated with industrial activity.

On November 16, 1990, (55 FR 47990), the Environmental Protection Agency (EPA) issued regulations establishing permit application requirements for storm water discharges associated with industrial activity. These regulations are primarily contained in Section 122.26 of Section 40 of the Code of Federal Regulations (40 CFR Part 122.26).

The purpose of this manual is to assist operators of facilities which discharge storm water associated with industrial activity in complying with the requirements for applying for an NPDES permit. This manual provides operators with an overview of the permitting process and information regarding the permit application requirements including: which forms are to be completed; where these are to be submitted; and when permit applications are due. In addition, this manual provides technical information on sample collection procedures.

1.2 How Is This Manual Organized?

This guidance manual contains five sections and several appendices. Section 2.0 explains the NPDES permit program, who must file an application and the different options for applying. Section 3.0 discusses the individual application requirements, including the necessary forms and information to be provided. Section 4.0 explains the permitting process, how applications are handled, whether an application is complete and public availability of the information. Technical guidance for the preparation of selected parts of the permit application forms is provided in Section 5.0. Pertinent regulatory guidance materials and other references are provided in Section 6.0.

Additional information is provided in the appendices to this manual. These appendices contain selected text from 40 CFR Part 122.26 (Appendix A), definitions of key terms (Appendix B), addresses for EPA Regional Offices and State agencies (Appendix C), procedures for filing a group application (Appendix D), and copies of the various permit application forms (Appendix E).

SECTION 2.0 WHAT IS THE NPDES PERMIT PROGRAM?

This section provides a description of the NPDES permitting program. Section 2.2 describes the regulatory term "storm water associated with industrial activity" which defines the scope of the NPDES program requirements with respect to industrial storm water discharges. Section 2.3 describes notification requirements for storm water discharges associated with industrial activity to large or medium municipal separate storm sewer systems. (These storm water discharges associated with industrial activity are also required to obtain NPDES permit coverage). Section 2.4 explains that storm water discharges associated with industrial activity to sanitary sewers, including combined sewers, are not required to obtain NPDES permit coverage. Section 2.5 describes three options that operators of storm water discharges associated with industrial activity may follow for obtaining permit coverage for storm water discharges associated with industrial activity: (1) individual permit applications; (2) group applications; and (3) case-by-case requirements developed for general permit coverage.

2.1 Authorized NPDES State Programs

The CWA allows States to request EPA authorization to administer the NPDES program instead of EPA. Upon authorization of a State program, the State is primarily responsible for issuing permits and administering the NPDES program in the State. At all times following authorization, State NPDES programs must be consistent with minimum Federal requirements, although they may always be more stringent.

State authority is divided into four parts: municipal and industrial permitting (including permitting for storm water discharges from non-Federal facilities); Federal facilities (including permitting for storm water discharges from Federal facilities); pretreatment; and general permitting. At this point in time, 39 States or Territories are authorized to, at a minimum, issue NPDES permits for municipal and industrial sources. In the 12 States and 6 territories without NPDES authorized programs, EPA issues all NPDES permits. In 6 of the 39 States that are authorized to issue NPDES permits for municipal and industrial sources, EPA issues permits for discharges from Federal facilities.

2.2 What Is A Storm Water Discharge Associated With Industrial Activity?

The November 16, 1990 regulation established the following definition of "storm water discharge associated with industrial activity" at 40 CFR 122.26(b)(14):

"Storm water discharge associated with industrial activity" means the discharge from any conveyance which is used for collecting and conveying storm water

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and which is directly related to manufacturing, processing or raw materials storage areas at an industrial plant. The term does not include discharges from facilities or activities excluded from the NPDES program under 40 CFR Part 122. For the categories of industries identified in subparagraphs (i) through (x) of this subsection, the term includes, but is not limited to, storm water discharges from industrial plant yards; immediate access roads and rail lines used or traveled by carriers of raw materials, manufactured products, waste material, or by-products used or created by the facility; material handling sites; refuse sites; sites used for the application or disposal of process waste waters (as defined at 40 CFR 401); sites used for the storage and maintenance of material handling equipment; sites used for residual treatment, storage, or disposal; shipping and receiving areas; manufacturing buildings; storage areas (including tank farms) for raw materials, and intermediate and finished products; and areas where industrial activity has taken place in the past and significant materials remain and are exposed to storm water. For the categories of industries identified in subparagraph (xi), the term includes only storm water discharges from all the areas (except access roads and rail lines) that are listed in the previous sentence where material handling equipment or activities, raw materials, intermediate products, final products, waste materials, by-products, or industrial machinery <u>are exposed to storm water</u>. For the purposes of this paragraph, material handling activities include the: storage, loading and unloading, transportation, or conveyance of any raw material, intermediate product, finished product, by-product or waste product. The term excludes areas located on plant lands separate from the plant's industrial activities, such as office buildings and accompanying parking lots as long as the drainage from the excluded areas is not mixed with storm water drained from the above described areas. Industrial facilities (including industrial facilities that are Federally, State, or municipally owned or operated that meet the description of the facilities listed in this paragraph (i)-(xi)) include those facilities designated under the provisions of 122.26(a)(1)(v). The following categories of facilities are considered to be engaging in "industrial activity" for purposes of this subsection:

*(i) Facilities subject to **storm water effluent limitations guidelines**, new source performance standards, or toxic pollutant effluent standards under 40 CFR Subchapter N (except facilities with toxic pollutant effluent standards which are exempted under category (xi) of this paragraph);* (See Table 2-1)

(ii) Facilities classified as Standard Industrial Classifications 24 (except 2434), 26 (except 265 and 267), 28 (except 283 and 285) 29, 311, 32 (except 323), 33, 3441, 373;

***(iii) Facilities classified as Standard Industrial Classifications 10 through 14 (mineral industry)** including active or inactive mining operations (except for areas of coal mining operations no longer meeting the definition of a reclamation area under 40 CFR 434.11(l) because the performance bond issued to the facility by the appropriate SMCRA authority has been released,*

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Table 2-1. CONTENTS OF 40 CFR PARTS 400 TO 471 (SUBCHAPTER N)

Part	Subchapter N - Effluent Guidelines and Standards
400	[Reserved]
401	General Provisions
402	[Reserved]
403	General pretreatment regulations for existing and new sources of pollution
405	Dairy products processing point source category
406	Grain mills point source category
407	Canned and preserved fruits and vegetables processing point source category
408	Canned and preserved seafood processing point source category
409	Sugar processing point source category
410	Textile mills point source category
411	Cement manufacturing point source category
412	Feedlots point source category
413	Electroplating point source category
414	Organic chemicals, plastics, and synthetic fibers
415	Inorganic chemicals manufacturing point source category
416	[Reserved]
417	Soap and detergent manufacturing point source category
418	Fertilizer manufacturing point source category
419	Petroleum refining point source category
420	Iron and steel manufacturing point source category
421	Nonferrous metals manufacturing point source category
422	Phosphate manufacturing point source category
423	Steam electric power generating point source category
424	Ferroalloy manufacturing point source category
425	Leather tanning and finishing point source category
426	Glass manufacturing point source category
427	Asbestos manufacturing point source category
428	Rubber manufacturing point source category
429	Timber products processing point source category
430	Pulp, paper, and paperboard point source category
431	The builders' paper and board mills point source category
432	Meat products point source category
433	Metal finishing point source category
434	Coal mining point source category; BPT, BAT, BCT limitations and new source performance standards
435	Oil and gas extraction point source category
436	Mineral mining and processing point source category
439	Pharmaceutical manufacturing point source category
440	Ore mining and dressing point source category
443	Effluent limitations guidelines for existing sources and standards of performance and pretreatment standards for new sources for the paving and roofing materials (tars and asphalt) point source category
446	Paint formulating point source category
447	Ink formulating point source category
454	Gum and wood chemicals manufacturing point source category
455	Pesticide chemicals
457	Explosives manufacturing point source category
458	Carbon black manufacturing point source category

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Table 2-1. CONTENTS OF 40 CFR PARTS 400 TO 471 (SUBCHAPTER N) (continued)

Part	Subchapter N - Effluent Guidelines and Standards
459	Photographic point source category
460	Hospital point source category
461	Battery manufacturing point source category
463	Plastics molding and forming point source category
464	Metal molding and casting point source category
465	Coil coating point source category
466	Porcelain enameling point source category
467	Aluminum forming point source category
468	Copper forming point source category
469	Electrical and electronic components point source category
471	Nonferrous metals forming and metal powders point source category

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or except for areas of non-coal mining operations which have been released from applicable State or Federal reclamation requirements after December 17, 1990 and oil and gas exploration, production, processing, or treatment operations, or transmission facilities that discharge storm water contaminated by contact with or that has come into contact with, any overburden, raw material, intermediate products, finished products, byproducts or waste products located on the site of such operations; (inactive mining operations are mining sites that are not being actively mined, but which have an identifiable owner/operator; inactive mining sites do not include sites where mining claims are being maintained prior to disturbances associated with the extraction, beneficiation, or processing of mined materials, nor sites where minimal activities are undertaken for the sole purpose of maintaining a mining claim);

(iv) Hazardous waste treatment, storage, or disposal facilities, including those that are operating under interim status or a permit under Subtitle C of RCRA;

(v) Landfills, land application sites, and open dumps that receive or have received any industrial wastes (waste that is received from any of the facilities described under this subsection) including those that are subject to regulation under Subtitle D of RCRA;

(vi) Facilities involved in the recycling of materials, including metal scrap yards, battery reclaimers, salvage yards, and automobile junkyards, including but limited to those classified as Standard Industrial Classification 5015 and 5093;

(vii) Steam electric power generating facilities, including coal handling sites;

(viii) Transportation facilities classified as Standard Industrial Classifications 40, 41, 42 (except 4221-25), 43, 44, 45, and 5171 which have vehicle maintenance shops, equipment cleaning operations, or airport deicing operations. Only those portions of the facility that are either involved in vehicle maintenance (including vehicle rehabilitation, mechanical repairs, painting, fueling, and lubrication), equipment cleaning operations, airport deicing operations, or which are otherwise identified under paragraphs (i)-(vii) or (ix)-(xi) of this subsection are associated with industrial activity;

(ix) Treatment works treating domestic sewage or any other sewage sludge or wastewater treatment device or system, used in the storage treatment, recycling, and reclamation of municipal or domestic sewage, including land dedicated to the disposal of sewage sludge that are located within the confines of the facility, with a design flow of 1.0 mgd or more, or required to have an approved pretreatment program under 40 CFR 403. Not included are farm lands, domestic gardens or lands used for sludge management where sludge is beneficially reused and which are not physically located in the confines of the facility, or areas that are in compliance with Section 405 of the CWA;

(x) Construction activity including clearing, grading and excavation activities except: operations that result in the disturbance of less than five acres of total land area which are not part of a larger common plan of development or sale;

(xi) Facilities under Standard Industrial Classifications 20, 21, 22, 23, 2434, 25, 265, 267, 27, 283, 285, 30, 31 (except 311), 323, 34 (except 3441), 35, 36, 37 (except 373), 38, 39, 4221-25, (and which are not otherwise included within categories (ii)-(x))."

Table 2-2 lists Standard Industrial Classification (SIC) Code groups which are referenced in the regulatory definition of 'storm water associated with industrial activity'.

Several aspects of the regulatory definition are highlighted below:

- The term 'storm water discharge associated with industrial activity' excludes storm water drained from areas located on plant lands separate from the plant's industrial activities, such as office buildings and accompanying parking lots as long as the drainage from the excluded areas is not mixed with storm water drained from the above described areas.

- Storm water discharges associated with industrial activity include appropriate storm water discharges from Federally, State, or municipally owned or operated facilities that conduct activities that are described in subparagraphs (i)-(xi) of the regulatory definition.

- For the categories of industries identified in subparagraph (xi), the term 'storm water discharges associated with industrial activity' includes only storm water discharges from all the areas (except access roads and rail lines) that are listed in the regulatory definition where material handling equipment or activities, raw materials, intermediate products, final products, waste materials, by-products, or industrial machinery are exposed to storm water.

2.3 Discharges Through Large And Medium Municipal Separate Storm Sewer Systems

Storm water discharges associated with industrial activity discharged through municipal separate storm sewers to waters of the United States are required to obtain NPDES permit coverage. In addition to meeting the requirements discussed in Section 4.0 of this manual, operators of storm water discharges associated with industrial activity which discharge through large or

Table 2-2. STANDARD INDUSTRIAL CLASSIFICATION (SIC) CODE GROUPS WHICH ARE REFERENCED IN THE NPDES STORM WATER REGULATIONS

SIC Code No.[1]	Title
10	Metal Mining
12	Coal Mining
13	Oil and Gas Extraction
14	Nonmetallic Minerals, Except Fuels
20	Food and Kindred Products
21	Tobacco Products
22	Textile Mill Products
23	Apparel and Other Textile Products
24	Lumber and Wood Products
25	Furniture and Fixtures
26	Paper and Allied Products
27	Printing and Publishing
28	Chemicals and Allied Products
29	Petroleum and Coal Products
30	Rubber and Miscellaneous Plastic Products
31	Leather and Leather Products (except 311)
32	Stone, Clay, and Glass Products
33	Primary Metal Industries
34	Fabricated Metal Products
35	Industrial Machinery and Equipment
36	Electronic and Other Electric Equipment
37	Transportation Equipment
38	Instruments and Related Products
39	Miscellaneous Manufacturing Industries
40	Railroad Transportation
41	Local and Interurban Passenger Transit
42	Trucking and Warehousing
43	United States Postal Service
44	Water Transportation
45	Transportation by Air
5015	Motor Vehicle Parts, Used
5093	Scrap and Waste Materials
5171	Petroleum Bulk Stations and Terminals

Notes:

(1) For the exact 4-digit SIC codes within each industry group number, refer to the Standard Industrial Classification Manual, 1987 Edition, U.S. Executive Office of the President, Office of Management and Budget.

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medium municipal separate storm sewer systems are required to submit the following information to the operator of the municipal separate storm sewer receiving the discharge no later than May 15, 1991 or 180 days prior to commencing such discharge:

(i) the name of the facility;

(ii) a contact person and phone number;

(iii) the location of the discharge; and

(iv) a description, including Standard Industrial Classification, which best reflects the principal products or services provided by each facility.

The terms "municipal separate storm sewer", "large municipal separate storm sewer system" and "medium municipal separate storm sewer system" are defined in Appendix B.

2.4 Discharges To Combined Sewer Systems

Discharges to municipal sanitary systems, including combined sewer systems (systems designed to convey municipal sanitary sewage and storm water) are not required to obtain NPDES permit coverage. However, these discharges may be subject to pretreatment requirements, including requirements implemented by permits issued by the operator of the municipal treatment plant.

2.5 Options For Applying For Permit Coverage

The NPDES regulatory scheme provides three potential tracts for obtaining permit coverage for storm water discharges associated with industrial activity: (1) individual permit applications; (2) group applications; and (3) case-by-case requirements developed for general permit coverage.

A flowchart illustrating the three potential routes, or tracks for applying for permit coverage, as well as a route or track for discharges to combined sewers is provided in Figure 2-1. The four tracks are named: the **general permit track**, the **group application track**, the **individual application track**, or the **combined sewer track**. Dischargers following the first three are required to submit information, whereas the fourth track, the combined sewer track, illustrates that permits are not required for industrial discharges to combined sewer systems[1].

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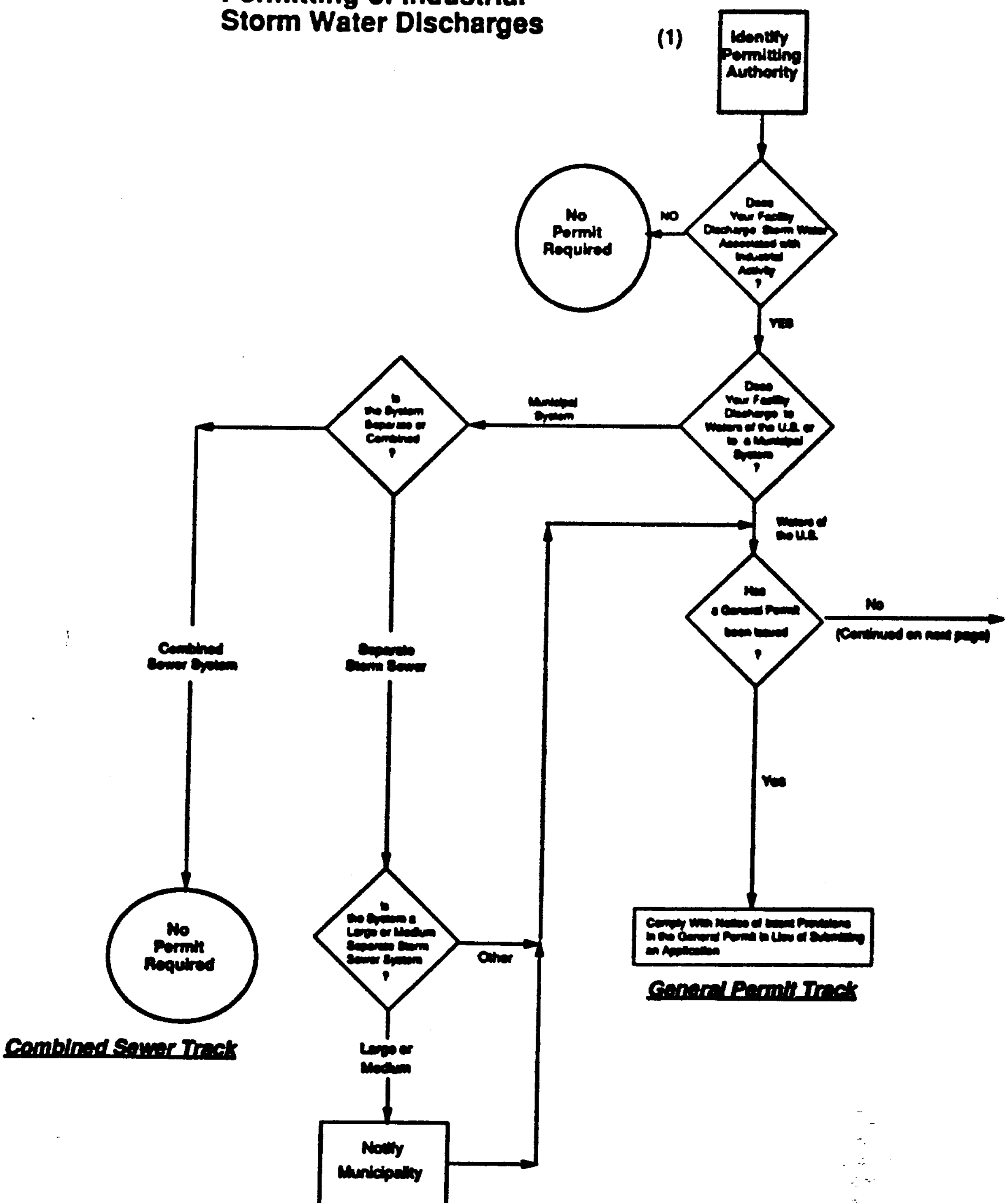
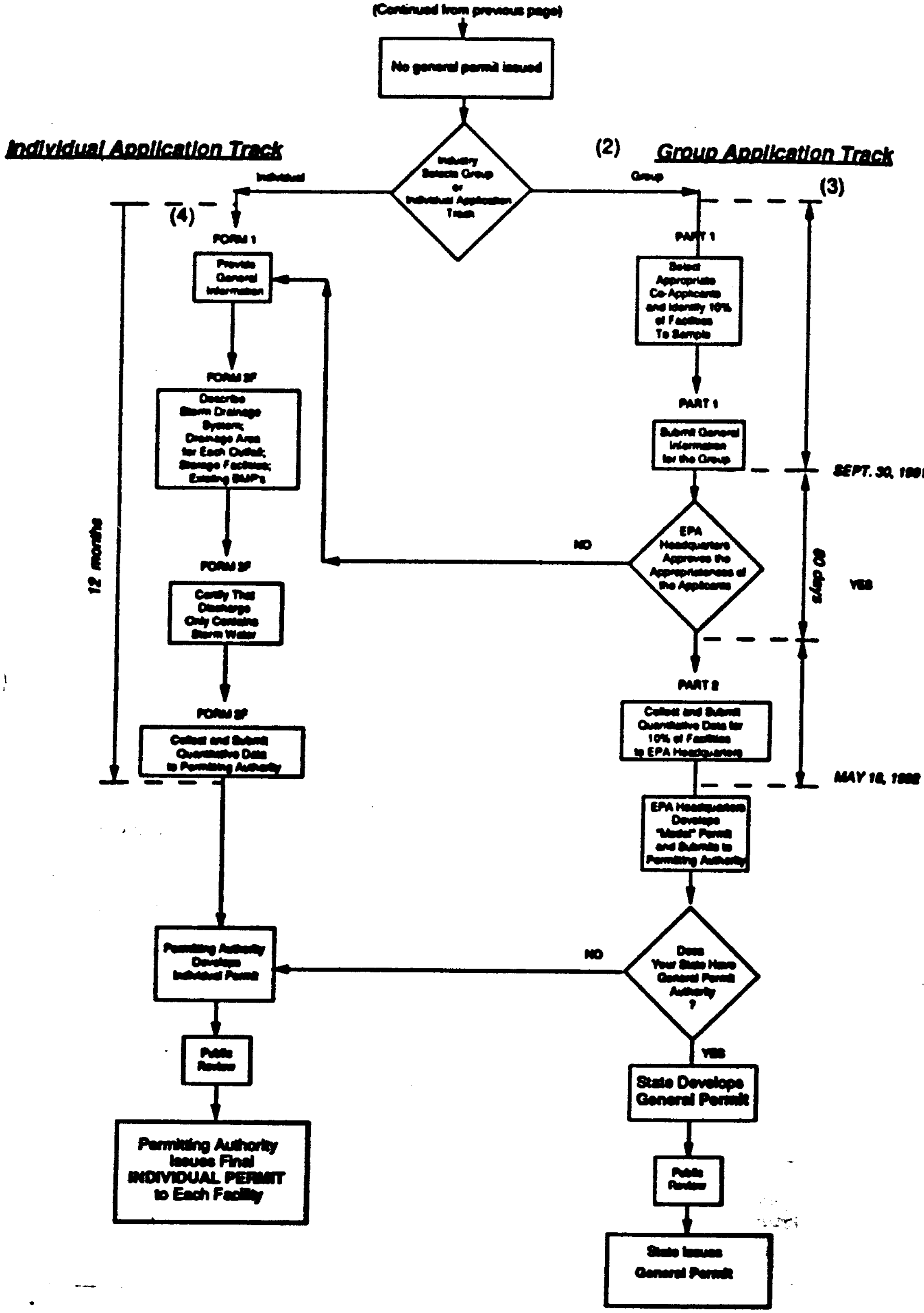
[1] *NPDES permit coverage is required for storm water discharges associated with industrial activity which either discharge directly to waters of the United States, through a municipal separate storm sewer to waters of the United States, or through a privately owned conveyance to waters of the United States. Permits are not required for industrial discharges to municipal sanitary sewer systems, including combined sewer systems. However, municipalities operating combined sewer overflows are required to obtain NPDES permits.*

Figure 2-1. Flowchart for NPDES Permitting of Industrial Storm Water Discharges



Notes:

(1) Permitting Authority: States which have NPDES permit authority, otherwise EPA regional offices
(2) States with NPDES permit authority can disallow participation in a group application
(3) Time line begins at the date of publication of the final rule
(4) Other forms may be required in addition to Forms 1 and 2F


(Continued from previous page)
No general permit issued
Individual Application Track
(2)
Group Application Track
Individual
Industry Selects Group or Individual Application Track
Group
(3)
(4)
FORM 1
Provide General Information
PART 1
Select Appropriate Co-Applicants and Identify 10% of Facilities To Sample
FORM 2F
Describe Storm Drainage System; Drainage Area for Each Outfall; Storage Facilities; Existing BMP's
PART 1
Submit General Information for the Group
SEPT. 30, 1991
12 months
NO
EPA Headquarters Approves the Appropriateness of the Applicants
60 days
YES
FORM 2F
Certify That Discharge Only Contains Storm Water
PART 2
Collect and Submit Quantitative Data for 10% of Facilities to EPA Headquarters
FORM 2F
Collect and Submit Quantitative Data to Permitting Authority
MAY 18, 1992
EPA Headquarters Develops "Model" Permit and Submits to Permitting Authority
Permitting Authority Develops Individual Permit
NO
Does Your State Have General Permit Authority ?
YES
Public Review
State Develops General Permit
Permitting Authority Issues Final INDIVIDUAL PERMIT to Each Facility
Public Review
State Issues General Permit

The **individual permit application track** (i.e., the third tier on the flowchart) is applicable to all storm water discharges associated with industrial activity except: where the operator of the discharge is participating in a group application; where a general permit has been issued to cover the discharge and the general permit provides alternative means to obtain permit coverage; or where the discharge is to a sanitary sewer, including a combined sewer. For most storm water discharges associated with industrial activity, the requirements for an individual permit application are incorporated into Form 1 and Form 2F. Special individual application requirements for storm water discharges associated with industrial activity from construction activities, mining operations, oil and gas operations, and small businesses are discussed in Chapter 3.

The **group application track** (i.e., the second tier of the flowchart) allows a group of similar industries to submit a group application. This will often be an efficient alternative to preparing and submitting individual permit applications because it may reduce the cost for applicants. The requirements for group applications are discussed in Appendix D. Authorized NPDES States may establish requirements which are more stringent than EPA requirements, and may require facilities with storm water discharges associated with industrial activity to submit individual applications rather than participate in a group application.

The **general permit track** (i.e., the top tier of the flowchart) may be available where a general permit for the discharge has been issued. In this case, the facility operator must comply with any applicable Notice of Intent (NOI) provisions of the general permit instead of submitting an individual permit application.

The **combined sewer track** (i.e., the bottom tier of the flowchart) is followed if an industrial facility discharges storm water associated with industrial activity to a municipal sanitary sewer, including sewers that are part of a combined sewer systems. In this case, an NPDES permit for the storm water discharge to the combined sewer is not required. However, the operator of the sewage treatment works may develop pretreatment requirements (including requirements implemented through permits issued by the sewage treatment operator) applicable to industrial facilities discharging to combined sewers.

Section 2.5 of this manual describes the three options that operators of storm water discharges associated with industrial activity may follow for obtaining permit coverage for storm water discharges associated with industrial activity: (1) individual permit applications; (2) group applications; and (3) case-by-case requirements developed for general permit coverage. In addition, section 2.4 explains that storm water discharges associated with industrial activity to municipal sanitary systems, including combined sewer systems (systems designed to convey municipal sanitary sewage and storm water) are not required to obtain NPDES permit coverage.

This Chapter focusses on the procedures and requirements associated with submitting individual permit applications. Appendix D.2 discusses the procedures and requirements associated with submitting group applications.

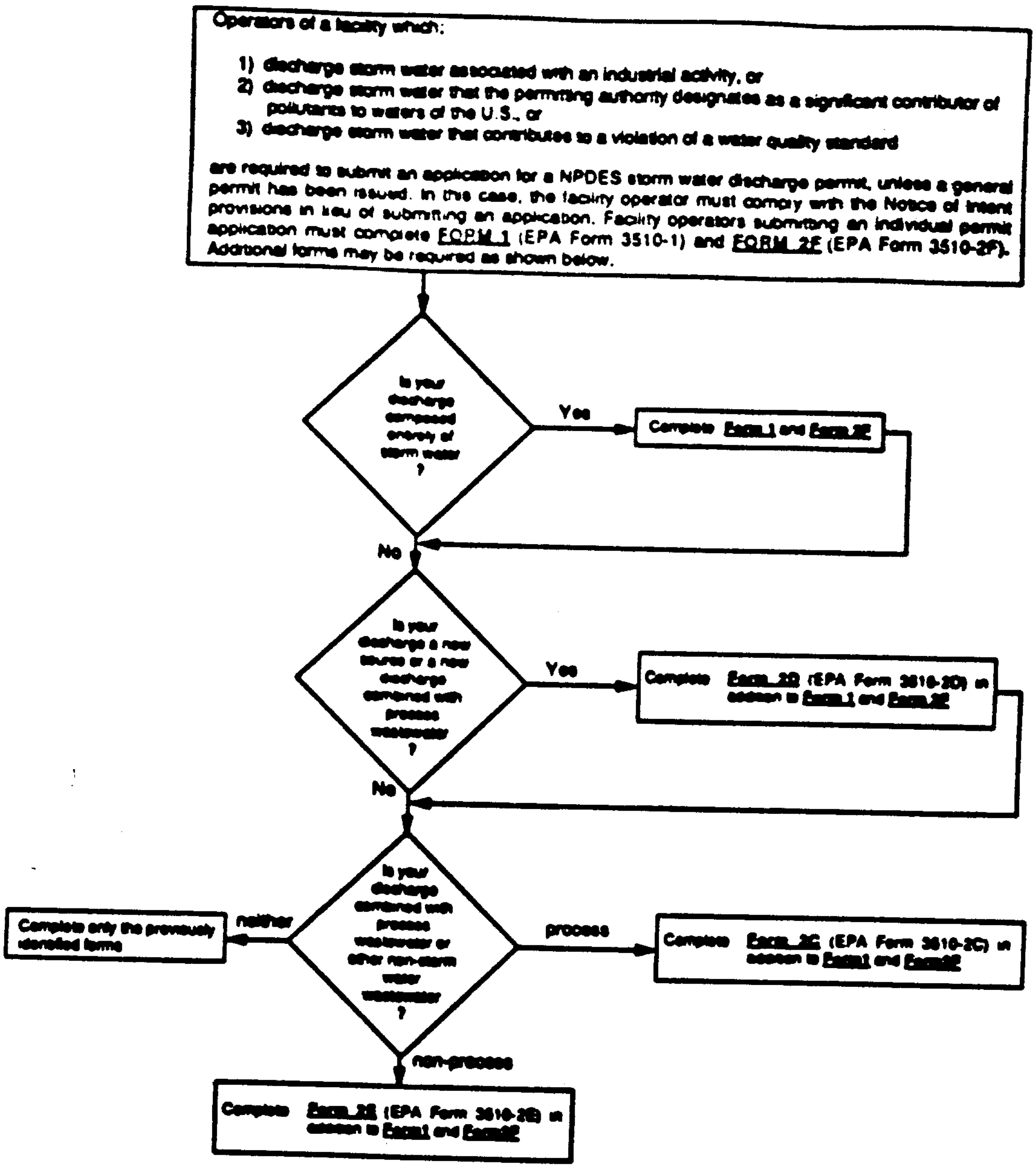
Section 3.1 discusses the process of submitting individual permit applications. Section 3.2 provides an overview of the requirements of Form 1 and Form 2F, the individual permit application forms for most storm water discharges associated with industrial activity. Section 3.3 discusses special provisions for individual applications for storm water discharges associated with industrial activity from: small businesses; construction activities; and mining and oil and gas operations. Section 3.4 discusses deadlines for submitting individual permit applications. Section 3.5 describes the additional application forms that are necessary if storm water associated with industrial activity is mixed with non-storm water. Section 3.6 explains where to obtain and submit permit applications. Section 3.7 describes signatory requirements for individual permit applications, and Section 3.8 describes penalties for knowingly submitting false information.

3.1 The Process Of Submitting Individual Applications

Figure 3-1 illustrates the process of selecting and submitting the application forms to use for individual permit applications for storm water discharges associated with industrial activity. The items on this list are discussed below:

1) Determine whether the discharge is considered a storm water discharge associated with industrial activity. Refer to the definition of "storm water discharge associated with industrial activity" provided in Section 2.2 of this guidance.

2) Determine whether the State in which the discharge(s) is located has an authorized NPDES program. A list of these States is provided in Appendix C. The permit application forms required by



Note: This flow chart does not address group application track or NOI/General permit track

FIGURE 3-1: FLOW DIAGRAM TO IDENTIFY WHICH FORMS MUST BE SUBMITTED WHEN APPLYING FOR AN INDIVIDUAL NPDES STORM WATER DISCHARGE PERMIT

authorized NPDES States may be different from the EPA-required forms that are discussed in this manual.

3) Determine the track (e.g. individual permit application track, group application track, general permit track, etc.) that the discharger will pursue to comply with application requirements. The options for different tracks are discussed in section 2.5 of this guidance.

4) Obtain the appropriate application forms if submitting an individual permit application. Sections 3.2, 3.3, and 3.5 of this guidance manual provide information on permit application forms and requirements. Section 3.6 describes where forms can be obtained.

5) Submit the completed application to the appropriate permitting regulatory agency by the application deadline (Section 3.4). Section 3.6 describes where applications are to be submitted.

3.2 Forms 1 And 2F

The requirements for individual permit application for most types of discharges composed of storm water associated with industrial activity are incorporated into Form 1 and Form 2F. (Section 3.3.2 discusses alternative individual permit application requirements for storm water discharges associated with industrial activity from construction activities and Section 3.5 discusses the additional forms necessary where storm water discharges associated with industrial activity are mixed with any non-storm water discharge).

Form 1 (EPA Form 3510-1) requires general information about the facility, including: the name and address of the facility; the facility type (i.e., SIC code); a map showing specified features, etc. See Appendix D.1 for a sample application form with instructions.

Form 2F (EPA Form 3510-2F) contains information which can be used to evaluate the pollution potential of storm water discharges associated with industrial activity, including:

- a map showing site drainage;
- an estimate of the area of impervious surfaces and the total area drained by each outfall;
- a narrative description of material management practices and control measures;
- a certification that separate storm water outfalls have been tested or evaluated for non-storm water discharges;

- existing information regarding significant leaks or spills of toxic or hazardous pollutants at the facility that have taken place within the three years prior to the submittal of the application; and

- sampling data for specified parameters.

See Appendix E.2 for a sample application form with instructions. Section 5.0 provides technical guidance for obtaining or estimating the following information required by Form 2F: preparing a site drainage map, detecting the presence of non-storm water discharges, measuring storm water runoff flow rates and volumes, and sampling equipment and procedures for collecting storm water discharge samples.

3.3 Special Provisions For Selected Discharges

3.3.1 Special Provisions For Small Businesses

Small businesses with storm water discharges associated with industrial activity do not have to analyze storm water discharges associated with industrial activity for the organic toxic pollutants listed in Table 2F-3 of Form 2F. (Small business with storm water discharges associated with industrial activity are subject to the other appropriate requirements of Form 1 and Form 2F, including requirements to sample for specified conventional pollutants and other specified constituents (40 CFR 122.21(g)(8)).

There are two ways in which a facility can qualify as a "small business." If the facility is a coal mine, and if the probable total annual production is less than 100,000 tons per year, past production data or estimated future production (such as a schedule of estimated total production under 30 CFR 79514[c]) may be submitted instead of conducting analyses for the organic toxic pollutants. Facilities that are not a coal mine with gross total annual sales for the most recent three years average less that $100,000 per year (in second quarter 1980 dollars), may submit sales data for those years instead of conducting analyses for the organic toxic pollutants. The production or sales data must be for the facility which is the source of the discharge. The data should not be limited to production or sales for the process or processes which contribute to the discharge, unless those are the only processes at the facility. For sales data, in situations involving intra-corporate transfer of goods and services, the transfer price per unit should approximate market prices for those goods and services as closely as possible. Sales figures for years after 1980 should be indexed to the second quarter of 1980 by using the gross national product price deflator (second quarter of 1980 = 100). This index is available in National Income and Product Accounts of the United States (Department of Commerce, Bureau of Economic Analysis).

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3.3.2 Special Provisions For Construction Activities

The application requirements for operators of storm water discharges associated with industrial activity from construction activities include Form 1 and a narrative description of:

(i) the location (including a map) and the nature of the construction activity;

(ii) the total area of the site and the area of the site that is expected to undergo excavation during the life of the permit;

(iii) proposed measures, including best management practices, to control pollutants in storm water discharges during construction, including a brief description of applicable State and local erosion and sediment control requirements;

(iv) proposed measures to control pollutants in storm water discharges that will occur after construction operations have been completed, including a brief description of applicable State and local storm water management controls;

(v) an estimate of the runoff coefficient of the site and the increase in impervious area after the construction addressed in the permit application is completed, the nature of fill material and existing data describing the soil or the quality of the discharge; and

(vi) the name of the receiving water.

At this time, EPA has not developed a standardized form for the narrative information accompanying Form 1 that is required in individual applications for storm water discharges associated with industrial activity from construction sites.

3.3.3 Mining And Oil And Gas Operations

Several specific regulatory provisions are applicable to storm water discharges associated with industrial activity from mining and oil and gas operations:

(1) **Mining operations and Oil and Gas- (40 CFR 122.26(a)(2)):** The permitting authority may not require a permit for discharges of storm water runoff from mining operations or oil and gas exploration, production, processing or treatment operations or transmission facilities, composed entirely of flows which are from conveyances or systems of conveyances (including but not limited to pipes, conduits, ditches, and channels) used for collecting and conveying precipitation runoff and which are not contaminated by contact with or that has not come into contact with, any overburden,

raw material, intermediate products, finished product, byproduct or waste products located on the site of such operations.

(2) Oil and gas- (40 CFR 122.26(c)(1)(iii)): The operator of an existing or new discharge composed entirely of storm water from an oil or gas exploration, production, processing, or treatment operation, or transmission facility is not required to submit a permit application, unless the facility:

(A) has had a discharge of storm water resulting in the discharge of a reportable quantity for which notification is or was required pursuant to 40 CFR 117.21 or 40 CFR 302.6 at anytime since November 16, 1987; or

(B) has had a discharge of storm water resulting in the discharge of a reportable quantity for which notification is or was required pursuant to 40 CFR 110.6 at any time since November 16, 1987; or

(C) contributes to a violation of a water quality standard.

3.4 Individual Applications Deadlines

Individual permit applications for storm water discharges associated with industrial activity which are currently not covered by an NPDES permit must be submitted by November 18, 1991.

Operators of discharges which are authorized by an individual NPDES permit must resubmit individual permit applications 180 days prior to the termination of the existing NPDES permit.

Permit applications for a new discharge of storm water associated with industrial activity must be submitted 180 days before that facility commences industrial activity which may result in a discharge of storm water associated with that industrial activity. Permit applications for a new discharge of storm water associated with industrial activity from a construction activity (see subparagraph (x) of the definition in section 2.3 of this document) must be submitted at least 90 days before the date on which construction is to commence. Persons proposing a new discharge are encouraged to submit their application well in advance of the 90 or 180 day requirements to avoid delay.

Where a general permit has been issued, deadlines for submitting a notice of intent (NOI) to be authorized to discharge under the permit are established in the permit.

3.5 When Are Additional Forms Required?

Where a storm water discharge associated with industrial activity is mixed with a non-storm water component prior to discharge, an additional application form must be submitted.

A complete permit application for a storm water discharge associated with industrial activity mixed with process wastewater, (process wastewater is water that comes into direct contact with or results from the production or use of any raw material, intermediate product, finished product, byproduct, waste product or wastewater) includes Form 1, Form 2F and Form 2C.

A complete permit application for a storm water discharge associated with industrial activity mixed with new sources or new discharges of non-storm water (non-NPDES permitted discharges commencing after August 13, 1979) includes Form 1, Form 2F and Form 2D.

A complete permit application for a storm water discharge associated with industrial activity mixed with nonprocess wastewater (nonprocess wastewater includes noncontact cooling water and sanitary wastes which are not regulated by effluent guidelines or a new source performance standard, except discharges by educational, medical, or commercial chemical laboratories) includes Form 1, Form 2F and Form 2E.

3.6 Where To Obtain And Submit Applications

In States without an authorized NPDES State program, EPA issues all NPDES permits. Where EPA issues permits, permit application forms can be obtained from and submitted to the appropriate EPA Regional office. (See Appendix C.2 for a list of the addresses and telephone numbers of the EPA Regional offices).

In States with authorized NPDES programs, application forms can be obtained from and submitted to the appropriate State office. A list of these States is provided in Appendix C. The permit application forms required by authorized NPDES States may be different from the EPA-required forms that are discussed in this manual.

3.7 Signatories

Section X of Form 2F requires that all permit applications must be signed with the following certification:

"I certify under penalty of law that this document and all attachments were prepared under my direction or supervision in accordance with a system designed to assure that qualified personnel properly gather and evaluate the

information submitted. Based on my inquiry of the person or persons who manage the system, or those persons directly responsible for gathering the information, the information submitted is, to the best of my knowledge and belief, true, accurate, and complete. I am aware that there are significant penalties for submitting false information, including the possibility of fine and imprisonment for knowing violations."

This certification is to be signed as follows:

(A) **For a corporation:** by a responsible corporate official. For purposes of this section, a responsible corporate official means (i) a president, secretary, treasurer, or vice-president of the corporation in charge of a principal business function, or any other person who performs similar policy or decision-making functions for the corporation, or (ii) the manager of one or more manufacturing, production, or operating facilities employing more than 250 persons or having gross annual sales or expenditures exceeding $25,000,000 (in second-quarter 1980 dollars), if authority to sign documents has been assigned or delegated to the manager in accordance with corporate procedures.

EPA does not require specific assignments or delegation of authority to responsible corporate officers. The Agency will presume that these responsible corporate officers have the requisite authority to sign permit applications unless the corporation has notified the Director to the contrary. Corporate procedures governing authority to sign permit applications may provide for assignment or delegation to applicable corporate position rather than to specific individuals.

(B) **For a partnership or sole proprietorship:** by a general partner or the proprietor, respectively; or

(C) **For a municipality, State, Federal, or other public agency:** by either a principal executive officer or ranking elected official. For purposes of this section, a principal executive officer of a Federal agency includes (i) the chief executive officer of the agency, or (ii) a senior executive officer having responsibility for the overall operations of a principal geographic unit of the agency (e.g. Regional Administrators of EPA).

3.8 Penalties For Knowingly Submitting False Information

The Clean Water Act provides for severe penalties for knowingly submitting false information on application forms. Section 309(c)(4) of the Clean Water Act provides that *"Any person who knowingly makes any false material statement, representation, or certification in any application, . . . shall upon conviction, be punished by a fine of not more than $10,000 or by imprisonment for not more than 2 years or by both. If a conviction of such person is for a violation committed after a first conviction of such person under this paragraph, punishment shall be by a fine of not more than $20,000 per day of violation, or by imprisonment of not more than 4 years or by both."*

SECTION 4.0 THE PERMITTING PROCESS

The purpose of this section is to provide the applicant with a summary of the process of issuing NPDES permits for storm water discharges associated with industrial activity.

4.1 How Are Individual Applications Processed?

Following the submission of the NPDES permit application, the permitting authority reviews the application for completeness. If additional information is required to complete the application, the permitting authority will notify the applicant. The permitting authority will specify a deadline for submitting the additional information. The effective date of the application is the date when the permitting authority determines that the application is complete.

The permitting authority may request additional information beyond what is required in the application form. The permit writer will use available information, primarily that in the permit application, to develop a draft permit or a notice to deny a permit. All draft permits and notices of intent to deny a permit will include a statement of basis or a draft fact sheet. The statement of basis will briefly describe the rationale for either proceeding with issuing a permit or denying a permit. The draft fact sheet will include the principal facts, methodology, and any legal or policy questions considered in the decision to proceed with issuing a permit.

All draft permits and notices of intent to deny a permit are subject to public notice and will be made available for public comment. The permitting agency will give public notice when: (1) a permit application has been tentatively denied, (2) a draft permit is issued, (3) an evidentiary hearing is granted, or (4) when a new source determination has been made.

After the close of the public comment period, the permitting agency will issue a final decision. The permitting agency, upon issuance of the final decision, will respond to comments, identify any changes in the tentative decision (to either permit or deny a permit) and give any reason pertinent to the changes. If a final NPDES permit is issued, the permit usually specifies the effective date, at which time, the facility is legally authorized to discharge storm water associated with an industrial activity subject to the permit conditions. A more complete description of the processes involved in obtaining an NPDES Permit is provided in 40 CFR Part 124, especially Subpart D.

4.2 Completeness Of The Application

Prospective applicants seeking an NPDES permit for storm water related industrial activity can refer to the following list that summarizes the applicant's primary responsibilities (Table 4-1). This application checklist is useful

Table 4-1. PERMIT APPLICATION CHECKLIST

Action Checklist	Date Completed/ Signature of Person Filling out
1. Determine whether a permit is required for the storm water discharge.	______
o Refer to Section 3.0 of this manual	______
o Contact the permitting authority, if necessary	______
o Record name of contact person	______
2. Determine whether the state in which the discharge(s) is located has an EPA-approved NPDES program.	______
o Refer to Appendix C of this manual	______
o Determine which forms need to be submitted for individual applications.	______
o If EPA is the permitting authority, list appropriate forms (Refer to Figure 4-1)	______
o For EPA-approved states, contact the permitting authority for appropriate forms and instructions	______
3. Determine if a general permit will be, or has been, issued for the discharge.	______

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Table 4-1. PERMIT APPLICATION CHECKLIST (continued)

Action Checklist	Date Completed/ Signature of Person Filling out
4. If no general permit, select between participating in a group application or submitting an individual application.	____________
5. Determine what the deadlines are for the permit application.	____________
o Check Section 4.6 of this manual if EPA is the permitting authority	____________
o Contact the state permitting agency if this information is not provided in the application form or instructions provided by that agency	____________
6. Complete the appropriate application forms. All applicants are to submit Forms #1 and 2F. Refer to Figure 4-1 to determine if Forms 2C, 2D, and/or 2E need to be submitted.	____________
7. Retain a complete copy of the permit application and all supporting documentation.	____________
8. Submit the completed application forms to the appropriate permitting agency by the application deadline identified above.	____________

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for the applicant for self-checking the completeness of the application prior to submission. Applications will not be considered complete unless all applicable information required is provided. If an item does not apply, "NA"(for "not applicable") may be entered in the appropriate space. If additional information is required, the applicant will be notified.

4.3 Public Availability Of Submitted Information

Section 402(j) of the Clean Water Act requires that all permit applications will be available to the public. Information in permit applications will be made available to the public upon request. Any information required in a permit application may not be claimed as confidential. Any information submitted to EPA which goes beyond that required by Form 1, Form 2F or other appropriate forms may be claimed as confidential. However, claims for confidentiality of effluent data will be denied.

If a claim of confidentiality is not asserted at the time of submitting the information, EPA may make the information public without further notice to the applicant. Claims of confidentiality will be handled in accordance with EPA's business confidentiality regulations at 40 CFR Part 2.

4.4 How Long Is A Permit Valid?

A permit will be issued by the permitting agency for a period up to, but not more than 5 years. Dischargers must reapply for a permit 180 days before the expiration date of the permit.

The permit is not transferable except after notice to and approval by the permitting authority. The Director of the permitting authority may require modification or revocation and reissuance of the permit to change the name of the permittee and incorporate such other requirements that may be necessary under the CWA.

4.5 How Are NPDES Permits Enforced?

The CWA provides that any person who violates a permit condition is subject to a civil penalty not to exceed $25,000 per day of violation. Any person who willfully or negligently violates a permit is subject to a fine of not less than $2,500 or more than $25,000 per day of violation, or imprisonment for not more that 1 year, or both (40 CFR 122.41(a)).

The operator of a facility must allow a representative of the permitting authority upon the presentation of credentials and other documents as may be required by law, to enter the regulated facility and inspect records pertaining to the permit. This includes, but is not limited to, monitoring and control equipment, practices, and operations regulated under this permit. The representative may also sample the storm water discharge for any substance to assure compliance with the permit conditions. Inspection activities are to be conducted at reasonable times (40 CFR 122.41(i)(1) to (4)).

The operator must retain all records of discharge monitoring for at least three years from the date of the sample, measurement, report, or application. This includes all calibration and maintenance records, all original strip charts from continuous monitoring, copies of all records required by the permit, and all records of data used to complete the NPDES permit application 40 CFR 122.41(j)(2).

The CWA provides that any person who knowingly falsifies any record or document, tampers with or renders inaccurate any monitoring device, shall upon conviction be punished by a fine of not more than $10,000 per violation, or by imprisonment for not more than 2 years, or both (40 CFR 122.41(j)(5) and (k)(2)).

Additional penalties for knowingly submitting false information in applications are described in Section 2 of this manual.

SECTION 5.0 TECHNICAL SUPPORT FOR SPECIFIC ELEMENTS OF THE NPDES PERMIT APPLICATION FORMS

5.1 Overview

The instructions provided with Form 2F are expected to be sufficient for most applicants. This section provides additional technical guidance for obtaining information required by Form 2F, including guidance for: developing site maps; identification of outfalls that discharge storm water associated with industrial activity; testing for the presence of non-storm water discharges; estimating storm water runoff flow rates and volumes; and collecting samples.

5.2 Site Drainage Map

Section III of Form 2F requires that a site drainage map be attached to the application. The site drainage map must show either topography or a delineation of the drainage area served by each outfall which discharges storm water associated with industrial activity if a topographic base map is not used. The delineation of the drainage area for each outfall that discharges storm water associated with industrial activity, can be based on site observations which identify drainage patterns. Drainage patterns should be shown on the site drainage map so that runoff from each drainage area drains to a separate outfall.

The site drainage map must show the location (and size - approximate for earthen structures) of all drainage conveyances or natural channels that convey or drain storm water off the applicant's property. The map must indicate whether the drainage system receiving the discharge is a natural water body, part of a municipal or non-municipal drainage system, or other system as applicable.

The following information must be provided and recorded on the map where appropriate:

- Paved areas and buildings at the facility
- Past and present outdoor areas used for storage or disposal of significant materials
- Hazardous waste treatment, storage or disposal facilities, or accumulation areas (including those not requiring a RCRA permit)
- Injection wells

- Material loading and access areas (e.g., loading docks and main truck routes on the facility property)

- Areas where pesticides, herbicides, soil conditioners, and fertilizers are applied

- Structural control measures to reduce pollutants in storm water runoff

- Surface water bodies which receive storm water discharges from the facility

During the preparation of a site drainage map, or the review of an existing one, emphasis should be placed on the identification of all inflow sources to ensure that inappropriate sources of non-storm water entry are not present. The map should identify points of entry to the facility site storm water drain system, including catchbasins, floor drains, and roof leaders.

The site drainage map required in Form 2F should show the location and an identifying number or name for each storm water outfall at the facility.

5.3 Identification Of Outfalls To Be Monitored

Form 2F requires that applicants provide quantitative data for samples of storm water discharges associated with industrial activity. If a facility discharges storm water associated with industrial activity to a municipal separate storm sewer, then the facility should sample the storm water from the site prior to discharging to the municipal separate storm sewer. Storm runoff from areas located on plant lands separate from the plant's industrial activities, such as administrative buildings roofs and accompanying parking lots are not defined as storm water associated with industrial activity and hence do not need to be monitored unless the runoff is combined with storm water associated with industrial activity. Figure 5-1 shows several scenarios for storm water outfalls that may or may not need to be monitored as part of a NPDES permit application. 40 CFR 122.21(g)(7) provides that when an applicant has two or more outfalls with substantially identical effluents, the Director may allow the applicant to test only one outfall and report that the quantitative data also apply to substantially identical outfalls.

5.4 Evaluation Of The Presence Of Non-storm Water Discharges

Form 2F requires applicants to certify that all outfalls that discharge storm water associated with industrial activity have been tested or evaluated for the presence of non-storm water discharges. Applicants do not have to test for the presence of non-storm water discharges already subject to an NPDES permit. Acceptable procedures include: dry weather observations of outfalls or other appropriate observation locations; the analysis and validation of accurate piping

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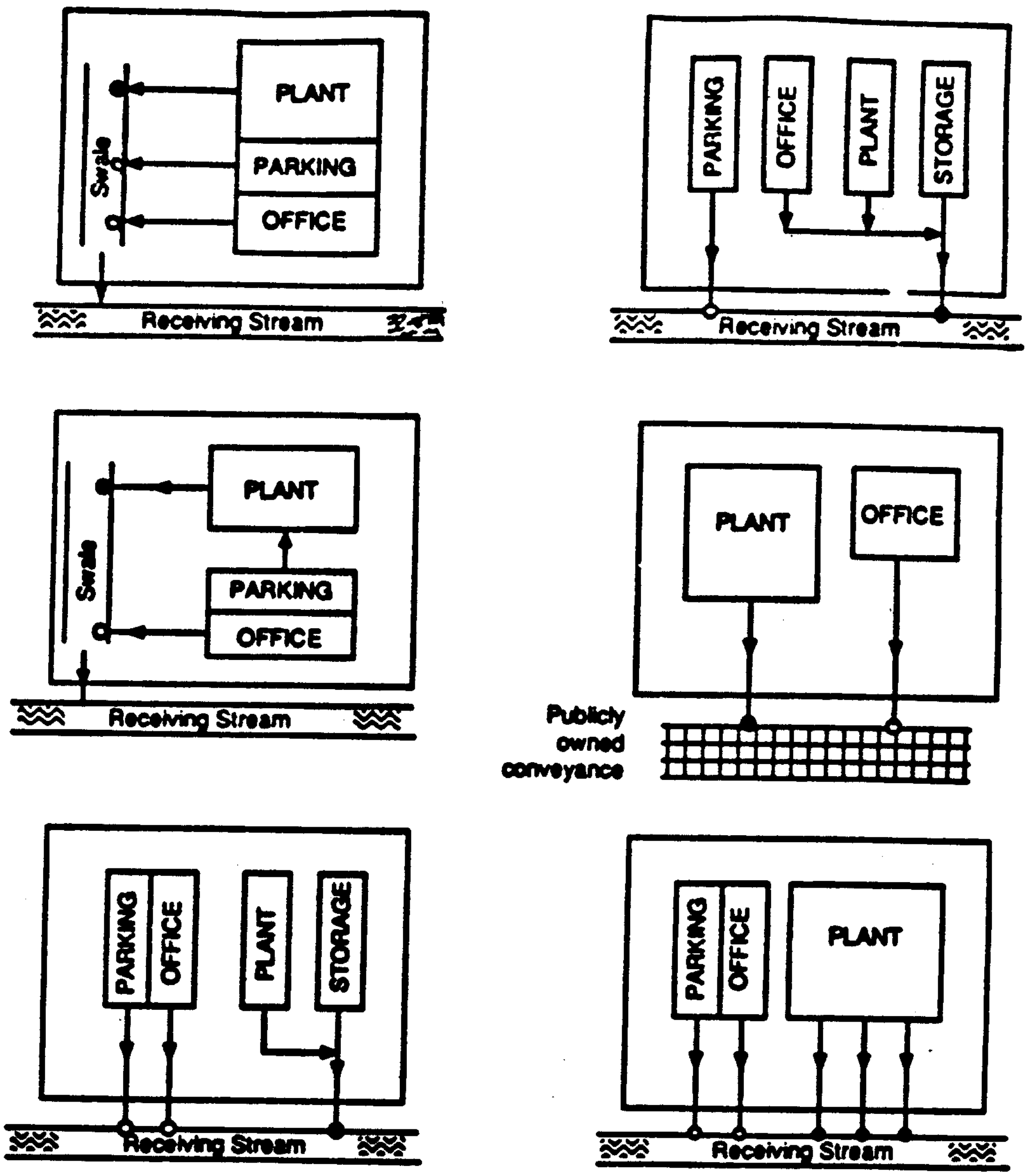

● Outfall discharges storm water associated with industrial activity (sampling typically required in Form 2F).

○ Outfall discharges storm water that is not associated with industrial activity (sample typically not required in Form 2F).

→ Storm runoff direction

Figure 5-1. EXAMPLE INDUSTRIAL STORM RUNOFF OUTFALLS WITH STORM WATER DISCHARGE ASSOCIATED WITH INDUSTRIAL ACTIVITY

schematics; dye tests; or other procedures for ensuring that there are no inappropriate connections or discharges to the storm drain system. The permit application requires a description of the method used, the date of testing (if applicable), and the onsite drainage locations observed during the test. Any non-storm water discharge which is not already identified in a NPDES permit which is detected must be identified in Form 2C (for process wastewater) or Form 2E (for non-process wastewater) which must accompany the storm water discharge application (Form 1 and Form 2F).

The following sections provide a description of several procedures that can be used in developing a certification and an overview of the applicability of the tests and the resources required for performing the tests. A first step should be to identify potential sources of non-storm water at the facility and to focus on those places.

5.4.1 Visual Inspection of Storm Drain at Manhole Inlet or Outfall Description

A visual inspection of the system conducted during dry weather, can be an effective method of locating illicit connections to the storm drain system. The observation should be made during normal business hours when sources of non-storm water are typically operating. A record should be kept of all observed flows and any stains, sludges, or other abnormal conditions observed. Where flows are observed, additional analysis, such as dye testing (described below) may be necessary to identify the source of the flows.

Applicability: This method is applicable to any industrial site with a storm drain system where an outfall or other location (e.g. manhole) down gradient from potential non-storm water discharges can be observed.

Resources: No special equipment is required.

5.4.2 Review and Validation of Piping Schematics Description

A careful review of piping schematic drawings for industrial sites can identify the intended routing of flows from particular areas or drains. This review should be accompanied by visual inspection to compare the "as built" condition to the plans and to determine whether any unrecorded piping modifications have been made.

Applicability: This method is most applicable for industrial sites which have large or elaborate piping arrangements, usually recorded on schematic piping drawings. It is most applicable in conjunction with use of the other techniques described below.

Resources: No special equipment is required, though dye tests may be useful in specific situations to clarify discrepancies which cannot be resolved visually.

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5.4.3 Dye Tests Description

Dye tests are used to determine whether a particular inlet or fixture discharges non-storm water to the storm drain. A quantity of dye is released at the selected location while an observer watches for the dye at a downstream location. If the inlet is discharging to the storm drain, the dye will be detected at the downstream location. Dye doses should be sufficiently large so that the dye at the downstream location is visible to the naked eye.

Applicability: Dye tests are most effective for determining if an identified drain or catchbasin is connected to the storm sewer where the outfall of the storm sewer is submerged, but the receiving water can be observed. (Where the outfall or other point can be observed and is not submerged, dry weather observation can be made or water can be used instead of a dye). Dye tests can also be used where dry weather flows have been observed, but the source of the flow has not yet been observed. It is best used when there are only a limited number of possible sources of non-storm water to the storm drain that need to be investigated.

Resources: No special equipment is necessary to conduct a dye test. Dye is the only material required. Effective dyes that are safe and harmless are available in powder, tablet, or liquid form. A 20% solution of Rhodamine (liquid) costs about $15/lb. Dye can be purchased in 2-1/2 gallon containers which weigh 25 pounds and cost about $400. This can be diluted before each test by an approximate ratio of 10 to 1. A minimum field crew of two is needed, one to apply the dye, the other to observe the storm drain.

5.4.4 TV Line Surveys Description

TV surveys are conducted with a mobile closed-circuit television system consisting of a monitor screen, camera, drag lines, and reels and cables that allow the camera to be guided through a section of pipeline. The TV picture allows a visual inspection of the interior of the drain pipe and can be used for pipelines with diameters that range from 4 inches to approximately 48 inches. Television inspection of a storm drain provides positive information (and a documented record) of the interior of the pipelines. All inlets to the line can be identified and located. Systems for conducting TV surveys can be purchased, leased, or rented. Alternatively, a firm which specializes in this work can be hired.

Applicability: TV surveys may serve as useful tools where an initial survey identifies a non-storm water discharge and the operator is having difficulty in finding the source. A TV survey can locate entry points to the storm drain system, determine whether or not there is flow in them, and permit estimates of the flow to be made. However, in many cases, these observations will need to be supplemented by other methods to identify the specific source (above ground) of the connection. This may be accomplished by inspection of drain maps, dye tests, or possibly smoke tests.

Resources: Resources required for a TV survey of storm drains include the following:

- TV camera
- TV monitor and VCR to record survey
- Rig consisting of video cables, tow lines, and related equipment for properly guiding the camera in the line at a controlled rate, recording distance moved, and withdrawing the camera from the pipeline

The cost to conduct a TV survey can range from $1 to $3 per foot of storm sewer. For small surveys costs could vary from $125 to $200 per hour, including labor and rental of the necessary equipment. However, this cost can increase significantly if the storm sewer must be cleaned of debris prior to conducting the TV survey. On average, approximately 1000 feet of sewer can be inspected in a day. In a clean sewer, up to 2000 feet can be inspected.

The applicant should refer to "Operation and Maintenance of Wastewater Collection Systems" (CSU 1983) or similar appropriate reference documents for a detailed description of these test methods.

5.5 Estimates Of Discharge Flow Rates And Volumes

Form 2F requires applicants to provide quantitative data based on samples collected during storm event(s). One set of parameters that must be provided for such storm event(s) are flow estimates or flow measurements, and an estimate of the total volume of the discharge. The method of flow estimation or measurement must be described in the application.

EPA intends that applicants need only provide rough estimates of flows in Form 2F. The following section discusses methods for obtaining the required information. Section 5.5.1 presents a method for approximating flows and volumes which does not require flow velocity measurements. The following subsections discuss other methods that require measurements of flow velocities.

5.5.1 Estimating Flows and Volumes

Runoff flow rates and volumes can be estimated by using the total rainfall amount for the storm event and estimated runoff coefficients for the facility. Runoff coefficients represent the fraction of total rainfall that will be transmitted as runoff from the facility. As such, the coefficients reflect the ground surface or cover material. To estimate runoff volume and rates, it can be assumed that paved areas and other impervious structures such as roofs have a runoff coefficient of 0.90 and, therefore, 90% of the rainfall is conveyed from the facility as runoff. For unpaved surfaces, it can be assumed that the runoff coefficient is about 0.50. The total volume of discharge for the event is then estimated by:

> total runoff volume (cubic ft) = total rainfall (ft) x [facility paved area x 0.90 + facility unpaved area x 0.50]

The facility areas used in this calculation should be in units of square feet and should include only those areas drained by the outfall sampled. To estimate an average flow rate, divide the volume by the duration of the rainfall event. If desired, a more accurate estimate can be made by using more specific runoff coefficients for different parts of the facility based on the type of ground cover (Chow 1964 contains various runoff coefficients and discusses their use).

5.5.2 Flow Rate Measurements

There are a variety of techniques for measuring or estimating flow rates. Flow measuring devices based on pipe invert sections (e.g., flumes, weirs, and others) are commercially available. For locations that may be used for routine monitoring in the future, the applicant may consider installing these types of devices for ease in future measurements. The installed cost of a weir, for example, typically ranges from about $1,000 to $5,000. Once installed, the weir must be calibrated so that future measurements of stage (i.e., depth of flow) can be converted directly to flow volumes. The installation and calibration of such devices should be performed by experienced personnel.

To estimate flow rates in units of volume per time such as cubic feet per second, information on flow velocities and depth of flow are required. The remainder of this section discusses methods for collecting these data.

Flow rate estimates may also be obtained by measuring depth of flow and velocity in a pipe of known diameter or other conveyance structure at frequent intervals during a storm runoff event. For a pipe or other structure of known size, the cross-sectional area of flow can be calculated for any depth of flow using geometric relationships. Flow velocities can be measured by using suitable units (e.g., propeller operated devices) attached to a portable current meter. Flow velocity measurements should be obtained from representative locations throughout the flow cross-section. Such units are commercially available at costs ranging from about $1,000 to $3,000. While these devices may be fairly expensive, they are easy to use and they provide accurate data if used properly.

Flow velocities can be estimated using simpler methods, such as measuring the time of passage of an object (e.g., an orange) between two points a known distance apart (e.g., manholes).

Facility operators who are more familiar with measuring flows in pipes or open channels may use the Chezy-Manning equation, for example, to calculate flow velocities:

$$v = \frac{1.49}{n} (r_H)^{2/3} (S^{\frac{1}{2}})$$

where: v = velocity [ft/s]
n = Manning roughness constant
r_H = hydraulic radius [ft]
S = slope of the energy line [ft/ft]

A complete discussion of the use of this equation, other appropriate equations, and the identified parameters can be found in most fluid mechanics references (e.g., Chow, 1964).

5.5.3 Estimation of Flow Rates Based on Flow Velocity Measurements

If the measurements of flow depth are recorded and converted to cross-sectional areas (in square feet), and the corresponding velocities for each depth are recorded (in feet per minute), then the flow rate (Q) in cubic feet per minute (cfm) is:

$$Q = (\text{area})(\text{velocity})$$

The maximum flow rate is the highest value recorded during the storm event. The time-weighted average flow rate for the storm event can be estimated by the average of the individual values recorded.

5.5.4 Estimation of Volumes Based on Flow Rate Estimates

The total volume of discharge can be estimated by first multiplying each of the flow rates determined above by a time interval that represents the portion of the total storm duration associated with the measurement, and then adding all such partial volumes. If the time intervals used are seconds, then the total flow of runoff will be in units of cubic feet.

A procedure for calculating the total runoff volume from a set of discrete measurements of flow depth and velocity during a storm runoff event is discussed below and presented in Table 5-1. The basic steps for calculating this information are as follows:

Step 1: Measure and tabulate flow depths and velocities every 20 minutes during at least the first 3 hours of the runoff event.

Step 2: Calculate and tabulate the cross-sectional area of flow for each of the flow depths measured. Calculate the flow rate (Q) for each discrete set of flow rate and flow velocity measurements. Q = (area)(velocity).

Step 3: Plot flow rate, Q versus time as shown in Table 5-1.

Step 4: Assign each flow rate measurement a duration equal to the sum of 1/2 the time interval between the preceding and succeeding measurements. In the ideal case of uniform 20 minute intervals, the durations are [(20)½ + (20)½ = 20 minutes].

Step 5: Compute the flow volume associated with each observation (V_1, V_2, ..., V_9) by multiplying the measured flow rate by the duration (in this case, 20 minutes). Be sure the units are consistent. For example, if durations are in minutes and flow velocities are in cubic feet per second (cfs), convert the durations to seconds or the velocities to feet per minute.

Volume (V) = Flow Rate (cfm) x Duration (minutes)

Step 6: The beginning volume can be approximated by assuming that the flow rate is zero at time zero and increases linearly to the first calculated flow rate (Q_1) at 20 minutes (see Table 5-1).

The final volume can be approximated similarly by assuming that flow drops uniformly from the last calculated flow rate (Q_9) to zero at the time when Q_{10} would have been taken.

Step 7: Total the individual volumes calculated in Step 5 with the initial and final volume approximations calculated in Step 6 to obtain the total runoff volume.

Table 5-1. Example Calculation of the Total Runoff Flow Volume from Field Data

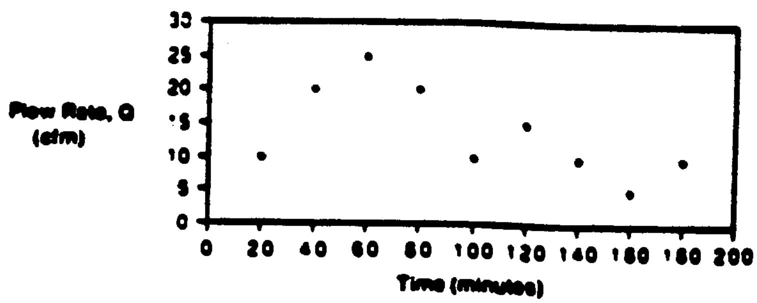
Station: OUTFALL-1
Date: 7-20-90

Step 1: Measure or estimate the following data

TIME (minutes)	FLOW VELOCITY (feet per minute)	FLOW DEPTH (feet)
0	-	-
20	4	0.2
40	8	0.4
60	10	0.5
80	8	0.4
100	4	0.2
120	6	0.3
140	4	0.2
160	2	0.1
180	4	0.2

Step 2: Convert flow depths to area of flow based on the geometry of the conveyance structure and calculate flow rates, Q (cubic feet per minute - cfm). Q = (area)(velocity)

Step 3: Plot flow rate Q versus time



Step 4: Assign a time duration to each flow rate

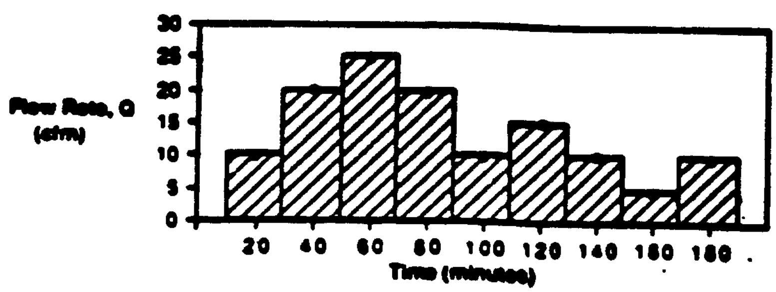
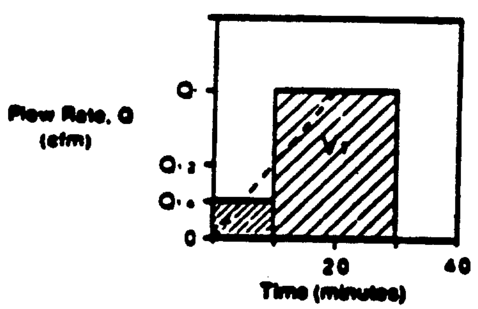


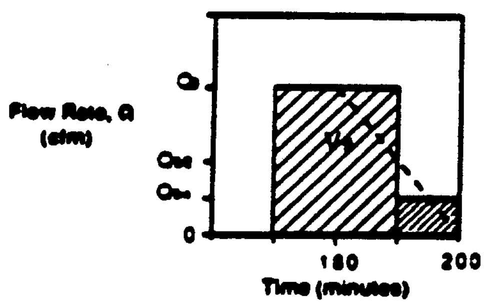
Table 5-1. Example Calculation of the Total Runoff Flow Volume from Field Data (concluded)

Step 5: Calculate individual flow volumes

Flow Volume (V)	=	Flow Rate (Q)	x	Time		
V_1	=	10 cfm	x	20 min	=	200 cubic feet
V_2	=	20 cfm	x	20 min	=	400 cubic feet
V_3	=	25 cfm	x	20 min	=	500 cubic feet
V_4	=	20 cfm	x	20 min	=	400 cubic feet
V_5	=	10 cfm	x	20 min	=	200 cubic feet
V_6	=	15 cfm	x	20 min	=	300 cubic feet
V_7	=	10 cfm	x	20 min	=	200 cubic feet
V_8	=	5 cfm	x	20 min	=	100 cubic feet
V_9	=	10 cfm	x	20 min	=	200 cubic feet

Step 6: Calculate the initial and final volumes





$$\text{initial volume} = \frac{Q_1}{4} \times 10 \text{ minutes} = 25 \text{ cubic feet}$$

$$\text{final volume} = \frac{Q_9}{4} \times 10 \text{ minutes} = 25 \text{ cubic feet}$$

Step 7: Total the partial volumes calculated in steps 5 and 6

Total storm runoff = 2,550 cubic feet

5.6 Collecting Storm Water Discharge Samples

This section provides guidance for collecting grab samples, flow-weighted composite samples, and identifying the constituents or parameters that must be monitored. Section VII of Form 2F requires that specific pollutants in storm water discharges be measured and reported as concentrations and as total mass. At least one representative storm event must be sampled to collect this information. If samples from more than one storm are analyzed and the results are representative of the discharge, the results must be reported in Section VII of Form 2F.

A representative storm is a storm that is "typical"for the area in terms of intensity, volume, and duration. The storm must have a volume greater than 0.1 inch, must be preceded by at least 72 hours of dry weather, and should not vary by more than 50% from the average rainfall volume and duration.

A representative storm event must be sampled to provide water quality data for the initial runoff period (i.e., a grab sample to measure first-flush effects). A flow-weighted composite sample must also be collected and analyzed separately from the grab sample to provide an estimate of the average runoff water quality for the storm event. Data from samples analyzed in the past may be used, provided that:

- All data requirements in Form 2F are met;
- Sampling was done no more than three years before submission of the permit application; and
- All water quality data are representative of the present discharge.

Among the factors which would cause the data to be unrepresentative are significant changes in production level, changes in raw materials, processes, or final products, and significant changes in storm water management activities.

Grab samples and flow-weighted composite samples must be collected and analyzed from each of the storm runoff outfalls identified on the site drainage map in Section III of Form 2F. However, if an applicant has two or more substantially identical outfalls, they may request permission from the permitting authority to sample and analyze only one outfall and submit the results of the analysis for the other substantially identical outfalls. Substantially identical outfalls are those from drainage areas undergoing similar activities where the discharges are expected to be of similar water quality. If the request is granted, identify which outfall was tested and describe why the outfalls which were not tested are substantially identical. Provide this information on a separate sheet attached to the application form.

5.6.1 Grab Samples

A grab sample must be collected during the first 30 minutes of the runoff (or as soon thereafter as practicable). The sample collected should be large enough for all of the laboratory analyses to be performed, but at least 100 milliliters (ml). Grab samples are typically collected by filling the sample container just below the water surface in the flow channel. Extension rods or cables can be used to reach inaccessible locations. The grab sample should be collected from near the center of the flow channel, where turbulence is at a maximum (and therefore the storm runoff is well mixed), or at a site specified in an existing permit, or at any site adequate for the collection of a sample that would be representative of the storm water quality.

All samples must be properly handled (i.e., holding time prior to analysis, storage temperature, preservation methods) and analyzed by the methods contained in 40 CFR Part 136. Most commercial laboratories will be familiar with these requirements and can provide information on appropriate handling procedures. Quality assurance/quality control (QA/QC) methods must be implemented both in the field by the applicant and in the lab to ensure the accuracy and validity of the analytical results. Most labs can assist applicants in designing a field QA/QC program and will also provide sample containers that are suitable (e.g., container material, type, and size) to the analysis to be performed. The labs will also typically report to the applicant the results of their internal QA/QC upon request.

If an analytical method is not listed in 40 CFR 136 for a particular pollutant, then the applicant may use any suitable method for measuring the level of the pollutant in the discharge provided that the applicant submits a description of the method or a reference to a published method. The description should include the sample holding time, preservation methods, and the quality control measures used.

The parameters pH and temperature are time-dependent and must be measured in the field at the time of sample collection rather than in the laboratory.

5.6.2 Flow-Weighted Composite Samples

A flow-weighted composite sample is a single sample intended to provide the average water quality for the entire runoff event. Because this type of sample accounts for variations in flow that occur during an event, water quality data from a flow-weighted composite sample is considered to be more representative of the average runoff quality for other methods such as a time-weighted composite.

A flow-weighted composite sample can be collected during either the entire runoff event (which may be less than 3 hours) or during at least the first 3 hours of the runoff. The sample can be collected using either automatic sampling equipment or by manually collecting and combining a series of discrete grab samples (aliquots) in an appropriate manner. In either case, appropriate procedures must be followed to obtain a sample for analysis that is flow-weighted, and hence will provide an indication of the average (or event mean) concentration for the storm runoff event.

Manually Collected Samples: A manually collected composite flow-weighted sample can be prepared by the following procedures. Collect samples of the same size (at least 100 ml and preferably 1000 ml) at regular intervals during the duration of the entire runoff event or for at least the first 3 hours of the event. Samples should be collected every 20 minutes to meet the requirement of at least 15 minutes between sample collection times. Storm runoff flow rates and flow cross-sectional areas in the conveyance should be estimated (see Section 5.5) each time an individual sample is taken. Relative flow rates rather than actual flow rates can be used. Where flow rates are estimated based on runoff coefficients, then the amount of rainfall during a given time period should be measured or estimated, and discharge flow rates assumed to be proportional to the amount of rainfall occurring during a given interval. Remove a portion (or aliquot) from each of the individual samples that is proportional to the flow rate for that time interval (there should be at least nine individual samples--i.e., three samples collected each hour during the first 3 hours of runoff) and combine them in the container that will be sent to the laboratory for analysis. Only the composite sample needs to be sent to the laboratory for analysis. The actual amount taken from each of the individual samples should be in proportion to the flow rate or volume of flow associated with that sample.

The procedure for combining aliquots of individual samples to form a flow-weighted composite sample is described below by example and shown in Table 5-2. The example is the same as that discussed in Section 5.5 and shown in Table 5-1. In the example shown in Table 5-2, the minimum number of nine samples were collected for use in preparing the composite sample. Because a grab sample must also be collected within the first 20 minutes of the runoff, two separate samples should be collected. One of the grab samples will be analyzed separately, while the second grab sample will be available for use in preparing the flow-weighted composite sample. Note that 40 CFR 122.21(g)(7) provides that quantitative data from grab samples, rather than flow-weighted samples, be provided for pH, temperature, cyanide, total phenols, residual chlorine, oil and grease, fecal coliform, and fecal streptococcus.

Other methods can be used for collecting flow-weighted composite samples, including the following four methods taken from EPA's NPDES Compliance Sampling Inspection Manual, MCD-51.

a) Constant time interval between samples, sample volume proportional to flow rate at time of sampling;

b) Constant time interval between samples, sample volume proportional to total flow (volume) since last sample. For the first sample, the flow rate at the time the sample was collected may be used;

c) Constant sample volume, time interval between samples proportional to flow (i.e., sample taken every "X" gallons of flow); and

d) Continuous collection of sample, with sample collection rate proportional to flow rate.

A different amount of each of the nine individual aliquots is used so that they are combined in proportion to the volume of runoff they represent. In the case of uniform time intervals between samples, the sample portions can be based on the measured flow rate associated with each sample rather than on the flow volumes calculated from each flow rate. For uniform time intervals, both flow rates (Q) and flow volumes (V) will result in the same aliquot proportions used to prepare the composite. The procedures are as follows:

1. For the sample that was collected at the highest flow rate (or volume), add the full sample volume (e.g., 1000 ml) to the composite sample container. The other eight samples will provide smaller amounts.

2. For each of the other samples, take an amount that is proportional to the largest flow rate. In other words, the amount of the individual samples used will be a simple ratio of the measured flow rates:

$$\text{Sample X (ml)} = \frac{Q_x \text{ (cfs)}}{Q_{max} \text{ (cfs)}}$$

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Table 5-2. EXAMPLE PREPARATION OF A MANUALLY COMPOSITED FLOW-WEIGHTED SAMPLE

Station: OUTFALL-1
Date: 7-20-90

Step 1: Tabulate flow rates (if a constant time duration was used) or flow volumes (if a non-constant time duration was used)

Sample	Flow Rate (cfm)
1	10
2	20
3	25
4	20
5	10
6	15
7	10
8	5
9	10

Step 2: Calculate proportions of individual samples to be used in preparing the composite sample

$$\text{Sample X (ml)} = [\text{Sample MAX (ml)}] \frac{Q_x(\text{cfs})}{Q_{max}(\text{cfs})}$$

Note: Sample 3 is Q_{max} (25 cfm)

Sample 1 = Sample 3 x 10/25 = 0.40
Sample 2 = Sample 3 x 20/25 = 0.80
Sample 3 = = 1.0
Sample 4 = Sample 3 x 20/25 = 0.80
Sample 5 = Sample 3 x 10/25 = 0.40
Sample 6 = Sample 3 x 15/25 = 0.30
Sample 7 = Sample 3 x 10/25 = 0.40
Sample 8 = Sample 3 x 5/25 = 0.20
Sample 9 = Sample 3 x 10/25 = 0.40

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Table 5-2. EXAMPLE PREPARATION OF A MANUALLY COMPOSITED FLOW-WEIGHTED SAMPLE (continued)

Step 3: Use a convenientvolume from the sample corresponding to the largest flow rate (Sample 3) and corresponding amounts from the other samples

Note: The final volume of the composite sample must be large enough so that all of the appropriate analyses can be performed. The analytical laboratory should be consulted prior to sample collection. The amount of Sample 3 used in this sample is 1000 ml.

Remaining amounts used:

Sample 1: 400 ml
Sample 2: 800 ml
Sample 4: 800 ml
Sample 5: 400 ml
Sample 6: 300 ml
Sample 7: 400 ml
Sample 8: 200 ml
Sample 9: 400 ml

Therefore, the total sample volume is 4,700 ml (i.e., 4.7 liters or about 1.2 gallons)

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In the example shown in Table 5-2, Sample 3 had the highest flow rate (Q_3 = 25 cfm). Assume that 1000 ml of this sample was added to the composite container. Then the amount of Sample 1 to add to the composite, assuming that flow rate Q_1 = 10 cfm, is:

$$\text{Sample 1 (ml)} = \frac{[\text{Sample 3 (in ml)}] \times Q_1 \text{ (cfs)}}{Q_3 \text{ (cfs)}}$$

$$= \frac{(1000 \text{ ml}) \times 10 \text{ (cfs)}}{25 \text{ (cfs)}}$$

3. Repeat this process for each discrete sample to produce a flow-weighted composite sample for laboratory analysis. As shown in Table 5-2, the total composite sample volume is 4,700 ml.

The personnel collecting the individual samples and preparing the composite sample should contact the analytical laboratory personnel to ensure that a large enough sample is submitted. Based on the analyses to be performed on the composite sample, the laboratory personnel can require a minimum sample size.

As illustrated in the example, the computation is simplified when the time interval between the samples is uniform. When there are different time intervals between samples, the procedure is only slightly more complicated. In this case, the individual sample volumes used should be based on the runoff volume (calculated from the individual flow rates and durations) associated with the sample, as opposed to simply the storm flow rate associated with each sample.

Automatic Samplers: Automatic samplers are labor-saving devices but are fairly expensive to purchase. The samplers consist of an intake device set in the channel which is attached by tubing to a pump that can draw a sample from the storm drain into a sample bottle. However, in order for the sample obtained to be flow-weighted composite, the automatic sampler must be triggered by the flow sensing device. Samples of fixed volume are collected each time the flow sensing device indicates that a specified quantity of flow has passed the sample point.

An appropriate flow sensing device, coupled to the automatic sampler is necessary for the automatic system to produce a flow-weighted composite. If the monitoring equipment does not employ such a coupled system, then the automatic sampler merely serves as a mechanical means for withdrawing the sample (usually at fixed time intervals). The guidance given above for properly combining manually collected samples to obtain a flow-weighted composite will apply in this case.

Automatic samplers generally range in price from about $8,000 to $16,000 for equipment costs alone. Units with telemetry are in the upper end of this range. The equipment included with a standard unit includes a fabricated weir, an automatic sampler with silica sample containers, software to control the remote computer data logger, housing for unit, thermistor, and pressure sensor. The installation and flow rating of a unit will cost approximately $6,000 to $8,000 depending on whether the unit is installed in a manhole, open culvert or channel, or stream. Digital doppler velocity sensors can also be purchased and installed. Such units would replace the weir, data logger, and pressure sensor identified above.

5.6.3 Pollutants to Be Analyzed

Section VII of Form 2F requires that several common pollutants must be analyzed for in both the grab sample and the flow-weighted composite sample while additional analyses are dependent upon existing NPDES permit conditions or whether the discharger has reason to believe other pollutants may be present in the storm runoff discharge. A separate table should be completed for each outfall. Note that 40 CFR 122.21(g)(7) provides that rather than using a flow-weighted sample for quantitative data for pH, temperature, cyanide, total phenols, residual chlorine, oil and grease, fecal coliform, and fecal streptococcus, a grab sample must be used.

Part A of Section VII requires that both grab samples and flow-weighted composite samples be analyzed for:

Biological oxygen demand (BOD_5)
Chemical oxygen demand (COD)
Total suspended solids (TSS)
Total Kjeldahl Nitrogen (TKN)
Nitrate plus nitrite nitrogen
Total phosphorus

In addition, grab samples must be analyzed for pH.

Part B of Section VII requires that each pollutant limited in an effluent guideline which the facility is subject to or any pollutant listed in the facility's NPDES permit for its process wastewater (if the facility is operating under an existing permit) be analyzed for and reported separately for each outfall in Part B.

Part C of Section VII requires the listing of any pollutant shown in Tables 2F-2, 2F-3, and 2F-4 that the discharger knows or has reason to believe is present in the discharge and was not already identified above (see Form 2F in Appendix D for these three tables).

Table 2F-2 includes conventional and non-conventional pollutants. For any pollutant from this table listed in Part C, the applicant is required to either report quantitative data or briefly describe the reason the pollutant is expected to be discharged.

Table 2F-3 lists toxic pollutants. For every pollutant listed in Table 2F-3 that is expected to be discharged in concentrations of 10 parts per billion (ppb) or greater, the applicant is required to submit quantitative data. For acrolein; acrylonitrile; 2,4 dinitrophenol; and 2-methyl-4, 6 dinitrophenol the applicant must submit quantitative data if these four pollutants (collectively) are expected to be discharged in concentrations of 100 ppb or greater. For every other pollutant listed in Table 2F-3 that is expected to be discharged in concentrations less than 10 ppb (or 100 ppb total for the four pollutants listed above), then the applicant must either submit quantitative data or briefly describe the reasons the pollutant is expected to be discharged.

Table 2F-4 lists hazardous substances. For each outfall, the applicant must list any pollutant from Table 2F-4 that is known or believed to be present in the discharge and explain why they believe it to be present. No analysis is required, but if the applicant has analytical data, it must be reported.

Under 40 CFR 117.12(a)(2), certain discharges of hazardous substances (listed in 40 CFR 177.21 or 40 CFR 302.4) may be exempted from the requirements of Section 311 of the CWA, which establishes reporting requirements, civil penalties, and liability for cleanup costs for spills of oil and hazardous substances. A discharge of a particular substance may be exempted if the origin, source, and amounts of the discharged substances are identified in the NPDES permit application or in the permit, if the permit contains a requirement for treatment of the discharge, and if the treatment is in place. To apply for an exclusion of the discharge of any hazardous substance from the requirements of Section 311, attach additional sheets of paper to the form and provide for the following information:

1. The substance and the amount of each substance which may be discharged.

2. The origin and source of the discharge of the substance.

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3. The treatment which is to be provided for the discharge by:

a. An onsite treatment system separate from any treatment system treating the normal discharge;

b. A treatment system designed to treat the normal discharge and which is additionally capable of treating the amount of the substance identified under paragraph 1 above, or

c. Any combination of the above.

See 40 CFR 117.12(a)(2) and (c), published on August 29, 1979, in 44 Federal Register (FR) 50766 for further information on exclusions from Section 311 of the CWA.

5.6.4 Reporting

All sampling data obtained for the purpose of completing Section VII of Form 2F must be reported as concentration and as total mass. The applicant may report some or all of the required data by attaching separate sheets of paper instead of filling out pages VII-1 and VII-2 if the separate sheets contain all the required information in a format which is consistent with pages VII-1 and VII-2 in spacing and in identification of pollutants and columns. Use the following abbreviations in the columns headed "Units."

ppm = parts per million
mg/l = milligrams per liter
ppb = parts per billion
ug/l = micrograms per liter
lbs = pounds
ton = tons (English tons)
mg = milligrams
g = grams
T = tonnes (metric tons)
kg = kilograms

All reporting of values for metals must be in terms of "total recoverable metal" unless:

(i) An applicable promulgated effluent limitation or standard specifies the limitation for the metal in dissolved, valent, or total form

(ii) All approved analytical methods for the metal measure only its dissolved form (e.g., hexavalent chromium)

(iii) The permitting authority has determined that in establishing case-by-case limitations it is necessary to express the limitations on the metal in dissolved, valent, or total form to carry out the provisions of the CWA.

If only one grab sample and one flow-weighted composite sample is collected and analyzed for a given outfall, complete only the "Maximum Values" columns and insert "1" into the "Number of Storm Events Sampled" column.

To calculate total mass from the water quality analyses, multiply the concentration reported by the lab by the flow volume associated with the sample. For the grab samples collected within 30 minutes of the storm runoff, the concentrations of the individual pollutants should all be multiplied by the flow volume calculated in Step 5 shown in Table 5-1. Care must be exercised to ensure that consistent units are used. For the flow-weighted composite sample, the concentrations of the individual pollutants should all by multiplied by the total runoff volume calculated in Step 7 of Table 5-1.

SECTION 6.0 REFERENCES

California State University, Sacramento, Department of Civil Engineering. 1983. Operation and Maintenance of Wastewater Collection Systems. A field training program for EPA, Office of Water Programs Operations.

Chow, V.T. 1964. Handbook of Applied Hydrology. McGraw-Hill, Inc. New York. 1418 p.

Shelly, P.E. 1979. Monitoring Requirements, Methods, and Costs for the Nationwide Urban Runoff Program (NURP). EPA-600/9-76-014.

U.S. Environmental Protection Agency, Office of Water, Nonpoint Source Division. Methodology for Analysis of Detention Basins for control of urban Runoff Quality. Prepared by Woodward-Clyde Consultants. September 1986.

U.S. Executive Office of the President, Office of Management and Budget. 1987. Standard Industrial Classification Manual.

U.S. Environmental Protection Agency, Office of Water. NPDES Compliance Inspection Manual, May 1988. MCD-51.

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APPENDIX A: SELECTED TEXT FROM 40 CFR SECTION 122.26

Section 122.26(a) Storm water discharges (applicable to State NPDES programs, see § 123.25).
(a) Permit requirement. (1) Prior to October 1, 1992, discharges composed entirely of storm water shall not be required to obtain a NPDES permit except:
(i) a discharge with respect to which a permit has been issued prior to February 4, 1987;
(ii) A discharge associated with industrial activity (see 122.26(a)(4));
(iii) A discharge from a large municipal separate storm sewer system;
(iv) A discharge from a medium municipal separate storm sewer system;
(v) A discharge which the Director, or in States with approved NPDES programs, either the Director or the EPA Regional Administrator, determines to contribute to a violation of a water quality standard or is a significant contributor of pollutants to waters of the United States. This designation may include a discharge from any conveyance or system of conveyances used for collecting and conveying storm water runoff or a system of discharges from municipal separate storm sewers, except for those discharges from conveyances which do not require a permit under paragraph (2) of this subsection or agricultural storm water runoff which is exempted from the definition of point source at 122.2.
The Director may designate discharges from municipal separate storm sewers on a system-wide or jurisdiction-wide basis. In making this determination the Director may consider the following factors:
(A) The location of the discharge with respect to waters of the United States as defined at 40 CFR 122.2.
(B) The size of the discharge;
(C) The quantity and nature of the pollutants discharged to waters of the United States; and
(D) Other relevant factors.
(2) The Director may not require a permit for discharges of storm water runoff from mining operations or oil and gas exploration, production, processing or treatment operations or transmission facilities, composed entirely of flows which are from conveyances or systems of conveyances (including but not limited to pipes, conduits, ditches, and channels) used for collecting and conveying precipitation runoff and which are not contaminated by contact with or that has not come into contact with, any overburden, raw material, intermediate products, finished product, byproduct or waste products located on the site of such operations.
(3) Large and Medium Municipal Separate Storm Sewer Systems. (i) Permits must be obtained for all discharges from large and medium municipal separate storm sewer systems.
(ii) The Director may either issue one system-wide permit covering all discharges from municipal separate storm sewers within a large or medium municipal storm sewer system or issue distinct permits for appropriate categories of discharges within a large or medium municipal separate storm sewer system including, but not limited to: all discharges owned or operated by the same municipality; located within the same jurisdiction; all discharges within a system that discharge to the same watershed; discharges within a system that are similar in nature; or for individual discharges from municipal separate storm sewers within the system.
(iii) The operator of a discharge from a municipal separate storm sewer which is part of a large or medium municipal separate storm sewer system must either:
(A) participate in a permit application (to be a permittee or a co-permittee) with one or more other operators of discharges from the large or medium municipal storm sewer system which covers all, or a portion of all, discharges from the municipal separate storm sewer system;
(B) submit a distinct permit application which only covers discharges from the municipal separate storm sewers for which the operator is responsible; or
(C) a regional authority may be responsible for submitting a permit application under the following guidelines:
(1) the regional authority together with co-applicants shall have authority over a storm water management program that is in existence, or shall be in existence at the time Part I of the application is due;

(2) the permit applicant or co-applicants shall establish their ability to make a timely submission of Part 1 and Part 2 of the municipal application;

(3) each of the operators of municipal separate storm sewer within the systems described in paragraphs 122.26(b)(4)(i), (ii), and (iii) or (b)(7)(i), (ii), and (iii), that are under the purview of the designated regional authority, shall comply with the application requirements of paragraph 122.26(d).

(iv) One permit application may be submitted for all or a portion of all municipal separate storm sewers within adjacent or interconnected large or medium municipal separate storm sewer systems. The Director may issue one system-wide permit covering all, or a portion of all municipal separate storm sewers in adjacent or interconnected large or medium municipal separate storm sewer systems.

(v) Permits for all or a portion of all discharges from large or medium municipal separate storm sewer systems that are issued on a system-wide, jurisdiction-wide, watershed or other basis may specify different conditions relating to different discharges covered by the permit, including different management programs for different drainage areas which contribute storm water to the system.

(vi) Co-permittees need only comply with permit conditions relating to discharges from the municipal separate storm sewers for which they are operators.

(4) Discharges through large and medium municipal separate storm sewer systems. In addition to meeting the requirements of 122.26(c), an operator of a storm water discharge associated with industrial activity which discharges through a large or medium municipal separate storm sewer system shall submit, to the operator of the municipal separate storm sewer system receiving the discharge no later than [insert date 180 days after publication] or 180 days prior to commencing such discharge: the name of the facility; a contact person and phone number; the location of the discharge; a description, including Standard Industrial Classification, which best reflects the principal products or services provided by each facility; and any existing NPDES permit number.

(5) Other Municipal Separate Storm Sewers. The Director may issue permits for municipal separate storm sewers that are designated under subparagraph (1)(v) of this paragraph on a system-wide basis, jurisdiction-wide basis, watershed basis or other appropriate basis, or may issue permits for individual discharges.

(6) Non-Municipal Separate Storm Sewers. For storm water discharges associated with industrial activity from point sources which discharge through a non-municipal or non-publicly owned separate storm sewer system, the Director, in his discretion, may issue: a single NPDES permit, with each discharger a co-permittee to a permit issued to the operator of the portion of the system that discharges into waters of the United States; or, individual permits to each discharger of storm water associated with industrial activity through the non-municipal conveyance system.

(i) All storm water discharges associated with industrial activity that discharge through a storm water discharge system that is not a municipal separate storm sewer must be covered by an individual permit, or a permit issued to the operator of the portion of the system that discharges to waters of the United States, with each discharger to the non-municipal conveyance a co-permittee to that permit.

(ii) Where there is more than one operator of a single system of such conveyances, all operators of storm water discharges associated with industrial activity must submit applications.

(iii) Any permit covering more than one operator shall identify the effluent limitations, or other permit conditions, if any, that apply to each operator.

(7) Combined Sewer Systems. Conveyances that discharge storm water runoff combined with municipal sewage are point sources that must obtain NPDES permits in accordance with the procedures of 122.21 and are not subject to the provisions of this section.

(8) Whether a discharge from a municipal separate storm sewer is or is not subject to regulation under this section shall have no bearing on whether the owner or operator of the discharge is eligible for funding under Title II, Title III or Title VI of the Clean Water Act. See 40 CFR Part 35, Subpart I, Appendix A(b)H.2.j.

Section 122.26(c) Application requirements for storm water discharges associated with industrial activity.

(1) Individual application. Dischargers of storm water associated with industrial activity are required to apply for an individual permit, apply for a permit through a group application, or seek coverage under a promulgated storm water general permit. Facilities that are required to obtain an individual permit, or any discharge of storm water which the Director is evaluating for designation (see

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40 CFR 124.52(c)) under paragraph (a)(1)(v) and is not a municipal separate storm sewer, and which is not part of a group application described under paragraph (2), shall submit an NPDES application in accordance with the requirements of § 122.21 as modified and supplemented by the provisions of the remainder of this paragraph. Applicants for discharges composed entirely of storm water shall submit Form 1 and Form 2F. Applicants for discharges composed of storm water and non-storm water shall submit Form 1, Form 2C, and Form 2F. Applicants for new sources or new discharges (as defined in § 122.2 of this part) composed of storm water and non-storm water shall submit Form 1, Form 2D, and Form 2F.

(i) Except as provided in paragraphs 122.26(c)(1)(ii)-(iv), the operator of a storm water discharge associated with industrial activity subject to this section shall provide:

(A) a site map showing topography (or indicating the outline of drainage areas served by the outfall(s) covered in the application if a topographic map is unavailable) of the facility including: each of its drainage and discharge structures; the drainage area of each storm water outfall; paved areas and buildings within the drainage area of each storm water outfall, each past or present area used for outdoor storage or disposal of significant materials, each existing structural control measure to reduce pollutants in storm water runoff, materials loading and access areas, areas where pesticides, herbicides, soil conditioners and fertilizers are applied, each of its hazardous waste treatment, storage or disposal facilities (including each area not required to have a RCRA permit which is used for accumulating hazardous waste under 40 CFR 262.34); each well where fluids from the facility are injected underground; springs, and other surface water bodies which receive storm water discharges from the facility;

(B) an estimate of the area of impervious surfaces (including paved areas and building roofs) and the total area drained by each outfall (within a mile radius of the facility) and a narrative description of the following: significant materials that in the three years prior to the submittal of this application have been treated, stored or disposed in a manner to allow exposure to storm water; method of treatment, storage or disposal of such materials; materials management practices employed, in the three years prior to the submittal of this application, to minimize contact by these materials with storm water runoff; materials loading and access areas; the location, manner and frequency in which pesticides, herbicides, soil conditioners and fertilizers are applied; the location and a description of existing structural and non-structural control measures to reduce pollutants in storm water runoff; and a description of the treatment the storm water receives, including the ultimate disposal of any solid or fluid wastes other than by discharge;

(C) a certification that all outfalls that should contain storm water discharges associated with industrial activity have been tested or evaluated for the presence of non-storm water discharges which are not covered by a NPDES permit; tests for such non-storm water discharges may include smoke tests, fluorometric dye tests, analysis of accurate schematics, as well as other appropriate tests. The certification shall include a description of the method used, the date of any testing, and the on-site drainage points that were directly observed during a test;

(D) existing information regarding significant leaks or spills of toxic or hazardous pollutants at the facility that have taken place within the three years prior to the submittal of this application;

(E) quantitative data based on samples collected during storm events and collected in accordance with section 122.21 of this Part from all outfalls containing a storm water discharge associated with industrial activity for the following parameters:

(1) Any pollutant limited in an effluent guideline to which the facility is subject;

(2) Any pollutant listed in the facility's NPDES permit for its process wastewater (if the facility is operating under an existing NPDES permit);

(3) Oil and grease, pH, BOD5, COD, TSS, total phosphorus, total Kjeldahl nitrogen, and nitrate plus nitrite nitrogen;

(4) Any information on the discharge required under paragraph 122.21(g)(7)(iii) and (iv) of this Part;

(5) Flow measurements or estimates of the flow rate, and the total amount of discharge for the storm event(s) sampled, and the method of flow measurement or estimation; and

(6) The date and duration (in hours) of the storm event(s) sampled, rainfall measurements or estimates of the storm event (in inches) which generated the sampled runoff and the duration between the storm event sampled and the end of the previous measurable (greater than 0.1 inch rainfall) storm event (in hours);

(F) Operators of a discharge which is composed entirely of storm water are exempt from the requirements of paragraphs 122.21(g)(2), (g)(3), (g)(4), (g)(5), (g)(7)(i), (g)(7)(ii), and (g)(7)(v); and

(G) Operators of new sources or new discharges (as defined in § 122.2 of this Part) which are composed in part or entirely of storm water must include estimates for the pollutants or parameters listed in subparagraph (E) of this paragraph instead of actual sampling data, along with the source of each estimate. Operators of new sources or new discharges composed in part or entirely of storm water must provide quantitative data for the parameters listed in subparagraph (E) of this paragraph within two years after commencement of discharge, unless such data has already been reported under the monitoring requirements of the NPDES permit for the discharge. Operators of a new source or new discharge which is composed entirely of storm water are exempt from the requirements of paragraphs 122.21(k)(3)(ii), (k)(3)(iii), and (k)(5).

(ii) The operator of an existing or new storm water discharge that is associated with industrial activity solely under paragraph (b)(14)(x) of this section, is exempt from the requirements of paragraphs 122.21(g) and 122.26(c)(1)(i) of this Part. Such operator shall provide a narrative description of:

(A) the location (including a map) and the nature of the construction activity;

(B) the total area of the site and the area of the site that is expected to undergo excavation during the life of the permit;

(C) proposed measures, including best management practices, to control pollutants in storm water discharges during construction, including a brief description of applicable State and local erosion and sediment control requirements;

(D) proposed measures to control pollutants in storm water discharges that will occur after construction operations have been completed, including a brief description of applicable State or local erosion and sediment control requirements;

(E) an estimate of the runoff coefficient of the site and the increase in impervious area after the construction addressed in the permit application is completed, the nature of fill material and existing data describing the soil or the quality of the discharge; and

(F) the name of the receiving water.

(iii) The operator of an existing or new discharge composed entirely of storm water from an oil or gas exploration, production, processing, or treatment operation, or transmission facility is not required to submit a permit application in accordance with paragraph (i) of this section, unless the facility:

(A) has had a discharge of storm water resulting in the discharge of a reportable quantity for which notification is or was required pursuant to 40 CFR 117.21 or 40 CFR 302.6 at anytime since November 16, 1987; or

(B) has had a discharge of storm water resulting in the discharge of a reportable quantity for which notification is or was required pursuant to 40 CFR 110.6 at any time since November 16, 1987; or

(C) contributes to a violation of a water quality standard.

(iv) The operator of an existing or new discharge composed entirely of storm water from a mining operation is not required to submit a permit application unless the discharge has come into contact with, any overburden, raw material, intermediate products, finished product, byproduct or waste products located on the site of such operations.

(v) Applicants shall provide such other information the Director may reasonably require under paragraph 122.21(g)(13) of this Part to determine whether to issue a permit and may require any facility subject to paragraph (c)(1)(ii) to comply with paragraph (c)(1)(i) of this section.

Section 122.26(e) Application deadlines. Any operator of a point source required to obtain a permit under paragraph (a)(1) that does not have an effective NPDES permit covering its storm water outfalls shall submit an application in accordance with the following deadlines:

(1) For any storm water discharge associated with industrial activity identified in 122.26(b)(14)(i)-(xi), that is not part of a group application as described in paragraph (c)(2) or which is not covered under a promulgated storm water general permit, a permit application made pursuant to 122.26(c) shall be submitted to the Director by November 18, 1991;

(2) For any group application submitted in accordance with 122.26(c)(2):

(i) Part 1 of the application shall be submitted to the Director, Office of Water Enforcement and Permits by September 30, 1991;

(ii) Based on information in the Part 1 application, the Director will approve or deny the members in the group application within 60 days after receiving Part 1 of the group application.

(iii) Part 2 of the application shall be submitted to the Director, Office of Water Enforcement and Permits no later than 12 months, or by May 18, 1992 whichever comes first after the date of approval of the Part 1 application.

(iv) Facilities that are rejected as members of a group by the permitting authority shall have 12 months to file an individual permit application from the date they receive notification of their rejection.

(v) A facility listed under paragraph (b)(14)(i)-(xi) may add on to a group application submitted in accordance with paragraph (e)(2)(i) at the discretion of the Office of Water Enforcement and Permits, and only upon a showing of good cause by the facility and the group applicant; the request for the addition of the facility shall be made no later than February 18, 1992; the addition of the facility shall not cause the percentage of the facilities that are required to submit quantitative data to be less than 10%, unless there are over 100 facilities in the group that are submitting quantitative data; approval to become part of group application must be obtained from the group or the trade association representing the individual facilities.

(3) For any discharge from a large municipal separate storm sewer system;

(i) Part 1 of the application shall be submitted to the Director by November 18, 1991;

(ii) Based on information received in the Part 1 application the Director will approve or deny a sampling plan under 122.26(d)(1)(iv)(E) within 90 days after receiving the Part 1 application;

(iii) Part 2 of the application shall be submitted to the Director by November 16, 1992.

(4) For any discharge from a medium municipal separate storm sewer system;

(i) Part 1 of the application shall be submitted to the Director by May 18, 1992.

(ii) Based on information received in the Part 1 application the Director will approve or deny a sampling plan under 122.26(d)(1)(iv)(E) within 90 days after receiving the Part 1 application.

(iii) Part 2 of the application shall be submitted to the Director by May 17, 1993.

(5) A permit application shall be submitted to the Director within 60 days of notice, unless permission for a later date is granted by the Director (see 40 CFR 124.52(c)), for:

(i) a storm water discharge which the Director, or in States with approved NPDES programs, either the Director or the EPA Regional Administrator, determines that the discharge contributes to a violation of a water quality standard or is a significant contributor of pollutants to waters of the United States (see paragraph (a)(1)(v) of this section);

(ii) A storm water discharge subject to paragraph (c)(1)(v) of this section.

(6) Facilities with existing NPDES permits for storm water discharges associated with industrial activity shall maintain existing permits. New applications shall be submitted in accordance with the requirements of 40 CFR 122.21 and 40 CFR 122.26(c) 180 days before the expiration of such permits. Facilities with expired permits or permits due to expire before May 18, 1992 shall submit applications in accordance with the deadline set forth under 122.26(e)(1).

Section 122.26(f) Petitions.

(1) Any operator of a municipal separate storm sewer system may petition the Director to require a separate NPDES permit (or a permit issued under an approved NPDES State program) for any discharge into the municipal separate storm sewer system.

(2) Any person may petition the Director to require a NPDES permit for a discharge which is composed entirely of storm water which contributes to a violation of a water quality standard or is a significant contributor of pollutants to waters of the United States.

(3) The owner or operator of a municipal separate storm sewer system may petition the Director to reduce the Census estimates of the population served by such separate system to account for storm water discharged to combined sewers as defined by 40 CFR 35.2005(b)(11) that is treated in a publicly owned treatment works. In municipalities in which combined sewers are operated, the Census estimates of population may be reduced proportional to the fraction, based on estimated lengths, of the length of combined sewers over the sum of the length of combined sewers and municipal separate storm sewers where an applicant has submitted the NPDES permit number associated with each discharge point and

a map indicating areas served by combined sewers and the location of any combined sewer overflow discharge point.

(4) Any person may petition the Director for the designation of a large or medium municipal separate storm sewer system as defined by subsections (b)(4)(iv) or (b)(7)(iv) of this rule.

(5) The Director shall make a final determination on any petition received under this section within 90 days after receiving the petition.

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APPENDIX B: DEFINITIONS OF KEY TERMS

The following are definitions of terms found in the NPDES general definitions (40 CFR 122.2), the storm water regulations (55 FR 47990), and terms commonly used in relation to storm water discharges.

(1) "Best management practices ("BMPs")"means schedules of activities, prohibitions of practices, maintenance procedures, and other management practices to prevent or reduce the pollution of "waters of the United States." BMPs also include treatment requirements, operating procedures, and practices to control plant site runoff, spillage or leaks, sludge or waste disposal, or drainage from raw material storage.

(2) "Contiguous zone" means the entire zone established by the United States under Article 24 of the Convention on the Territorial Sea and the Contiguous Zone.

(3) "Co-permittee"means a permittee to a NPDES permit that is only responsible for permit conditions relating to the discharge for which it is operator.

(4) "Discharge"when used without qualification means the "discharge of a pollutant."

(5) "Discharge of a pollutant" means:

(i) Any addition of any "pollutant"or combination of pollutants to "waters of the United States" from any "point source," or

(ii) Any addition of any pollutant or combination of pollutants to the waters of the "contiguous zone" or the ocean from any point source other than a vessel or other floating craft which is being used as a means of transportation.

This definition includes additions of pollutants into waters of the United States from: surface runoff which is collected or channelled by man; discharges through pipes, sewers, or other conveyances owned by a State, municipality, or other person which do not lead to a treatment works; and discharges through pipes, sewers, or other conveyances, leading into privately owned treatment works. This term does not include an addition of pollutants by any "indirect discharger."

(6) "Effluent limitation" means any restriction imposed by the Director on quantities, discharge rates, and concentrations of "pollutants"which are "discharged"from "point sources" into "waters of the United States," the waters of the "contiguous zone," or the ocean.

(7) "Effluent limitations guidelines" means a regulation published by the Administrator under section 304(b) of CWA to adopt or revise "effluent limitations."

(8) "Illicit discharge" means any discharge to a municipal separate storm sewer that is not composed entirely of storm water except discharges pursuant to NPDES permit (other than the NPDES permit for discharges from the municipal separate storm sewer) and discharges from fire fighting activities.

(9) "Incorporated place" means the District of Columbia, or a city, town or village that is incorporated under the laws of the State in which it is located.

(10) "Large municipal separate storm sewer system" means all municipal separate storm sewers that are either:

(i) located in an incorporated place with a population of 250,000 or more as determined by the latest Decennial Census by the Bureau of Census (Appendix F); or
(ii) located in the counties listed in Appendix H, except municipal separate storm sewers that are located in the incorporated places, townships or towns within such counties; or
(iii) owned or operated by a municipality other than those described in paragraph (i) or (ii) and that are designated by the Director as part of the large or medium municipal separate storm sewer system due to the interrelationship between the discharges of the designated storm sewer and the discharges from municipal separate storm sewers described under paragraphs (i) or (ii). In making this determination the Director may consider the following factors:
(A) physical interconnections between the municipal separate storm sewers;
(B) the location of discharges from the designated municipal separate storm sewer relative to discharges from municipal separate storm sewers described in subparagraph (i);
(C) the quantity and nature of pollutants discharged to waters of the United States;
(D) the nature of the receiving waters; and
(E) other relevant factors; or
(iv) the Director may, upon petition, designate as a large municipal separate storm sewer system, municipal separate storm sewers located within the boundaries of a region defined by a storm water management regional authority based on a jurisdictional, watershed, or other appropriate basis that includes one or more of the systems described in paragraphs (i), (ii), (iii).

(11) "Major municipal separate storm sewer outfall" (or "major outfall") means a municipal separate storm sewer outfall that discharges from a single pipe with an inside diameter of 36 inches or more or its equivalent (discharge from a single conveyance other than circular pipe which is associated with a drainage area of more than 50 acres); or for municipal separate storm sewers that receive storm water from lands zoned for industrial activity (based on comprehensive zoning plans or the equivalent), an outfall that discharges from a single pipe with an inside diameter of 12 inches or more or from its equivalent (discharge from other than a circular pipe associated with a drainage area of 2 acres or more).

(12) "Major outfall" means a major municipal separate storm sewer outfall.

(13) "Medium municipal separate storm sewer system" means all municipal separate storm sewers that are either:
(i) located in an incorporated place with a population of 100,000 or more but less than 250,000, as determined by the latest Decennial Census by the Bureau of Census (Appendix G); or
(ii) located in the counties listed in Appendix I, except municipal separate storm sewers that are located in the incorporated places, townships or towns within such counties; or
(iii) owned or operated by a municipality other than those described in paragraph (i) or (ii) and that are designated by the Director as part of the large or medium municipal separate storm sewer system due to the interrelationship between the discharges of the designated storm sewer and the discharges from municipal separate storm sewers described under paragraphs (i) or (ii). In making this determination the Director may consider the following factors:
(A) physical interconnections between the municipal separate storm sewers;
(B) the location of discharges from the designated municipal separate storm sewer relative to discharges from municipal separate storm sewers described in subparagraph (i);
(C) the quantity and nature of pollutants discharged to waters of the United States;
(D) the nature of the receiving waters; or
(E) other relevant factors; or
(iv) the Director may, upon petition, designate as a medium municipal separate storm sewer system, municipal separate storm sewers located within the boundaries of a region defined by a storm water management regional authority based on a jurisdictional, watershed, or

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other appropriate basis that includes one or more of the systems described in paragraphs (i), (ii), (iii).

(14) "Municipal separate storm sewer" means a conveyance or system of conveyances (including roads with drainage systems, municipal streets, catch basins, curbs, gutters, ditches, man-made channels, or storm drains):

(i) owned or operated by a State, city, town, borough, county, parish, district, association, or other public body (created by or pursuant to State law) having jurisdiction over disposal of sewage, industrial wastes, storm water, or other wastes, including special districts under State law such as a sewer district, flood control district or drainage district, or similar entity, or an Indian tribe or an authorized Indian tribal organization, or a designated and approved management agency under section 208 of the CWA that discharges to waters of the United States;
(ii) designed or used for collecting or conveying storm water;
(iii) which is not a combined sewer; and
(iv) which is not part of a Publicly Owned Treatment Works (POTW) as defined at 40 CFR 122.2.

(15) "National Pollutant Discharge Elimination System (NPDES)" means the national program for issuing, modifying, revoking and reissuing, terminating, monitoring and enforcing permits, and imposing and enforcing pretreatment requirements, under sections 307, 402, 318, and 405 of CWA. The term includes an "approved program."

(16) "New discharger" means any building, structure, facility, or installation:

(i) From which there is or may be a "discharge of pollutants;"
(ii) That did not commence the "discharge of pollutants" at a particular "site" prior to August 13, 1979;

(iii) Which is not a "new source," and

(iv) Which has never received a finally effective NPDES permit for discharges at that "site."

This definition includes an "indirect discharger" which commences discharging into "waters of the United States" after August 13, 1979. It also includes any existing mobile point source (other than an offshore or coastal oil and gas exploratory drilling rig or a coastal oil and gas developmental drilling rig) such as a seafood processing rig, seafood processing vessel, or aggregate plant, that begins discharging at a "site" for which it does not have a permit; and any offshore or coastal mobile oil and gas exploratory drilling rig or coastal mobile oil and gas developmental drilling rig that commences the discharge of pollutants after August 13, 1979, at a "site" under EPA's permitting jurisdiction for which it is not covered by an individual or general permit and which is located in an area determined by the Regional Administrator in the issuance of a final permit to be an area of biological concern. In determining whether an area is an area of biological concern, the Regional Administrator shall consider the factors specified in 40 CFR 125.122(a) (1) through (10).

An offshore or coastal mobile exploratory drilling rig or coastal mobile developmental drilling rig will be considered a "new discharger" only for the duration of its discharge in an area of biological concern.

(17) "New source" means any building, structure, facility, or installation from which there is or may be a "discharge of pollutants," the construction of which commenced:

(i) After promulgation of standards of performance under section 306 of CWA which are applicable to such source, or

(ii) After proposal of standards of performance in accordance with section 306 of CWA which are applicable to such source, but only if the standards are promulgated in accordance with section 306 within 120 days of their proposal.

(18) "Outfall" means a "point source" as defined by 40 CFR 122.2 at the point where a municipal separate storm sewer discharges to waters of the United States and does not include open conveyances connecting two municipal separate storm sewers, or pipes, tunnels or other conveyances which connects segments of the same stream or other waters of the United States and are used to convey waters of the United States.

(19) "Overburden" means any material of any nature, consolidated or unconsolidated, that overlies a mineral deposit, excluding topsoil or similar naturally-occurring surface materials that are not disturbed by mining operations.

(20) "Owner or operator" means the owner or operator of any "facility or activity" subject to regulation under the NPDES program.

(21) "Permit" means an authorization, license, or equivalent control document issued by EPA or an "approved State" to implement the requirements of this part and Parts 123 and 124. "Permit" includes an NPDES "general permit" (Section 122.28). Permit does not include any permit which has not yet been the subject of final agency action, such as a "draft permit" or a "proposed permit."

(22) "Person" means an individual, association, partnership, corporation, municipality, State or Federal agency, or an agent or employee thereof.

(23) "Point source" means any discernible, confined, and discrete conveyance, including but not limited to, any pipe, ditch, channel, tunnel, conduit, well, discrete fissure, container, rolling stock, concentrated animal feeding operation, vessel, or other floating craft from which pollutants are or may be discharged. This term does not include return flows from irrigated agriculture.

(24) "Pollutant" means dredged spoil, solid waste, incinerator residue, filter backwash, sewage, garbage, sewage sludge, munitions, chemical wastes, biological materials, radioactive materials (except those regulated under the Atomic Energy Act of 1954, as amended (42 (U.S.C. 2011 et seq.)), heat, wrecked or discharged equipment, rock, sand, cellar dirt and industrial, municipal, and agricultural waste discharged into water. It does not mean:

(i) Sewage from vessels; or

(ii) Water, gas, or other material which is injected into a well to facilitate production of oil or gas, or water derived in association with oil and gas production and disposed of in a well, if the well used either to facilitate production or for disposal purposes is approved by authority of the State in which the well is located, and if the State determines that the injection or disposal will not result in the degradation of ground or surface water resources.

Radioactive materials covered by the Atomic Energy Act are those encompassed in its definition of source, byproduct, or special nuclear materials. Examples of materials not covered include radium and accelerator-produced isotopes. See Train v. Colorado Public Interest Research Group, Inc., 426 U.S. 1 (1976).

(25) "Privately owned treatment works" means any device or system which is (a) used to treat wastes from any facility whose operator is not the operator of the treatment works and (b) not a "POTW."

(26) "Process wastewater" means any water which, during manufacturing or processing, comes into direct contact with or results from the production or use of any raw material, intermediate product, finished product, byproduct, or waste product.

(27) "Proposed permit" means a State NPDES "permit" prepared after the close of the public comment period (and, when applicable, any public hearing and administrative appeals) which is sent to EPA for review before final issuance by the State. A "proposed permit" is not a "draft permit."

(28) "Publicly owned treatment works ("POTW")" means any device or system used in the treatment (including recycling and reclamation) of municipal sewage or industrial wastes of a liquid nature which is owned by a "State" or "municipality." This definition includes sewers, pipes, or other conveyances only if they convey wastewater to a POTW providing treatment.

(29) "Runoff coefficient" means the fraction of total rainfall that will appear at the conveyance as runoff.

(30) "Significant materials" includes, but is not limited to: raw materials; fuels; materials such as solvents, detergents, and plastic pellets; finished materials such as metallic products; raw materials used in food processing or production; hazardous substances designated under section 101(14) of CERCLA; any chemical the facility is required to report pursuant to Section 313 of Title III of SARA; fertilizers; pesticides; and waste products such as ashes, slag and sludge that have the potential to be released with storm water discharges.

(31) "Site" means the land or water area where any "facility or activity" is physically located or conducted, including adjacent land used in connection with the facility or activity.

(32) "Storm water" means storm water runoff, snow melt runoff, and surface runoff and drainage.

(33) "Storm water discharge associated with industrial activity" means the discharge from any conveyance which is used for collecting and conveying storm water and which is directly related to manufacturing, processing or raw materials storage areas at an industrial plant. The term does not include discharges from facilities or activities excluded from the NPDES program under 40 CFR Part 122. For the categories of industries identified in subparagraphs (i) through (x) of this subsection, the term includes, but is not limited to, storm water discharges from industrial plant yards; immediate access roads and rail lines used or traveled by carriers of raw materials, manufactured products, waste material, or by-products used or created by the facility; material handling sites; refuse sites; sites used for the application or disposal of process waste waters (as defined at 40 CFR 401); sites used for the storage and maintenance of material handling equipment; sites used for residual treatment, storage, or disposal; shipping and receiving areas; manufacturing buildings; storage areas (including tank farms) for raw materials, and intermediate and finished products; and areas where industrial activity has taken place in the past and significant materials remain and are exposed to storm water. For the categories of industries identified in subparagraph (xi), the term includes only storm water discharges from all the areas (except access roads and rail lines) that are listed in the previous sentence where material handling equipment or activities, raw materials, intermediate products, final products, waste materials, by-products, or industrial machinery are exposed to storm water. For the purposes of this paragraph, material handling activities include the: storage, loading and unloading, transportation, or conveyance of any raw material, intermediate product, finished product, by-product or waste product. The term excludes areas located on plant lands separate from the plant's industrial activities, such as office buildings and accompanying parking lots as long as the drainage from the excluded areas is not mixed with storm water drained from the above described areas. Industrial facilities (including industrial facilities that are Federally, State, or municipally owned or operated that meet the description of the facilities listed in this paragraph (i)-(xi)) include those facilities designated under the provisions of 122.26(a)(1)(v). The

following categories of facilities are considered to be engaging in "industrial activity" for purposes of this subsection:

(i) Facilities subject to storm water effluent limitations guidelines, new source performance standards, or toxic pollutant effluent standards under 40 CFR Subchapter N (except facilities with toxic pollutant effluent standards which are exempted under category (xi) of this paragraph);

(ii) Facilities classified as Standard Industrial Classifications 24 (except 2434), 26 (except 265 and 267), 28 (except 283) 29, 311, 32 (except 323), 33, 3441, 373;

(iii) Facilities classified as Standard Industrial Classifications 10 through 14 (mineral industry) including active or inactive mining operations (except for areas of coal mining operations no longer meeting the definition of a reclamation area under 40 CFR 434.11(l) because the performance bond issued to the facility by the appropriate SMCRA authority has been released, or except for areas of non-coal mining operations which have been released from applicable State or Federal reclamation requirements after December 17, 1990 and oil and gas exploration, production, processing, or treatment operations, or transmission facilities that discharge storm water contaminated by contact with or that has come into contact with, any overburden, raw material, intermediate products, finished products, byproducts or waste products located on the site of such operations; (inactive mining operations are mining sites that are not being actively mined, but which have an identifiable owner/operator; inactive mining sites do not include sites where mining claims are being maintained prior to disturbances associated with the extraction, beneficiation, or processing of mined materials, nor sites where minimal activities are undertaken for the sole purpose of maintaining a mining claim);

(iv) Hazardous waste treatment, storage, or disposal facilities, including those that are operating under interim status or a permit under Subtitle C of RCRA;

(v) Landfills, land application sites, and open dumps that receive or have received any industrial wastes (waste that is received from any of the facilities described under this subsection) including those that are subject to regulation under Subtitle D of RCRA;

(vi) Facilities involved in the recycling of materials, including metal scrapyards, battery reclaimers, salvage yards, and automobile junkyards, including but limited to those classified as Standard Industrial Classification 5015 and 5093;

(vii) Steam electric power generating facilities, including coal handling sites;

(viii) Transportation facilities classified as Standard Industrial Classifications 40, 41, 42 (except 4221-25), 43, 44, 45, and 5171 which have vehicle maintenance shops, equipment cleaning operations, or airport deicing operations. Only those portions of the facility that are either involved in vehicle maintenance (including vehicle rehabilitation, mechanical repairs, painting, fueling, and lubrication), equipment cleaning operations, airport deicing operations, or which are otherwise identified under paragraphs (i)-(vii) or (ix)-(xi) of this subsection are associated with industrial activity;

(ix) Treatment works treating domestic sewage or any other sewage sludge or wastewater treatment device or system, used in the storage treatment, recycling, and reclamation of municipal or domestic sewage, including land dedicated to the disposal of sewage sludge that are located within the confines of the facility, with a design flow of 1.0 mgd or more, or required to have an approved pretreatment program under 40 CFR 403. Not included are farm lands, domestic gardens or lands used for sludge management where sludge is beneficially reused and which are not physically located in the confines of the facility, or areas that are in compliance with Section 405 of the CWA;

(x) Construction activity including clearing, grading and excavation activities except: operations that result in the disturbance of less than five acres of total land area which are not part of a larger common plan of development or sale;

(xi) Facilities under Standard Industrial Classifications 20, 21, 22, 23, 2434, 25, 265, 267, 27, 283, 285, 30, 31 (except 311), 323, 34 (except 3441), 35, 36, 37 (except 373), 38, 39, 4221-25, (and which are not otherwise included within categories (ii)-(x));

(34) "Total dissolved solids" means the total dissolved (filterable) solids as determined by use of the method specified in 40 CFR Part 136.

(35) "Toxic pollutant" means any pollutant listed as toxic under section 307(a)(1) of CWA.

(36) "Variance" means any mechanism or provision under section 301 or 316 of CWA or under 40 CFR Part 125, or in the applicable "effluent limitations guidelines" which allows modification to or waiver of the generally applicable effluent limitation requirements or time deadlines of CWA. This includes provisions which allow the establishment of alternative limitations based on fundamentally different factors or on sections 301(c), 301(g), 301(h), 301(i), or 316(a) of CWA.

(37) "Waters of the United States" or "waters of the U.S." means:

(i) All waters which are currently used, were used in the past, or may be susceptible to use in interstate or foreign commerce, including all waters which are subject to the ebb and flow of the tide;

(ii) All interstate water, including interstate "wetlands",

(iii) All other water such as intrastate lakes, rivers, streams (including intermittent steams), mudflats, sandflats, "wetlands", sloughs, prairie potholes, wet meadows, playa lakes, or natural ponds the use, degradation, or destruction of which would affect or could affect interstate or foreign commerce including any such waters:

(A) Which are or could be used by interstate or foreign travelers for recreational or other purposes;

(B) From which fish or shellfish are or could be taken and sold in interstate or foreign commence; or

(C) Which are used or could be used for industrial purposes by industries in interstate commerce:

(iv) All impoundments of waters otherwise defined as waters of the United States under this definition;

(v) Tributaries of waters identified in paragraphs (i) through (vi) of this definition;

(vi) The territorial sea; and

(vii) "Wetlands" adjacent to waters (other than waters that are themselves wetlands) identified in paragraphs (i) through (vi) of this definition.

Waste treatment systems, including treatment ponds or lagoons designed to meet the requirements of CWA (other than cooling ponds as defined in 40 CFR 423.11(m) which also meet the criteria of this definition) are not waters of the United States. This exclusion applies only to manmade bodies of water which neither were originally created in waters of the United States (such as disposal area in wetlands) nor resulted from the impoundment of waters of the United States. [See Note 1 of this section.]

(38) "Wetlands" means those areas that are inundated or saturated by surface or groundwater at a frequency and duration sufficient to support, and that under normal circumstances, do support a prevalence of vegetation typically adapted for life in saturated soil conditions. Wetlands generally include swamps, marshes, bogs, and similar areas.

APPENDIX C: INFORMATION FOR EPA REGIONAL OFFICES AND STATES WITH APPROVED NPDES PROGRAMS

C.1 Federal, State, and Regional Permitting Agency Contacts

C.2 Addresses and Telephone Numbers of EPA Regional Offices and States within the Regional Office Jurisdictions

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APPENDIX C.1: FEDERAL, STATE, AND REGIONAL PERMITTING AGENCY CONTACTS

Alabama
Department of Environmental Management
Water Division
1751 Cong. W.L. Dickinson Drive
Montgomery, AL 36130
(205) 271-7825

Alaska
Department of Environmental Conservation
Division of Environmental Quality Management
Pouch O
Juneau, AK 99811
(907) 465-2640
and U.S. EPA Region X

Arizona
Department of Health Services
Office of Waste and Water Quality Management
2005 N. Central Avenue
Phoenix, AZ 85007
(602) 257-2305
and U.S. EPA Region IX

Arkansas
Department of Pollution Control and Ecology
NPDES Branch
8001 National Drive
Little Rock, AR 72209
(501) 562-7444

California
State Water Resources Control Board
P.O. Box 100
901 P Street
Sacramento, CA 95801
(916) 322-3132

Colorado
Department of Health
Water Quality Control Division
Permits and Enforcement Section
4210 E. 11th Avenue, Room 200
Denver, CO 80220
(303) 331-3015

Connecticut
Department of Environmental Protection
Water Compliance and Hazardous Substances
122 Washington Street
Hartford, CT 06106
(203) 566-3245

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Delaware Department of Natural Resources and Environmental Control
Division of Water Resources
89 Kings Highway
P.O. Box 1401
Dover, DE 19903
(302) 736-4761

District of Columbia Department of Consumer and
Environmental Control Division
5010 Overlook Avenue, S.W.
Washington, D.C. 20032
(202) 767-7370
and U.S. EPA Region III

Florida Department of Environmental Regulation
Div. of Environmental Programs
Water Quality Planning Section
2600 Blairstone Road, Ste 531
Twin Towers Office Building
Tallahassee, FL 32301
(904) 488-0780
and U.S. EPA Region IV

Georgia Department of Natural Resources
Environmental Protection Division,
Water Protection Branch
Floyd Towers East - Room 1058
205 Butler Street, S.W.
Atlanta, GA 30334
(404) 656-4887

Hawaii Department of Health
Pollution Investigation and Enforcement Division
P.O. Box 3378
Honolulu, HI 96801
(808) 548-6505

Idaho Department of Health and Welfare
Bureau of Water Quality
State House
Boise, ID 83720
(208) 334-4250
and U.S. EPA Region X

Illinois Illinois Environmental Protection Agency
Division of Water Pollution Control
2200 Churchill Road
Springfield, IL 62706
(217) 782-1654

Indiana Indiana Department of Environmental Management
105 S. Meridian Street
P.O. Box 6015
Indianapolis, IN 46225
(317) 232-8488

Iowa	Department of Natural Resources Environmental Protection Division Surface and Ground Water Protection Bureau Henry A. Wallace Building 900 E. Grand Avenue Des Moines, IA 50319 (515) 281-8690		
Kansas	State Department of Health and Environment Division of Environment Bureau of Water Quality Forbes AFB Building No. 740 Topeka, KS 66612 (913) 862-9360x257		
Kentucky	Department of Environmental Protection Department of Environmental Protection Division of Water Quality 18 Reilly Road, Fort Boone Plaza Frankfort, KY 40601 (502) 564-3410		
Louisiana	Department of Environmental Quality Office of Water Resources Permits Programs P.O. Box 44091 Baton Rouge, LA 70804-4091 (504) 922-0530	and	U.S. EPA Region VI
Maine	Department of Environmental Protection Bureau of Water Quality Control State House, Station 17 Augusta, ME 04333 (207) 289-3355 Boston, MA 02203 (617) 565-3519	and	U.S. EPA Region I
Maryland	Department of Natural Resources Water Resources Administration (water resources programs) Tawes State Office Building Annapolis, MD 21401 (301) 269-3846		
	Department of Health and Mental Hygiene Environmental Health Administration (water quality standards, NPDES permits, and sewage treatment) 201 W. Preston Street Baltimore, MD 21203 (301) 225-6300		

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Massachusetts Department of Environmental Quality Engineering
Division of Water Pollution Control & Division of Water Supply
1 Winter Street
Boston, MA 02108
(617) 292-5673

and U.S. EPA
Region I

Michigan Department of Natural Resources
Water Resources Commission
Water Quality Division
P.O. Box 30028
Lansing, MI 48909
(517) 373-1949

Minnesota Minnesota Pollution Control Agency
Division of Water Pollution Control
520 Lafayette Road
St. Paul, MN 55155
(612) 296-7202

Mississippi Dept. of Natural Resources and Water Division
P.O. Box 10385, Southport Mall
Jackson, MS 39209
(601) 961-5171

and Department of Environmental Quality
Surface Water Division
Bureau of Pollution Control
P.O. Box 10385
Jackson, MS 39289

Missouri Department of Natural Resources
Water Quality Program
Division of Environmental Quality
Jefferson State Office Building
205 Jefferson Street
Jefferson City, MO 65102
(314) 751-1300

Montana Department of Health and Environmental Sciences
Division of Environmental Sciences
Water Quality Bureau
Cogswell Building, Room A206
Helena, MT 59620
(406) 444-2406

Nebraska Department of Environmental Control
Water Pollution Control Division
State House Station
P.O. Box 94877-301 Centennial Mall
Lincoln, NE 68509
(402) 471-2186

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Nevada Department of Conservation and Natural Resources
Water Resources Division
201 S. Fall Street, Room 221
Carson City, NV 89710
(702) 885-4380

New Hampshire Water Supply and Pollution Control Commission
Hazen Drive
P.O. Box 95
Concord, NH 03301
(603) 271-2458
and U.S. EPA Region I

New Jersey Department of Environmental Protection
Division of Water Resources
1474 Prospect Street
P.O. Box CN029
Trenton, NJ 08625
(609) 292-1638

New Mexico Health and Environment Department
Environmental Improvement Division
Surface Water Quality Bureau
1190 St. Francis Drive
Santa Fe, NM 87504-0968
(505) 827-2918
and U.S. EPA Region VI

New York Department of Environmental Conservation
Permit Administrator
50 Wolf Road
Albany, NY 12233

North Carolina Department of Natural Resources and Community Development
Division of Environmental Management
Water Quality Section
P.O. Box 27687
Raleigh, NC 27611
(919) 733-5083

North Dakota Department of Health
Division of Water Supply and Pollution Control
1200 Missouri Avenue
Bismark, ND 58501
(701) 224-2345

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Ohio	Environmental Protection Agency Waste Water Pollution Control 1800 Watermark Drive P.O. Box 1049 Columbus, OH 43266-0149 (614) 466-7427		
Oklahoma	Water Resources Board P.O. Box 53585 Oklahoma City, OK 73152 State Department of Health Permits and Compliance Division P.O. Box 53551 Oklahoma City, OK 73152	and	U.S. EPA Region VI
Oregon	Department of Environmental Quality (DEQ) Water Quality Division 522 S.W. Fifth Avenue P.O. Box 1760 Portland, OR 97207 (503) 229-5324		
Pennsylvania	Department of Environmental Resources Bureau of Water Quality Management P.O. Box 2063, 11th Floor/Fulton Bldg. 200 N. 3rd Street Harrisburg, PA 17120 (717) 787-2666		
Puerto Rico	Environmental Quality Board Division of Water/Water Resources P.O. Box 11488 Santurce, PR 00910 (809) 725-5140	and	U.S. EPA Region II
Rhode Island	Department of Environmental Management Division of Water Resources 75 Davis St., 209 Cannon Bldg. Providence, RI 02908 (401) 277-2234		

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South Carolina
Department of Health and
Environmental Control
Environmental Quality Control
2600 Bull Street
Columbia, SC 29201
(803) 734-4880

South Dakota
Department of Water and
Natural Resources
Division of Environmental
Regulation
Point Source Control Program
Joe Foss Building
120 E. Capitol
Pierre,SD 57501
(605) 773-3351

and U.S. EPA
Region VIII

Tennessee
Department of Public Health
Division of Water Quality Control
TERRA Building, 2nd floor
150 9th Ave., N.
Nashville, TN 37219-5405
(615) 741-3111

Texas
Texas Water Commission
P.O. Box 13087
Capitol Station
Austin, TX 78711-3087
(512) 463-8028

and U.S. EPA
Region VI

Texas Railroad Commission
P.O. Drawer 12967
Austin, TX 78711
(512) 463-8028

Utah
Department of Health
Bureau of Water Pollution Control
288 N. 1460 W.
P.O. Box 16690
Salt Lake City, UT 84116-0690
(801) 538-6146

Vermont
State Water Resources Board
(water pollution control)
58 E. State Street
Montpelier, VT 05602
(802) 828-2871

Water Quality Division
(water quality)
Department of Water Resources
and Environmental Engineering
103 S. Main Street
Waterbury, VT 05676
(802) 244-5638

Virginia	State Water Control Board 211 N. Hamilton Street P.O. Box 11143 Richmond, VA 23230 (804) 257-0056		
Washington	Washington Dept. of Ecology Office of Water Programs Mail Stop PV/11 Olympia, WA 98504 (206) 459-6000	and	Environmental Permit Information Center Department of Ecology Headquarters Office, PV-11 St. Martin's College Campus-Lacey Olympia, WA 98504
West Virginia	Department of Natural Resources Division of Water Resources 1800 Washington Street, East Charleston, WV 25305 (304) 348-2107		
Wisconsin	Department of Natural Resources Division of Environmental Standards Bureau of Water Resources and Management P.O. Box 7921 Madison, WI 53707 (608) 266-2121		
Wyoming	Department of Environmental Quality Water Quality Division Herschler Building 122 West 25th Street Cheyenne, WY 82002 (307) 777-7781		
Virgin Islands	US EPA, Region II		
Guam	US EPA, Region IX		
American Samoa	US EPA, Region IX		
District of Columbia	US EPA, Region III		
Northern Marianas	US EPA, Region IX		

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APPENDIX C.2: ADDRESSES AND TELEPHONE NUMBERS OF EPA REGIONAL OFFICES AND STATES WITHIN THE REGIONAL OFFICE JURISDICTION

REGION I

NPDES Permits, Water Management Division, EPA 9141,
U.S. Environmental Protection Agency, John F. Kennedy Building,
Boston, Massachusetts 02203, (617) 565-3420, FTS 835-3420.

Connecticut, Maine, Massachusetts, New Hampshire, Rhode Island, and Vermont.

REGION II

NPDES Permits, Water Management Division, EPA 9270,
U.S. Environmental Protection Agency, Jacob K. Javitz Federal Building,
26 Federal Plaza, New York, New York 10278, (212) 264-2657, FTS 264-2657.

New Jersey, New York, Virgin Islands, and Puerto Rico.

REGION III

NPDES Permits, Water Management Division, EPA 9360,
U.S. Environmental Protection Agency, 841 Chestnut Building,
Philadelphia, Pennsylvania 19107, (215) 597-9800, FTS 597-9800.

Delaware, District of Columbia, Maryland, Pennsylvania, Virginia, and West Virginia.

REGION IV

NPDES Permits, Water Management Division, EPA 9441,
U.S. Environmental Protection Agency, 345 Courtland Street, N.E.,
Atlanta, Georgia 30365, (404) 347-4727, FTS 257-4727.

Alabama, Florida, Georgia, Kentucky, Mississippi, North Carolina, South Carolina, and Tennessee.

REGION V

NPDES Permits, Water Management Division, EPA 9560,
U.S. Environmental Protection Agency, 230 South Dearborn Street,
Chicago, Illinois 60604, (312) 353-2105, FTS 353-2105.

Illinois, Indiana, Michigan, Minnesota, Ohio, and Wisconsin.

REGION VI

NPDES Permits, Water Management Division, EPA 9670,
U.S. Environmental Protection Agency, First Interstate Bank Tower at Fountain Place,
1445 Ross Avenue, 12th Floor, Suite 1200,
Dallas, Texas 75202, (214) 655-6444, FTS 255-6444.

Arkansas, Louisiana, New Mexico, Oklahoma, and Texas.

REGION VII

NPDES Permits, Water Management Division, EPA 9790,
U.S. Environmental Protection Agency, 726 Minnesota Avenue,
Kansas City, Missouri 66101, (913) 551-7000, FTS 276-7000.

Iowa, Kansas, Missouri, and Nebraska.

REGION VIII

NPDES Permits, Water Management Division, EPA 9871,
999 18th Street, Suite 500, U.S. Environmental Protection Agency,
Denver, Colorado 80202, (303) 293-1603, FTS 330-1603.

Colorado, Montana, North Dakota, South Dakota, Utah, and Wyoming.

REGION IX

NPDES Permits, Water Management Division, EPA 9920,
U.S. Environmental Protection Agency, 75 Hawthorne Street,
San Francisco, California 94105, (415) 744-2125, FTS 484-2125.

Arizona, California, Hawaii, Nevada, Guam, American Samoa, and Trust Territories.

REGION X

NPDES Permits, Water Management Division, EPA 9031,
U.S. Environmental Protection Agency, 1200 6th Avenue,
Seattle, Washington 98101, (206) 442-1200, FTS 399-1200.

Alaska, Idaho, Oregon, and Washington.

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As an alternative to submitting an individual application, a facility (except facilities that have existing individual NPDES permits for storm water or process discharge) may participate in a group application for sufficiently similar facilities. The intent of the group application process is to reduce the collection and reporting burdens of participating industries. Group applications involve a two part application process. Group applications do not have specific forms; rather, the applicants are required to submit the information described below.

Acceptable participants for a group application include those facilities that are part of the same industrial subcategory (see Table 2-1 for a list of the SIC codes that are considered industrial plants in the regulations - Part 405 to Part 471) or have sufficiently similar services or activities.

Part 1 of the group application must contain the following information: (There is no standard form for Part 1 of a group application. For Part 2 the relevant portion of form 2F should be used.) **When determining the number of dischargers identified for Part 2 sampling under paragraph (D), unless the group is less than 11 members in size, a minimum of 10 facilities must conduct and submit quantitative sampling data.**

122.26(c)(2) Group application for discharges associated with industrial activity. In lieu of individual applications or notice of intent to be covered by a general permit for storm water discharges associated with industrial activity, a group application may be filed by an entity representing a group of applicants (except facilities that have existing individual NPDES permits for storm water) that are part of the same subcategory (see 40 CFR Subchapter N, Part 405 to 471) or, where such grouping is inapplicable, are sufficiently similar as to be appropriate for general permit coverage under § 122.28 of this Part. The Part 1 application shall be submitted to the Office of Water Enforcement and Permits, U.S. EPA, 401 M Street, S.W. Washington, D.C. 20460 (EN-336) for approval. Once a Part 1 application is approved, group applicants are to submit Part 2 of the group application to the Office of Water Enforcement and Permits. A group application shall consist of:

(i) Part 1. Part 1 of a group application shall:

(A) identify the participants in the group application by name and location. Facilities participating in the group application shall be listed in nine subdivisions, based on the facility location relative to the nine precipitation zones indicated in Appendix Figure D-1 to this Part.

(B) include a narrative description summarizing the industrial activities of participants of the group application and explaining why the participants, as a whole, are sufficiently similar to be a covered by a general permit;

(C) include a list of significant materials stored exposed to precipitation by participants in the group application and materials management practices employed to diminish contact by these materials with precipitation and storm water runoff;

(D) identify ten percent of the dischargers participating in the group application (with a minimum of 10 dischargers, and either a minimum of two dischargers from each precipitation zone indicated in Appendix Figure D-1 of this Part in which ten or more members of the group are located, or one discharger from each precipitation zone indicated in Appendix Figure D-1 of this Part in which nine or fewer members of the group are located) from which quantitative data will be submitted in Part 2. If more than 1,000 facilities are identified in a group application, no more than 100 dischargers must submit quantitative data in Part 2. Groups of between four and ten dischargers may be formed. However, in groups of between four and ten, at least half the facilities must submit quantitative data, and at least one facility in each precipitation zone in which members of the group are located must submit data. A description of why the facilities selected to perform sampling and analysis are representative of the group as a whole, in terms of the information provided in subparagraphs (i)(B) and (i)(C) of this paragraph, shall accompany this section. Different factors impacting the nature of the storm water discharges, such as processes used and material management, shall be represented, to the extent feasible, in a manner roughly equivalent to their proportion in the group.

(ii) Part 2. Part 2 of a group application shall contain quantitative data (NPDES Form 2F), as modified by paragraph (c)(1) of this section, so that when Part 1 and Part 2 of the group application are taken together, a complete NPDES application (Form 1, Form 2C, and Form 2F) can be evaluated for each discharger identified in paragraph (c)(2)(i)(D) of this section.

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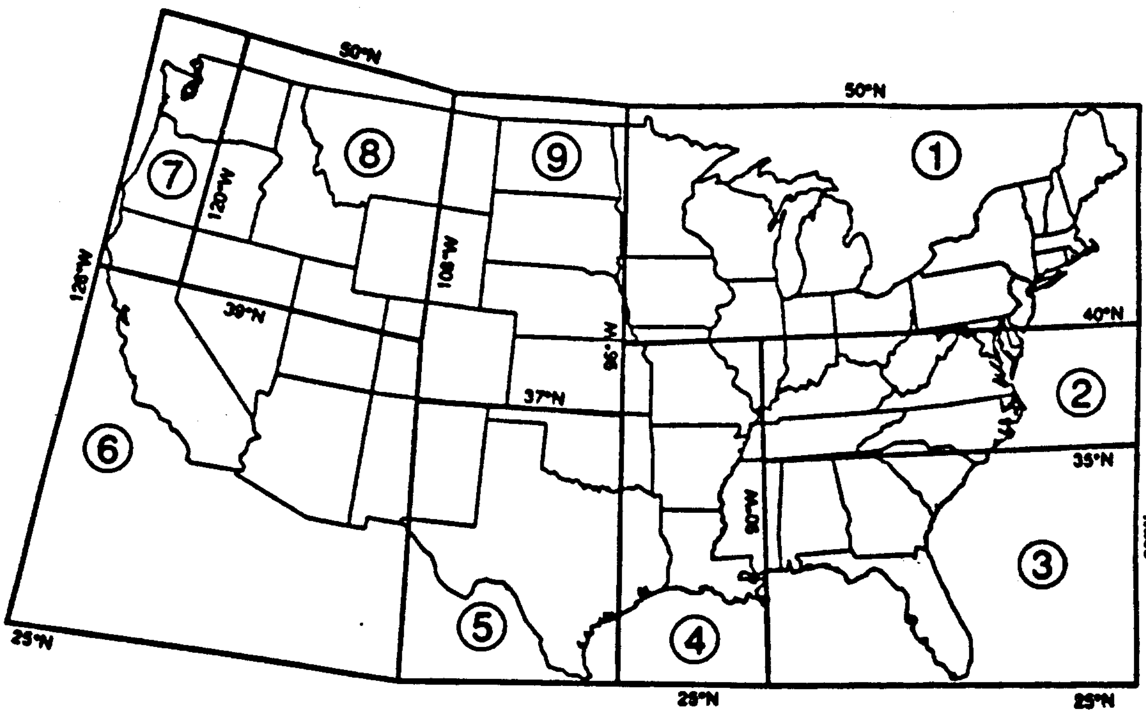

Source: Methodology for Analysis of Detention Basins for Control of Urban Runoff Quality, prepared for U.S. Environmental Protection Agency, Office of Water, Nonpoint Source Division, Washington, DC, 1986.

Note: Alaska and Hawaii are included in Zone 7. The Virgin Island and Puerto Rico are included in Zone 3.

Appendix Figure D-1. Rainfall Zones of the United States

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APPENDIX D.1: EPA REVIEW PROCEDURES FOR A GROUP APPLICATION

As shown in Figure 2-1, EPA Headquarters has 60 days to approve or deny the Part 1 application. When the Part 1 application is approved, group applicants are to submit Part 2 to the same address.

Part 2 of the group application must contain quantitative data (i.e., the data required in Form 2F) so that when Parts 1 and 2 of the group application are taken together, a complete NPDES permit application [Form 1, Form 2C (if necessary based on the criteria for use of this form), and Form 2F] can be evaluated for each of the dischargers designated in Item 4 of Part 1.

Although there in no such thing as a group permit, the data submitted by the group will be used to develop general permits or individual permits for all of the facilities participating in the group application (see Figure 2-1). EPA and NPDES States with general permit authority may develop a general permit that can then be modified as necessary for each industrial subcategory (e.g., based on SIC codes). NPDES States without general permitting authority can develop individual permits for the facilities participating in the group based on the information reported in the application. The group application process and related timeframes are summarized below:

a) Part 1 of the application must be submitted to the Director, EPA Office of Water Enforcement and Permits, by September 30, 1991.

b) Based on information submitted in Part 1 of the group application, EPA Headquarters will approve or deny the group coapplicants within 60 days after receipt.

c) Part 2 of the application must be submitted to EPA, Office of Water Enforcement and Permits no later than May 18, 1992.

d) A facility identified in the definition of "storm water associated with industrial activity" (summarized in Table 2-2) may add on to a group application submitted in accordance with item (2a) above at the discretion of the Office of Water Enforcement and Permits, and only upon a showing of good cause by the facility and the group applicant.

e) Facilities identified in Table 2-2 may apply for a storm water discharge permit as part of a group application previously submitted in accordance with item (2a) above, if the application for the additional facility is made within 15 months from the date of publication of the final general permit rule; the addition of the facility shall not reduce the percentage of the facilities that are required to submit quantitative data below 10%, unless there are over 100 facilities in the group that are submitting quantitative data. Approval to become part of group application must be obtained from the group or the trade association representing the individual facilities and from the Office of Water Enforcement and Permits.

APPENDIX E: NPDES PERMIT APPLICATION FORMS AND INSTRUCTIONS FOR THE PERMITTING PROCESS

Appendix	
E.1	Form 1
E.2	Form 2F
E.3	Form 2C
E.4	Form 2D
E.5	Form 2E

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APPENDIX E.1: FORM 1

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United States
Environmental Protection
Agency

Office of
Enforcement
Washington, DC 20460

EPA Form 3510-1
Revised August 1990

Permits Division

EPA

Application Form 1 - General Information

Consolidated Permits Program

This form must be completed by all persons applying for a permit under EPA's Consolidated Permits Program. See the general instructions to Form 1 to determine which other application forms you will need.

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DESCRIPTION OF CONSOLIDATED PERMIT APPLICATION FORMS	FORM 1 PACKAGE TABLE OF CONTENTS

The Consolidated Permit Application Forms are:

Form 1 – General Information *(included in this part)*;

Form 2 – Discharges to Surface Water *(NPDES Permits)*:

2A. Publicly Owned Treatment Works *(Reserved – not included in this package)*,

2B. Concentrated Animal Feeding Operations and Aquatic Animal Production Facilities *(not included in this package)*,

2C. Existing Manufacturing, Commercial, Mining, and Silvicultural Operations *(not included in this package)*, and

2D. New Manufacturing, Commercial, Mining, and Silvicultural Operations *(Reserved – not included in this package)*;

Form 3 – Hazardous Waste Application Form *(RCRA Permits – not included in this package)*;

Form 4 – Underground Injection of Fluids *(UIC Permits – Reserved – not included in this package)*; and

Form 5 – Air Emissions in Attainment Areas *(PSD Permits – Reserved – not included in this package)*.

SECTION A – GENERAL INSTRUCTIONS

Who Must Apply

With the exceptions described in Section C of these instructions, Federal laws prohibit you from conducting any of the following activities without a permit.

NPDES *(National Pollutant Discharge Elimination System Under the Clean Water Act, 33 U.S.C. 1251)*. Discharge of pollutants into the waters of the United States.

RCRA *(Resource Conservation and Recovery Act, 42 U.S.C. 6901)*. Treatment, storage, or disposal of hazardous wastes.

UIC *(Underground Injection Control Under the Safe Drinking Water Act, 42 U.S.C. 300f)*. Injection of fluids underground by gravity flow or pumping.

PSD *(Prevention of Significant Deterioration Under the Clean Air Act, 42 U.S.C. 7401)*. Emission of an air pollutant by a new or modified facility in or near an area which has attained the National Ambient Air Quality Standards for that pollutant.

Each of the above permit programs is operated in any particular State by either the United States Environmental Protection Agency *(EPA)* or by an approved State agency. You must use this application form to apply for a permit for those programs administered by EPA. For those programs administered by approved States, contact the State environmental agency for the proper forms.

If you have any questions about whether you need a permit under any of the above programs, or if you need information as to whether a particular program is administered by EPA or a State agency, or if you need to obtain application forms, contact your EPA Regional office *(listed in Table 1)*.

Upon your request, and based upon information supplied by you, EPA will determine whether you are required to obtain a permit for a particular facility. Be sure to contact EPA if you have a question, because Federal laws provide that you may be heavily penalized if you do not apply for a permit when a permit is required.

Form 1 of the EPA consolidated application forms collects general information applying to all programs. You must fill out Form 1 regardless of which permit you are applying for. In addition, you must fill out one of the supplementary forms *(Forms 2 – 5)* for each permit needed under each of the above programs. Item II of Form 1 will guide you to the appropriate supplementary forms.

You should note that there are certain exclusions to the permit requirements listed above. The exclusions are described in detail in Section C of these instructions. If your activities are excluded from permit requirements then you do not need to complete and return any forms.

NOTE: Certain activities not listed above also are subject to EPA administered environmental permit requirements. These include permits for ocean dumping, dredged or fill material discharging, and certain types of air emissions. Contact your EPA Regional office for further information.

Table 1. Addresses of EPA Regional Contacts and States Within the Regional Office Jurisdictions

REGION I

Permit Contact, Environmental and Economic Impact Office, U.S. Environmental Protection Agency, John F. Kennedy Building, Boston, Massachusetts 02203, (617) 223–4635, FTS 223–4635.
Connecticut, Maine, Massachusetts, New Hampshire, Rhode Island, and Vermont.

REGION II

Permit Contact, Permits Administration Branch, Room 432, U.S. Environmental Protection Agency, 26 Federal Plaza, New York, New York 10007, (212) 264–9880, FTS 264–9880.
New Jersey, New York, Virgin Islands, and Puerto Rico.

REGION III

Permit Contact *(3 EN 23)*, U.S. Environmental Protection Agency, 6th & Walnut Streets, Philadelphia, Pennsylvania 19106, (215) 597–8816, FTS 597–8816.
Delaware, District of Columbia, Maryland, Pennsylvania, Virginia, and West Virginia.

REGION IV

Permit Contact, Permits Section, U.S. Environmental Protection Agency, 345 Courtland Street, N.E., Atlanta, Georgia 30365, (404) 881–2017, FTS 257–2017.
Alabama, Florida, Georgia, Kentucky, Mississippi, North Carolina, South Carolina, and Tennessee.

REGION V

Permit Contact *(5EP)*, U.S. Environmental Protection Agency, 230 South Dearborn Street, Chicago, Illinois 60604, (312) 353–2105, FTS 353–2105.
Illinois, Indiana, Michigan, Minnesota, Ohio, and Wisconsin.

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Table 1 *(continued)*

REGION VI

Permit Contact *(6AEP)*, U.S. Environmental Protection Agency, First International Building, 1201 Elm Street, Dallas, Texas 75270, (214) 767–2765, FTS 729–2765.
Arkansas, Louisiana, New Mexico, Oklahoma, and Texas.

REGION VII

Permit Contact, Permits Branch, U.S. Environmental Protection Agency, 324 East 11th Street, Kansas City, Missouri 64106, (816) 758–5955, FTS 758–5955.
Iowa, Kansas, Missouri, and Nebraska.

REGION VIII

Permit Contact *(8E–WE)*, Suite 103, U.S. Environmental Protection Agency, 1860 Lincoln Street, Denver, Colorado 80295, (303) 837–4901, FTS 327–4901.
Colorado, Montana, North Dakota, South Dakota, Utah, and Wyoming.

REGION IX

Permit Contact, Permits Branch *(E–4)*, U.S. Environmental Protection Agency, 215 Fremont Street, San Francisco, California 94105, (415) 556–3450, FTS 556–3450.
Arizona, California, Hawaii, Nevada, Guam, American Samoa, and Trust Territories.

REGION X

Permit Contact *(M/S 521)*, U.S. Environmental Protection Agency, 1200 6th Avenue, Seattle, Washington 98101, (206) 442–7176, FTS 399–7176.
Alaska, Idaho, Oregon, and Washington.

Where to File

The application forms should be mailed to the EPA Regional office whose Region includes the State in which the facility is located *(see Table 1)*.

If the State in which the facility is located administers a Federal permit program under which you need a permit, you should contact the appropriate State agency for the correct forms. Your EPA Regional office *(Table 1)* can tell you to whom to apply and can provide the appropriate address and phone number.

When to File

Because of statutory requirements, the deadlines for filing applications vary according to the type of facility you operate and the type of permit you need. These deadlines are as follows:[1]

Table 2. Filing Dates for Permits

FORM*(permit)*	WHEN TO FILE
2A*(NPDES)*	180 days before your present NPDES permit expires.
2B*(NPDES)*	180 days before your present NPDES permit expires[2], or 180 days prior to start-up if you are a new facility.
2C*(NPDES)*	180 days before your present NPDES permit expires[2].
2D*(NPDES)*	180 days prior to startup.
3*(Hazardous Waste)*	Existing facility: Six months following publication of regulations listing hazardous wastes. New facility: 180 days before commencing physical construction.

Table 2 *(continued)*

FORM*(permit)*	WHEN TO FILE
4*(UIC)*	A reasonable time prior to construction for new wells; as directed by the Director for existing wells.
5*(PSD)*	Prior to commencement of construction.

[1] Please note that some of these forms are not yet available for use and are listed as "Reserved" at the beginning of these instructions. Contact your EPA Regional office for information on current application requirements and forms.

[2] If your present permit expires on or before November 30, 1980, the filing date is the date on which your permit expires. If your permit expires during the period December 1, 1980 – May 31, 1981, the filing date is 90 days before your permit expires.

Federal regulations provide that you may not begin to construct a new source in the NPDES program, a new hazardous waste management facility, a new injection well, or a facility covered by the PSD program before the issuance of a permit under the applicable program. Please note that if you are required to obtain a permit before beginning construction, as described above, you may need to submit your permit application well in advance of an applicable deadline listed in Table 2.

Fees

The U.S. EPA does not require a fee for applying for any permit under the consolidated permit programs. *(However, some States which administer one or more of these programs require fees for the permits which they issue.)*

Availability of Information to Public

Information contained in these application forms will, upon request, be made available to the public for inspection and copying. However, you may request confidential treatment for certain information which you submit on certain supplementary forms. The specific instructions for each supplementary form state what information on the form, if any, may be claimed as confidential and what procedures govern the claim. No information on Forms 1 and 2A through 2D may be claimed as confidential.

Completion of Forms

Unless otherwise specified in instructions to the forms, each item in each form must be answered. To indicate that each item has been considered, enter "NA," for not applicable, if a particular item does not fit the circumstances or characteristics of your facility or activity.

If you have previously submitted information to EPA or to an approved State agency which answers a question, you may either repeat the information in the space provided or attach a copy of the previous submission. Some items in the form require narrative explanation. If more space is necessary to answer a question, attach a separate sheet entitled "Additional Information."

Financial Assistance for Pollution Control

There are a number of direct loans, loan guarantees, and grants available to firms and communities for pollution control expenditures. These are provided by the Small Business Administration, the Economic Development Administration, the Farmers Home Administration, and the Department of Housing and Urban Development. Each EPA Regional office *(Table 1)* has an economic assistance coordinator who can provide you with additional information.

EPA's construction grants program under Title II of the Clean Water Act is an additional source of assistance to publicly owned treatment works. Contact your EPA Regional office for details.

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SECTION B – FORM 1 LINE–BY–LINE INSTRUCTIONS

This form must be completed by all applicants.

Completing This Form

Please type or print in the unshaded areas only. Some items have small graduation marks in the fill–in spaces. These marks indicate the number of characters that may be entered into our data system. The marks are spaced at 1/6" intervals which accommodate elite type *(12 characters per inch)*. If you use another type you may ignore the marks. If you print, place each character between the marks. Abbreviate if necessary to stay within the number of characters allowed for each item. Use one space for breaks between words, but not for punctuation marks unless they are needed to clarify your response.

Item I

Space is provided at the upper right hand corner of Form 1 for insertion of your EPA Identification Number. If you have an existing facility, enter your Identification Number. If you don't know your EPA Identification Number, please contact your EPA Regional office *(Table 1)*, which will provide you with your number. If your facility is new *(not yet constructed)*, leave this item blank.

Item II

Answer each question to determine which supplementary forms you need to fill out. Be sure to check the glossary in Section D of these instructions for the legal definitions of the bold faced words. Check Section C of these instructions to determine whether your activity is excluded from permit requirements.

If you answer "no" to every question, then you do not need a permit, and you do not need to complete and return any of these forms.

If you answer "yes" to any question, then you must complete and file the supplementary form by the deadline listed in Table 2 along with this form. *(The applicable form number follows each question and is enclosed in parentheses.)* You need not submit a supplementary form if you already have a permit under the appropriate Federal program, unless your permit is due to expire and you wish to renew your permit.

Questions (I) and (J) of Item II refer to major new or modified sources subject to Prevention of Significant Deterioration *(PSD)* requirements under the Clean Air Act. For the purpose of the PSD program, major sources are defined as: (A) Sources listed in Table 3 which have the potential to emit 100 tons or more per year emissions; and (B) All other sources with the potential to emit 250 tons or more per year. See Section C of these instructions for discussion of exclusions of certain modified sources.

Table 3. 28 Industrial Categories Listed in Section 169(1) of the Clean Air Act of 1977

Fossil fuel–fired steam generators of more than 250 million BTU per hour heat input;
Coal cleaning plants *(with thermal dryers)*;
Kraft pulp mills;
Portland cement plants;
Primary zinc smelters;
Iron and steel mill plants;
Primary aluminum ore reduction plants;
Primary copper smelters;
Municipal incinerators capable of charging more than 250 tons of refuse per day;
Hydrofluoric acid plants;
Nitric acid plants;
Sulfuric acid plants;
Petroleum refineries;
Lime plants;
Phosphate rock processing plants;
Coke oven batteries;
Sulfur recovery plants;
Carbon black plants *(furnace process)*;
Primary lead smelters;
Fuel conversion plants;
Sintering plants;
Secondary metal production plants;
Chemical process plants;
Fossil fuel boilers *(or combination thereof)* totaling more than 250 million BTU per hour heat input;

Table 3 *(continued)*

Petroleum storage and transfer units with a total storage capacity exceeding 300,000 barrels;
Taconite ore processing plants;
Glass fiber processing plants; and
Charcoal production plants.

Item III

Enter the facility's official or legal name. Do not use a colloquial name.

Item IV

Give the name, title, and work telephone number of a person who is thoroughly familiar with the operation of the facility and with the facts reported in this application and who can be contacted by reviewing offices if necessary.

Item V

Give the complete mailing address of the office where correspondence should be sent. This often is not the address used to designate the location of the facility or activity.

Item VI

Give the address or location of the facility identified in Item III of this form. If the facility lacks a street name or route number, give the most accurate alternative geographic information *(e.g., section number or quarter section number from county records or at intersection of Rts. 425 and 22)*.

Item VII

List, in descending order of significance, the four 4–digit standard industrial classification *(SIC)* codes which best describe your facility in terms of the principal products or services you produce or provide. Also, specify each classification in words. These classifications may differ from the SIC codes describing the operation generating the discharge, air emissions, or hazardous wastes.

SIC code numbers are descriptions which may be found in the "Standard Industrial Classification Manual" prepared by the Executive Office of the President, Office of Management and Budget, which is available from the Government Printing Office, Washington, D.C. Use the current edition of the manual. If you have any questions concerning the appropriate SIC code for your facility, contact your EPA Regional office *(see Table 1)*.

Item VIII–A

Give the name, as it is legally referred to, of the person, firm, public organization, or any other entity which operates the facility described in this application. This may or may not be the same name as the facility. The operator of the facility is the legal entity which controls the facility's operation rather than the plant or site manager. Do not use a colloquial name.

Item VIII–B

Indicate whether the entity which operates the facility also owns it by marking the appropriate box.

Item VIII–C

Enter the appropriate letter to indicate the legal status of the operator of the facility. Indicate "public" for a facility solely owned by local government*(s)* such as a city, town, county, parish, etc.

Items VIII–D – H

Enter the telephone number and address of the operator identified in Item VIII–A.

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Item IX

Indicate whether the facility is located on Indian Lands.

Item X

Give the number of each presently effective permit issued to the facility for each program or, if you have previously filed an application but have not yet received a permit, give the number of the application, if any. Fill in the unshaded area only. If you have more than one currently effective permit for your facility under a particular permit program, you may list additional permit numbers on a separate sheet of paper. List any relevant environmental Federal *(e.g., permits under the Ocean Dumping Act, Section 404 of the Clean Water Act or the Surface Mining Control and Reclamation Act)*, State *(e.g., State permits for new air emission sources in nonattainment areas under Part D of the Clean Air Act or State permits under Section 404 of the Clean Water Act)*, or local permits or applications under "other."

Item XI

Provide a topographic map or maps of the area extending at least to one mile beyond the property boundaries of the facility which clearly show the following

The legal boundaries of the facility;

The location and serial number of each of your existing and proposed intake and discharge structures;

All hazardous waste management facilities;

Each well where you inject fluids underground; and

All springs and surface water bodies in the area, plus all drinking water wells within 1/4 mile of the facility which are identified in the public record or otherwise known to you.

If an intake or discharge structure, hazardous waste disposal site, or injection well associated with the facility is located more than one mile from the plant, include it on the map, if possible. If not, attach additional sheets describing the location of the structure, disposal site, or well, and identify the U.S. Geological Survey *(or other)* map corresponding to the location.

On each map, include the map scale, a meridian arrow showing north, and latitude and longitude at the nearest whole second. On all maps of rivers, show the direction of the current, and in tidal waters, show the directions of the ebb and flow tides. Use a 7-1/2 minute series map published by the U.S. Geological Survey, which may be obtained through the U.S. Geological Survey Offices listed below. If a 7-1/2 minute series map has not been published for your facility site, then you may use a 15 minute series map from the U.S. Geological Survey. If neither a 7-1/2 nor 15 minute series map has been published for your facility site, use a plat map or other appropriate map, including all the requested information; in this case, briefly describe land uses in the map area *(e.g., residential, commercial)*.

You may trace your map from a geological survey chart, or other map meeting the above specifications. If you do, your map should bear a note showing the number or title of the map or chart it was traced from. Include the names of nearby towns, water bodies, and other prominent points. An example of an acceptable location map is shown in Figure 1–1 of these instructions. *(NOTE: Figure 1–1 is provided for purposes of illustration only, and does not represent any actual facility.)*

U.S.G.S. OFFICES	AREA SERVED
Eastern Mapping Center National Cartographic Information Center U.S.G.S. 536 National Center Reston, Va. 22092 Phone No. (703) 860–6336	Ala., Conn., Del., D.C., Fla., Ga., Ind., Ky., Maine, Md., Mass., N.H., N.J., N.Y., N.C., S.C., Ohio, Pa., Puerto Rico, R.I., Tenn., Vt., Va., W. Va., and Virgin Islands.

Item XI *(continued)*

Mid Continent Mapping Center National Cartographic Information Center U.S.G.S. 1400 Independence Road Rolla, Mo. 65401 Phone No. (314) 341–0851	Ark., Ill., Iowa, Kans., La., Mich., Minn., Miss., Mo., N. Dak., Nebr., Okla., S. Dak., and Wis.
Rocky Mountain Mapping Center National Cartographic Infomation Center U.S.G.S. Stop 504, Box 25046 Federal Center Denver, Co. 80225 Phone No. (303) 234–2326	Alaska, Colo., Mont., N. Mex., Tex., Utah, and Wyo.
Western Mapping Center National Cartographic Information Center U.S.G.S. 345 Middlefield Road Menlo Park, Ca. 94025 Phone No. (415) 323–8111	Ariz., Calif., Hawaii, Idaho, Nev., Oreg., Wash., American Samoa, Guam, and Trust Territories

Item XII

Briefly describe the nature of your business *(e.g., products produced or services provided)*.

Item XIII

Federal statues provide for severe penalties for submitting false information on this application form.

18 U.S.C. Section 1001 provides that "Whoever, in any matter within the jurisdiction of any department or agency of the United States knowingly and willfully falsifies, conceals or covers up by any trick, scheme, or device a material fact, or makes or uses any false writing or document knowing same to contain any false, fictitious or fraudulent statement or entry, shall be fined not more than $10,000 or imprisoned not more than five years, or both."

Section 309(c)(2) of the Clean Water Act and Section 113(c)(2) of the Clean Air Act each provide that "Any person who knowingly makes any false statement, representation, or certification in any application, . . . shall upon conviction, be punished by a fine of no more than $10,000 or by imprisonment for not more than six months, or both."

In addition, Section 3008(d)(3) of the Resource Conservation and Recovery Act provides for a fine up to $25,000 per day or imprisonment up to one year, or both, for a first conviction for making a false statement in any application under the Act, and for double these penalties upon subsequent convictions.

FEDERAL REGULATIONS REQUIRE THIS APPLICATION TO BE SIGNED AS FOLLOWS:

A. For a corporation, by a principal executive officer of at least the level of vice president. However, if the only activity in Item II which is marked "yes" is Question G, the officer may authorize a person having responsibility for the overall operations of the well or well field to sign the certification. In that case, the authorization must be written and submitted to the permitting authority.

B. For partnership or sole proprietorship, by a general partner or the proprietor, respectively; or

C. For a municipality, State, Federal, or other public facility, by either a principal executive officer or ranking elected official.

SECTION C – ACTIVITIES WHICH DO NOT REQUIRE PERMITS

I. National Pollutant Discharge Elimination System Permits Under the Clean Water Act. You are not required to obtain an NPDES permit if your discharge is in one of the following categories, as provided by the Clean Water Act *(CWA)* and by the NPDES regulations *(40 CFR Parts 122–125)*. However, under Section 510 of CWA a discharge exempted from the federal NPDES requirements may still be regulated by a State authority; contact your State environmental agency to determine whether you need a State permit.

A. DISCHARGES FROM VESSELS. Discharges of sewage from vessels, effluent from properly functioning marine engines, laundry, shower, and galley sink wastes, and any other discharge incidental to the normal operation of a vessel do not require NPDES permits. However, discharges of rubbish, trash, garbage, or other such materials discharged overboard require permits, and so do other discharges when the vessel is operating in a capacity other than as a means of transportation, such as when the vessel is being used as an energy or mining facility, a storage facility, or a seafood processing facility, or is secured to the bed of the ocean, contiguous zone, or waters of the United States for the purpose of mineral or oil exploration or development.

B. DREDGED OR FILL MATERIAL. Discharges of dredged or fill material into waters of the United States do not need NPDES permits if the dredging or filling is authorized by a permit issued by the U.S. Army Corps of Engineers or an EPA approved State under Section 404 of CWA.

C. DISCHARGES INTO PUBLICLY OWNED TREATMENT WORKS *(POTW)*. The introduction of sewage, industrial wastes, or other pollutants into a POTW does not need an NPDES permit. You must comply with all applicable pretreatment standards promulgated under Section 307(b) of CWA, which may be included in the permit issued to the POTW. If you have a plan or an agreement to switch to a POTW in the future, this does not relieve you of the obligation to apply for and receive an NPDES permit until you have stopped discharging pollutants into waters of the United States.

(NOTE: Dischargers into privately owned treatment works do not have to apply for or obtain NPDES permits except as otherwise required by the EPA Regional Administrator. The owner or operator of the treatment works itself, however, must apply for a permit and identify all users in its application. Users so identified will receive public notice of actions taken on the permit for the treatment works.)

D. DISCHARGES FROM AGRICULTURAL AND SILVICULTURAL ACTIVITIES. Most discharges from agricultural and silvicultural activities to waters of the United States do not require NPDES permits. These include runoff from orchards, cultivated crops, pastures, range lands, and forest lands. However, the discharges listed below do require NPDES permits. Definitions of the terms listed below are contained in the Glossary section of these instructions.

1. Discharges from Concentrated Animal Feeding Operations. *(See Glossary for definitions of "animal feeding operations" and "concentrated animal feeding operations." Only the latter require permits.)*

2. Discharges from Concentrated Aquatic Animal Production Facilities *(See Glossary for size cutoffs.)*

3. Discharges associated with approved Aquaculture Projects.

4. Discharges from Silvicultural Point Sources. *(See Glossary for the definition of "silvicultural point source.")* Nonpoint source silvicultural activities are excluded from NPDES permit requirements. However, some of these activities, such as stream crossings for roads, may involve point source discharges of dredged or fill material which may require a Section 404 permit. See 33 CFR 209.120.

E. DISCHARGES IN COMPLIANCE WITH AN ON-SCENE COORDINATOR'S INSTRUCTIONS.

II. Hazardous Waste Permits Under the Resource Conservation and Recovery Act. You may be excluded from the requirement to obtain a permit under this program if you fall into one of the following categories.

Generators who accumulate their own hazardous waste on-site for less than 90 days as provided in 40 CFR 262.34;

Farmers who dispose of hazardous waste pesticide from their own use as provided in 40 CFR 262.51;

Certain persons treating, storing, or disposing of small quantities of hazardous waste as provided in 40 CFR 261.4 or 261.5, and

Owners and operators of totally enclosed treatment facilities as defined in 40 CFR 260.10.

Check with your Regional office for details. Please note that even if you are excluded from permit requirements, you may be required by Federal regulations to handle your waste in a particular manner.

III. Underground Injection Control Permits Under the Safe Drinking Water Act. You are not required to obtain a permit under this program if you:

Inject into existing wells used to enhance recovery of oil and gas or to store hydrocarbons *(note, however, that these underground injections are regulated by Federal rules)*; or

Inject into or above a stratum which contains, within 1/4 mile of the well bore, an underground source of drinking water *(unless your injection is the type identified in Item II-H, for which you do need a permit)*. However, you must notify EPA of your injection and submit certain required information on forms supplied by the Agency, and your operation may be phased out if you are a generator of hazardous wastes or a hazardous waste management facility which uses wells or septic tanks to dispose of hazardous waste.

IV. Prevention of Significant Deterioration Permits Under the Clean Air Act. The PSD program applies to newly constructed or modified facilities *(both of which are referred to as "new sources")* which increase air emissions. The Clean Air Act Amendments of 1977 exclude small new sources of air emissions from the PSD review program. Any new source in an industrial category listed in Table 3 of these instructions whose potential to emit is less than 100 tons per year is not required to get a PSD permit. In addition, any new source in an industrial category not listed in Table 3 whose potential to emit is less than 250 tons per year is exempted from the PSD requirements.

Modified sources which increase their net emissions *(the difference between the total emission increases and total emission decreases at the source)* less than the significant amount set forth in EPA regulations are also exempt from PSD requirements. Contact your EPA Regional office *(Table 1)* for further information.

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SECTION D – GLOSSARY

NOTE: This Glossary includes terms used in the instructions and in Forms 1, 2B, 2C, and 3. Additional terms will be included in the future when other forms are developed to reflect the requirements of other parts of the Consolidated Permits Program. If you have any questions concerning the meaning of any of these terms, please contact your EPA Regional office *(Table 1)*.

ALIQUOT means a sample of specified volume used to make up a total composite sample.

ANIMAL FEEDING OPERATION means a lot or facility *(other than an aquatic animal production facility)* where the following conditions are met:

A. Animals *(other than aquatic animals)* have been, are, or will be stabled or confined and fed or maintained for a total of 45 days or more in any 12 month period; and

B. Crops, vegetation, forage growth, or post–harvest residues are not sustained in the normal growing season over any portion of the lot or facility.

Two or more animal feeding operations under common ownership are a single animal feeding operation if they adjoin each other or if they use a common area or system for the disposal of wastes.

ANIMAL UNIT means a unit of measurement for any animal feeding operation calculated by adding the following numbers: The number of slaughter and feeder cattle multiplied by 1.0; Plus the number of mature dairy cattle multiplied by 1.4; Plus the number of swine weighing over 25 kilograms *(approximately 55 pounds)* multiplied by 0.4. Plus the number of sheep multiplied by 0.1; Plus the number of horses multiplied by 2.0.

APPLICATION means the EPA standard national forms for applying for a permit, including any additions, revisions, or modifications to the forms; or forms approved by EPA for use in approved States, including any approved modifications or revisions. For RCRA, "application" also means "Application, Part B."

APPLICATION, PART A means that part of the Consolidated Permit Application forms which a RCRA permit applicant must complete to qualify for interim status under Section 3005(e) of RCRA and for consideration for a permit. Part A consists of Form 1 *(General Information)* and Form 3 *(Hazardous Waste Application Form)*.

APPLICATION, PART B means that part of the application which a RCRA permit applicant must complete to be issued a permit. *(NOTE: EPA is not developing a specific form for Part B of the permit application, but an instruction booklet explaining what information must be supplied is available from the EPA Regional office.)*

APPROVED PROGRAM or APPROVED STATE means a State program which has been approved or authorized by EPA under 40 CFR Part 123.

AQUACULTURE PROJECT means a defined managed water area which uses discharges of pollutants into that designated area for the maintenance or production of harvestable freshwater, estuarine, or marine plants or animals. "Designated area" means the portions of the waters of the United States within which the applicant plans to confine the cultivated species, using a method of plan or operation *(including, but not limited to, physical confinement)* which, on the basis of reliable scientific evidence, is expected to ensure the specific individual organisms comprising an aquaculture crop will enjoy increased growth attributable to the discharge of pollutants and be harvested within a defined geographic area.

AQUIFER means a geological formation, group of formations, or part of a formation that is capable of yielding a significant amount of water to a well or spring.

AREA OF REVIEW means the area surrounding an injection well which is described according to the criteria set forth in 40 CFR Section 146.06.

AREA PERMIT means a UIC permit applicable to all or certain wells within a geographic area, rather than to a specified well, under 40 CFR Section 122.37.

ATTAINMENT AREA means, for any air pollutant, an area which has been designated under Section 107 of the Clean Air Act as having ambient air quality levels better than any national primary or secondary ambient air quality standard for that pollutant. Standards have been set for sulfur oxides, particulate matter, nitrogen dioxide, carbon monoxide, ozone, lead, and hydrocarbons. For purposes of the Glossary, "attainment area" also refers to "unclassifiable area," which means, for any pollutants, an area designated under Section 107 as unclassifiable with respect to that pollutant due to insufficient information.

BEST MANAGEMENT PRACTICES *(BMP)* means schedules of activities, prohibitions of practices, maintenance procedures, and other management practices to prevent or reduce the pollution of waters of the United States. BMP's include treatment requirements, operation procedures, and practices to control plant site runoff, spillage or leaks, sludge or waste disposal, or drainage from raw material storage.

BIOLOGICAL MONITORING TEST means any test which includes the use of aquatic algal, invertebrate, or vertebrate species to measure acute or chronic toxicity, and any biological or chemical measure of bioaccumulation.

BYPASS means the intentional diversion of wastes from any any portion of a treatment facility.

CONCENTRATED ANIMAL FEEDING OPERATION means an animal feeding operation which meets the criteria set forth in either (A) or (B) below or which the Director designates as such on a case–by–case basis:

A. More than the numbers of animals specified in any of the following categories are confined:

1. 1,000 slaughter or feeder cattle,
2. 700 mature dairy cattle *(whether milked or dry cows)*,
3. 2,500 swine each weighing over 25 kilograms *(approximately 55 pounds)*,
4. 500 horses,
5. 10,000 sheep or lambs,
6. 55,000 turkeys,
7. 100,000 laying hens or broilers *(if the facility has a continuous overflow watering)*,
8. 30,000 laying hens or broilers *(if the facility has a liquid manure handling system)*,
9. 5,000 ducks, or
10. 1,000 animal units; or

B. More than the following numbers and types of animals are confined:

1. 300 slaughter or feeder cattle,
2. 200 mature dairy cattle *(whether milked or dry cows)*,
3. 750 swine each weighing over 25 kilograms *(approximately 55 pounds)*,
4. 150 horses,

CONCENTRATED ANIMAL FEEDING OPERATION *(continued)*

5. 3,000 sheep or lambs,

6. 16,500 turkeys,

7. 30,000 laying hens or broilers *(if the facility has continuous overflow watering)*,

8. 9,000 laying hens or broilers *(if the facility has a liquid manure handling system)*,

9. 1,500 ducks, or

10. 300 animal units; AND

Either one of the following conditions are met: Pollutants are discharged into waters of the United States through a manmade ditch, flushing system or other similar manmade device *("manmade" means constructed by man and used for the purpose of transporting wastes)*, or Pollutants are discharged directly into waters of the United States which originate outside of and pass over, across, or through the facility or otherwise come into direct contact with the animals confined in the operation.

Provided, however, that no animal feeding operation is a concentrated animal feeding operation as defined above if such animal feeding operation discharges only in the event of a 25 year, 24 hour storm event.

CONCENTRATED AQUATIC ANIMAL PRODUCTION FACILITY means a hatchery, fish farm, or other facility which contains, grows or holds aquatic animals in either of the following categories, or which the Director designates as such on a case–by–case basis:

A. Cold water fish species or other cold water aquatic animals including, but not limited to, the Salmonidae family of fish *(e.g., trout and salmon)* in ponds, raceways or other similar structures which discharge at least 30 days per year but does not include:

1. Facilities which produce less than 9,090 harvest weight kilograms *(approximately 20,000 pounds)* of aquatic animals per year; and

2. Facilities which feed less than 2,272 kilograms *(approximately 5,000 pounds)* of food during the calendar month of maximum feeding.

B. Warm water fish species or other warm water aquatic animals including, but not limited to, the Ameiuridae, Cetrarchidae, and Cyprinidae families of fish *(e.g., respectively, catfish, sunfish, and minnows)* in ponds, raceways, or other similar structures which discharge at least 30 days per year, but does not include:

1. Closed ponds which discharge only during periods of excess runoff; or

2. Facilities which produce less than 45,454 harvest weight kilograms *(approximately 100,000 pounds)* of aquatic animals per year.

CONTACT COOLING WATER means water used to reduce temperature which comes into contact with a raw material, intermediate product, waste product other than heat, or finished product.

CONTAINER means any portable device in which a material is stored, transported, treated, disposed of, or otherwise handled.

CONTIGUOUS ZONE means the entire zone established by the United States under article 24 of the convention of the Territorial Sea and the Contiguous Zone.

CWA means the Clean Water Act *(formerly referred to as the Federal Water Pollution Control Act)* Pub. L. 92–500, as amended by Pub. L. 95–217 and Pub. L. 95–576, 33 U.S.C. 1251 *et seq.*

DIKE means any embankment or ridge of either natural or manmade materials used to prevent the movement of liquids, sludges, solids, or other materials.

DIRECT DISCHARGE means the discharge of a pollutant as defined below.

DIRECTOR means the EPA Regional Administrator or the State Director as the context requires.

DISCHARGE *(OF A POLLUTANT)* means:

A. Any addition of any pollutant or combination of pollutants to waters of the United States from any point source; or

B. Any addition of any pollutant or combination of pollutants to the waters of the contiguous zone or the ocean from any point source other than a vessel or other floating craft which is being used as a means of transportation.

This definition includes discharges into waters of the United States from: Surface runoff which is collected or channelled by man; Discharges through pipes, sewers, or other conveyances owned by a State, municipality, or other person which do not lead to POTW's; and Discharges through pipes, sewers, or other conveyances, leading into privately owned treatment works. This term does not include an addition of pollutants by any indirect discharger.

DISPOSAL *(in the RCRA program)* means the discharge, deposit, injection, dumping, spilling, leaking, or placing of any hazardous waste into or on any land or water so that the hazardous waste or any constituent of it may enter the environment or be emitted into the air or discharged into any waters, including ground water.

DISPOSAL FACILITY means a facility or part of a facility at which hazardous waste is intentionally placed into or on land or water, and at which hazardous waste will remain after closure.

EFFLUENT LIMITATION means any restriction imposed by the Director on quantities, discharge rates, and concentrations of pollutants which are discharged from point sources into waters of the United States, the waters of the contiguous zone, or the ocean.

EFFLUENT LIMITATION GUIDELINE means a regulation published by the Administrator under Section 304(b) of the Clean Water Act to adopt or revise effluent limitations.

ENVIRONMENTAL PROTECTION AGENCY *(EPA)* means the United States Environmental Protection Agency.

EPA IDENTIFICATION NUMBER means the number assigned by EPA to each generator, transporter, and facility.

EXEMPTED AQUIFER means an aquifer or its portion that meets the criteria in the definition of USDW, but which has been exempted according to the procedures in 40 CFR Section 122.35(b).

EXISTING HWM FACILITY means a Hazardous Waste Management facility which was in operation, or for which construction had commenced, on or before October 21, 1976. Construction had commenced if (A) the owner or operator had obtained all necessary Federal, State, and local preconstruction approvals or permits, and either (B1) a continuous on–site, physical construction program had begun, or (B2) the owner or operator had entered into contractual obligations, which could not be cancelled or modified without substantial loss, for construction of the facility to be completed within a reasonable time.

(NOTE: This definition reflects the literal language of the statute. However, EPA believes that amendments to RCRA now in conference will shortly be enacted and will change the date for determining when a facility is an "existing facility" to one no earlier than May of 1980; indications are the conferees are considering October 30, 1980. Accordingly, EPA encourages every owner or operator of a facility which was built or under construction as of the promulgation date of the RCRA program regulations to file Part A of its permit application so that it can be quickly processed for interim status when the change in the law takes effect. When these amendments are enacted, EPA will amend this definition.)

EXISTING SOURCE or **EXISTING DISCHARGER** *(in the NPDES program)* means any source which is not a new source or a new discharger.

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EXISTING INJECTION WELL means an injection well other than a new injection well.

FACILITY means any HWM facility, UIC underground injection well, NPDES point source, PSD stationary source, or any other facility or activity *(including land or appurtenances thereto)* that is subject to regulation under the RCRA, UIC, NPDES, or PSD programs.

FLUID means material or substance which flows or moves whether in a semisolid, liquid, sludge, gas, or any other form or state.

GENERATOR means any person by site, whose act or process produces hazardous waste identified or listed in 40 CFR Part 261.

GROUNDWATER means water below the land surface in a zone of saturation.

HAZARDOUS SUBSTANCE means any of the substances designated under 40 CFR Part 116 pursuant to Section 311 of CWA. *(NOTE: These substances are listed in Table 2c–4 of the instructions to Form 2C.)*

HAZARDOUS WASTE means a hazardous waste as defined in 40 CFR Section 261.3 published May 19, 1980.

HAZARDOUS WASTE MANAGEMENT FACILITY *(HWM facility)* means all contiguous land, structures, appurtenances, and improvements on the land, used for treating, storing, or disposing of hazardous wastes. A facility may consist of several treatment, storage, or disposal operational units *(for example, one or more landfills, surface impoundments, or combinations of them)*.

IN OPERATION means a facility which is treating, storing, or disposing of hazardous waste.

INCINERATOR *(in the RCRA program)* means an enclosed device using controlled flame combustion, the primary purpose of which is to thermally break down hazardous waste. Examples of incinerators are rotary kiln, fluidized bed, and liquid injection incinerators.

INDIRECT DISCHARGER means a nondomestic discharger introducing pollutants to a publicly owned treatment works.

INJECTION WELL means a well into which fluids are being injected.

INTERIM AUTHORIZATION means approval by EPA of a State hazardous waste program which has met the requirements of Section 3006(c) of RCRA and applicable requirements of 40 CFR Part 123, Subparts A, B, and F.

LANDFILL means a disposal facility or part of a facility where hazardous waste is placed in or on land and which is not a land treatment facility, a surface impoundment, or an injection well.

LAND TREATMENT FACILITY *(in the RCRA program)* means a facility or part of a facility at which hazardous waste is applied onto or incorporated into the soil surface; such facilities are disposal facilities if the waste will remain after closure.

LISTED STATE means a State listed by the Administrator under Section 1422 of SDWA as needing a State UIC program.

MGD means millions of gallons per day.

MUNICIPALITY means a city, village, town, borough, county, parish, district, association, or other public body created by or under State law and having jurisdiction over disposal of sewage, industrial wastes, or other wastes, or an Indian tribe or an authorized Indian tribal organization, or a designated and approved management agency under Section 208 of CWA.

NATIONAL POLLUTANT DISCHARGE ELIMINATION SYSTEM *(NPDES)* means the national program for issuing modifying, revoking and reissuing, terminating, monitoring, and enforcing permits and imposing and enforcing pretreatment requirements, under Sections 307, 318, 402, and 405 of CWA. The term includes an approved program.

NEW DISCHARGER means any building, structure, facility, or installation. (A) From which there is or may be a new or additional discharge of pollutants at a site at which on October 18, 1972, it had never discharged pollutants. (B) Which has never received a finally effective NPDES permit for discharges at that site; and (C) Which is not a "new source." This definition includes an indirect discharger which commences discharging into waters of the United States. It also includes any existing mobile point source, such as an offshore oil drilling rig, seafood processing vessel, or aggregate plant that begins discharging at a location for which it does not have an existing permit.

NEW HWM FACILITY means a Hazardous Waste Management facility which began operation or for which construction commenced after October 21, 1976.

NEW INJECTION WELL means a well which begins injection after a UIC program for the State in which the well is located is approved.

NEW SOURCE *(in the NPDES program)* means any building, structure, facility, or installation from which there is or may be a discharge of pollutants, the construction of which commenced:

A. After promulgation of standards of performance under Section 306 of CWA which are applicable to such source; or

B. After proposal of standards of performance in accordance with Section 306 of CWA which are applicable to such source, but only if the standards are promulgated in accordance with Section 306 within 120 days of their proposal.

NON–CONTACT COOLING WATER means water used to reduce temperature which does not come into direct contact with any raw material, intermediate product, waste product *(other than heat)*, or finished product.

OFF–SITE means any site which is not "on–site."

ON–SITE means on the same or geographically contiguous property which may be divided by public or private right*(s)*–of–way, provided the entrance and exit between the properties is at a cross–roads intersection, and access is by crossing as opposed to going along, the right*(s)*–of–way. Non–contiguous properties owned by the same person, but connected by a right–of–way which the person controls and to which the public does not have access, is also considered on–site property.

OPEN BURNING means the combustion of any material without the following characteristics:

A. Control of combustion air to maintain adequate temperature for efficient combustion;

B. Containment of the combustion–reaction in an enclosed device to provide sufficient residence time and mixing for complete combustion; and

C. Control of emission of the gaseous combustion products.

(See also "incinerator" and "thermal treatment").

OPERATOR means the person responsible for the overall operation of a facility.

OUTFALL means a point source.

OWNER means the person who owns a facility or part of a facility.

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PERMIT means an authorization, license, or equivalent control document issued by EPA or an approved State to implement the requirements of 40 CFR Parts 122, 123, and 124.

PHYSICAL CONSTRUCTION *(in the RCRA program)* means excavation, movement of earth, erection of forms or structures, or similar activity to prepare a HWM facility to accept hazardous waste.

PILE means any noncontainerized accumulation of solid, nonflowing hazardous waste that is used for treatment or storage.

POINT SOURCE means any discernible, confined, and discrete conveyance, including but not limited to any pipe, ditch, channel, tunnel, conduit, well, discrete fissure, container, rolling stock, concentrated animal feeding operation, vessel or other floating craft from which pollutants are or may be discharged. This term does not include return flows from irrigated agriculture.

POLLUTANT means dredged spoil, solid waste, incinerator residue, filter backwash, sewage, garbage, sewage sludge, munitions, chemical waste, biological materials, radioactive materials *(except those regulated under the Atomic Energy Act of 1954, as amended (42 U.S.C. Section 2011 et seq.))*, heat, wrecked or discarded equipment, rocks, sand, cellar dirt and industrial, municipal, and agriculture waste discharged into water. It does not mean:

A. Sewage from vessels; or

B. Water, gas, or other material which is injected into a well to facilitate production of oil or gas, or water derived in association with oil and gas production and disposed of in a well, if the well used either to facilitate production or for disposal purposes is approved by authority of the State in which the well is located, and if the State determines that the injection or disposal will not result in the degradation of ground or surface water resources.

(NOTE: Radioactive materials covered by the Atomic Energy Act are those encompassed in its definition of source, byproduct, or special nuclear materials. Examples of materials not covered include radium and accelerator produced isotopes. See Train v. Colorado Public Interest Research Group, Inc., 426 U.S. 1 (1976).)

PREVENTION OF SIGNIFICANT DETERIORATION *(PSD)* means the national permitting program under 40 CFR 52.21 to prevent emissions of certain pollutants regulated under the Clean Air Act from significantly deteriorating air quality in attainment areas.

PRIMARY INDUSTRY CATEGORY means any industry category listed in the NRDC Settlement Agreement *(Natural Resources Defense Council v. Train, 8 ERC 2120 (D.D.C. 1976), modified 12 ERC 1833 (D.D.C. 1979))*.

PRIVATELY OWNED TREATMENT WORKS means any device or system which is: (A) Used to treat wastes from any facility whose operator is not the operator of the treatment works; and (B) Not a POTW.

PROCESS WASTEWATER means any water which, during manufacturing or processing, comes into direct contact with or results from the production or use of any raw material, intermediate product, finished product, byproduct, or waste product.

PUBLICLY OWNED TREATMENT WORKS or **POTW** means any device or system used in the treatment *(including recycling and reclamation)* of municipal sewage or industrial wastes of a liquid nature which is owned by a State or municipality. This definition includes any sewers, pipes, or other conveyances only if they convey wastewater to a POTW providing treatment.

RENT means use of another's property in return for regular payment.

RCRA means the Solid Waste Disposal Act as amended by the Resource Conservation and Recovery Act of 1976 *(Pub. L. 94–580, as amended by Pub. L. 95–609, 42 U.S.C. Section 6901 et seq.)*.

ROCK CRUSHING AND GRAVEL WASHING FACILITIES are facilities which process crushed and broken stone, gravel, and riprap *(see 40 CFR Part 436, Subpart B, and the effluent limitations guidelines for these facilities)*.

SDWA means the Safe Drinking Water Act *(Pub. L. 95–523, as amended by Pub. L. 95–1900, 42 U.S.C. Section 300(f) et seq.)*

SECONDARY INDUSTRY CATEGORY means any industry category which is not a primary industry category.

SEWAGE FROM VESSELS means human body wastes and the wastes from toilets and other receptacles intended to receive or retain body wastes that are discharged from vessels and regulated under Section 312 of CWA, except that with respect to commercial vessels on the Great Lakes this term includes graywater. For the purposes of this definition, "graywater" means galley, bath, and shower water.

SEWAGE SLUDGE means the solids, residues, and precipitate separated from or created in sewage by the unit processes of a POTW. "Sewage" as used in this definition means any wastes, including wastes from humans, households, commercial establishments, industries, and storm water runoff, that are discharged to or otherwise enter a publicly owned treatment works.

SILVICULTURAL POINT SOURCE means any discernable, confined, and discrete conveyance related to rock crushing, gravel washing, log sorting, or log storage facilities which are operated in connection with silvicultural activities and from which pollutants are discharged into waters of the United States. This term does not include nonpoint source silvicultural activities such as nursery operations, site preparation, reforestation and subsequent cultural treatment, thinning, prescribed burning, pest and fire control, harvesting operations, surface drainage, or road construction and maintenance from which there is natural runoff. However, some of these activities *(such as stream crossing for roads)* may involve point source discharges of dredged or fill material which may require a CWA Section 404 permit. "Log sorting and log storage facilities" are facilities whose discharges result from the holding of unprocessed wood, e.g., logs or roundwood with bark or after removal of bark in self–contained bodies of water *(mill ponds or log ponds)* or stored on land where water is applied intentionally on the logs *(wet decking)*. *(See 40 CFR Part 429, Subpart J, and the effluent limitations guidelines for these facilities.)*

STATE means any of the 50 States, the District of Columbia, Guam, the Commonwealth of Puerto Rico, the Virgin Islands, American Samoa, the Trust Territory of the Pacific Islands *(except in the case of RCRA)*, and the Commonwealth of the Northern Mariana Islands *(except in the case of CWA)*.

STATIONARY SOURCE *(in the PSD program)* means any building, structure, facility, or installation which emits or may emit any air pollutant regulated under the Clean Air Act. "Building, structure, facility, or installation" means any grouping of pollutant–emitting activities which are located on one or more contiguous or adjacent properties and which are owned or operated by the same person *(or by persons under common control)*.

STORAGE *(in the RCRA program)* means the holding of hazardous waste for a temporary period at the end of which the hazardous waste is treated, disposed, or stored elsewhere.

STORM WATER RUNOFF means water discharged as a result of rain, snow, or other precipitation.

SURFACE IMPOUNDMENT or **IMPOUNDMENT** means a facility or part of a facility which is a natural topographic depression, manmade excavation, or diked area formed primarily of earthen materials *(although it may be lined with manmade materials)*, which is designed to hold an accumulation of liquid wastes or wastes containing free liquids, and which is not an injection well. Examples of surface impoundments are holding, storage, settling, and aeration pits, ponds, and lagoons.

TANK *(in the RCRA program)* means a stationary device, designed to contain an accumulation of hazardous waste which is constructed primarily of non–earthen materials *(e.g., wood, concrete, steel, plastic)* which provide structural support.

THERMAL TREATMENT *(in the RCRA program)* means the treatment of hazardous waste in a device which uses elevated temperature as the primary means to change the chemical, physical, or biological character or composition of the hazardous waste. Examples of thermal treatment processes are incineration, molten salt, pyrolysis, calcination, wet air oxidation, and microwave discharge. *(See also "incinerator" and "open burning").*

TOTALLY ENCLOSED TREATMENT FACILITY *(in the RCRA program)* means a facility for the treatment of hazardous waste which is directly connected to an industrial production process and which is constructed and operated in a manner which prevents the release of any hazardous waste or any constituent thereof into the environment during treatment. An example is a pipe in which waste acid is neutralized.

TOXIC POLLUTANT means any pollutant listed as toxic under Section 307(a)(1) of CWA.

TRANSPORTER *(in the RCRA program)* means a person engaged in the off–site transportation of hazardous waste by air, rail, highway, or water.

TREATMENT *(in the RCRA program)* means any method, technique, or process, including neutralization, designed to change the physical, chemical, or biological character or composition of any hazardous waste so as to neutralize such waste, or so as to recover energy or material resources from the waste, or so as to render such waste non–hazardous, or less hazardous; safer to transport, store, or dispose of; or amenable for recovery, amenable for storage, or reduced in volume.

UNDERGROUND INJECTION means well injection.

UNDERGROUND SOURCE OF DRINKING WATER or USDW means an aquifer or its portion which is not an exempted aquifer and:

A. Which supplies drinking water for human consumption; or

B. In which the ground water contains fewer than 10,000 mg/l total dissolved solids.

UPSET means an exceptional incident in which there is unintentional and temporary noncompliance with technology–based permit effluent limitations because of factors beyond the reasonable control of the permittee. An upset does not include noncompliance to the extent caused by operational error, improperly designed treatment facilities, inadequate treatment facilities, lack of preventive maintenance, or careless or improper operation.

WATERS OF THE UNITED STATES means:

A. All waters which are currently used, were used in the past, or may be susceptible to use in interstate or foreign commerce, including all waters which are subject to the ebb and flow of the tide;

B. All interstate waters, including interstate wetlands;

C. All other waters such as intrastate lakes, rivers, streams *(including intermittent streams)*, mudflats, sandflats, wetlands, sloughs, prairie potholes, wet meadows, playa lakes, and natural ponds, the use, degradation, or destruction of which would or could affect interstate or foreign commerce including any such waters:

1. Which are or could be used by interstate or foreign travelers for recreational or other purposes,

2. From which fish or shellfish are or could be taken and sold in interstate or foreign commerce,

3. Which are used or could be used for industrial purposes by industries in interstate commerce;

D. All impoundments of waters otherwise defined as waters of the United States under this definition;

E. Tributaries of waters identified in paragraphs (A) – (D) above;

F. The territorial sea; and

G. Wetlands adjacent to waters *(other than waters that are themselves wetlands)* identified in paragraphs (A) – (F) of this definition.

Waste treatment systems, including treatment ponds or lagoons designed to meet requirement of CWA *(other than cooling ponds as defined in 40 CFR Section 423.11(m) which also meet the criteria of this definition)* are not waters of the United States. This exclusion applies only to manmade bodies of water which neither were originally created in waters of the United States *(such as a disposal area in wetlands)* nor resulted from the impoundments of waters of the United States.

WELL INJECTION or UNDERGROUND INJECTION means the subsurface emplacement of fluids through a bored, drilled, or driven well; or through a dug well, where the depth of the dug well is greater than the largest surface dimension.

WETLANDS means those areas that are inundated or saturated by surface or groundwater at a frequency and duration sufficient to support, and that under normal circumstances do support, a prevalence of vegetation typically adapted for life in saturated soil conditions. Wetlands generally include swamps, marshes, bogs, and similar areas.

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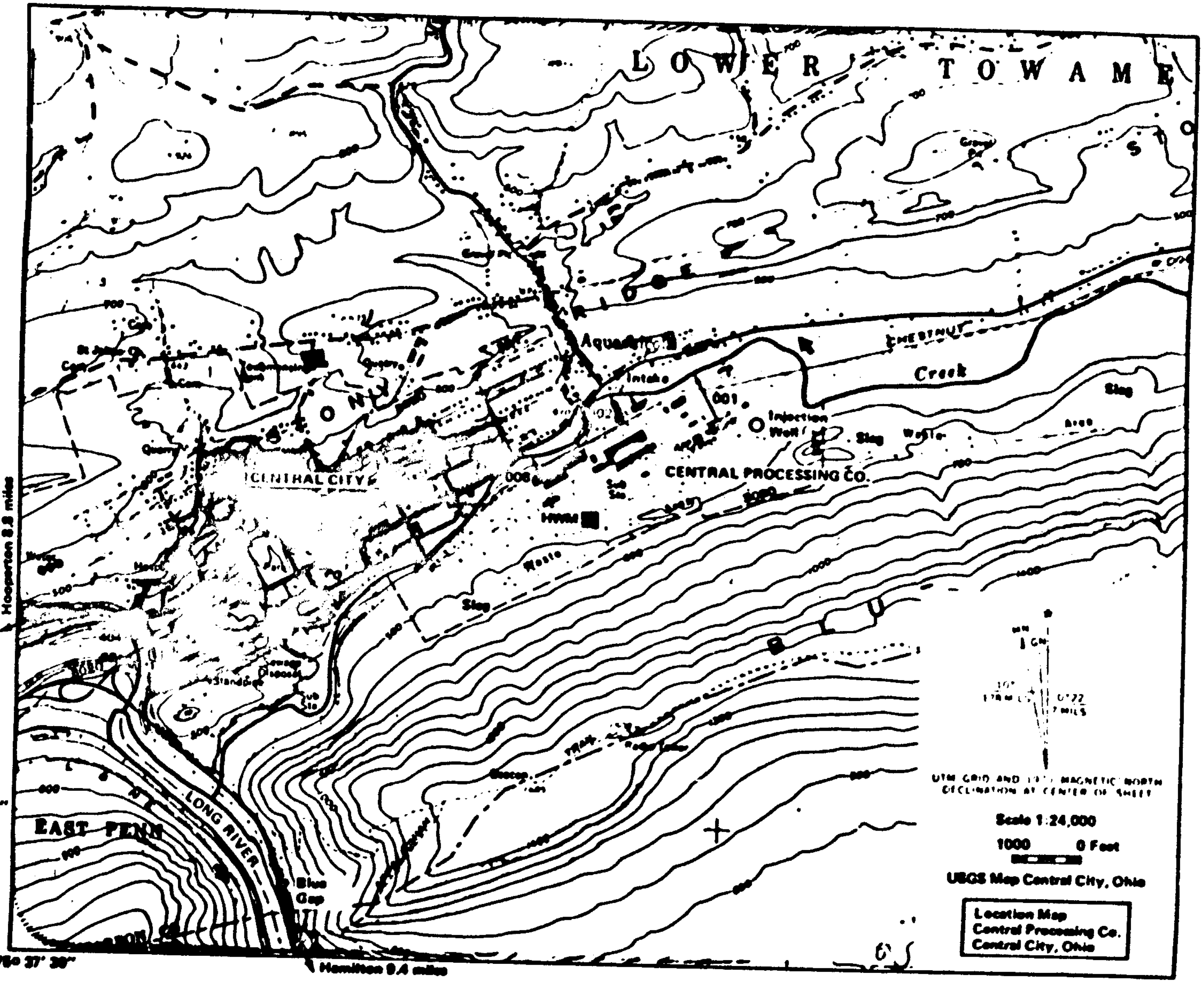

LOWER TOWAME
CHESTNUT
Creek
Aqueduct
Intake
001
002
008
Injection Well
Slag
Slag Waste
Area
CENTRAL CITY
CENTRAL PROCESSING CO.
HWM
Quarry
Cem
Sewage Disposal
Standpipe
Sub Sta
Slag Waste
LONG RIVER
EAST PENN
Blue Gap
TRAIL
Hooperton 8.8 miles
Hamilton 9.4 miles
40° 47' 30"
75° 37' 30"
UTM GRID AND MAGNETIC NORTH DECLINATION AT CENTER OF SHEET
Scale 1:24,000
1000 0 Feet
USGS Map Central City, Ohio
Location Map
Central Processing Co.
Central City, Ohio

FIGURE 1-1

Please print or type in the unshaded areas only
(fill-in areas are spaced for elite type, i.e., 12 characters/inch)

Form Approved OMB No 2040-0086 Approval expires 5-31-92

FORM **1** GENERAL

EPA

U.S. ENVIRONMENTAL PROTECTION AGENCY

GENERAL INFORMATION

Consolidated Permits Program

(Read the "General Instructions" before starting.)

I. EPA I.D. NUMBER

F | | D

LABEL ITEMS	
I. EPA I.D. NUMBER	PLEASE PLACE LABEL IN THIS SPACE
III. FACILITY NAME	
V. FACILITY MAILING ADDRESS	
VI. FACILITY LOCATION	

GENERAL INSTRUCTIONS

If a preprinted label has been provided, affix it in the designated space. Review the information carefully; if any of it is incorrect, cross through it and enter the correct data in the appropriate fill-in area below. Also, if any of the preprinted data is absent *(the area to the left of the label space lists the information that should appear)*, please provide it in the proper fill-in area(s) below. If the label is complete and correct, you need not complete Items I, III, V, and VI *(except VI-B which must be completed regardless)*. Complete all items if no label has been provided. Refer to the instructions for detailed item descriptions and for the legal authorizations under which this data is collected.

II. POLLUTANT CHARACTERISTICS

INSTRUCTIONS: Complete A through J to determine whether you need to submit any permit application forms to the EPA. If you answer "yes" to any questions, you must submit this form and the supplemental form listed in the parenthesis following the question. Mark "X" in the box in the third column if the supplemental form is attached. If you answer "no" to each question, you need not submit any of these forms. You may answer "no" if your activity is excluded from permit requirements; see Section C of the instructions. See also, Section D of the instructions for definitions of bold-faced terms.

SPECIFIC QUESTIONS	YES	NO	FORM ATTACHED	SPECIFIC QUESTIONS	YES	NO	FORM ATTACHED
A. Is this facility a publicly owned treatment works which results in a discharge to waters of the U.S.? (FORM 2A)				B. Does or will this facility (either existing or proposed) include a concentrated animal feeding operation or aquatic animal production facility which results in a discharge to waters of the U.S.? (FORM 2B)			
C. Is this a facility which currently results in discharges to waters of the U.S. other than those described in A or B above? (FORM 2C)				D. Is this a proposed facility (other than those described in A or B above) which will result in a discharge to waters of the U.S.? (FORM 2D)			
E. Does or will this facility treat, store, or dispose of hazardous wastes? (FORM 3)				F. Do you or will you inject at this facility industrial or municipal effluent below the lowermost stratum containing, within one quarter mile of the well bore, underground sources of drinking water? (FORM 4)			
G. Do you or will you inject at this facility any produced water or other fluids which are brought to the surface in connection with conventional oil or natural gas production, inject fluids used for enhanced recovery of oil or natural gas, or inject fluids for storage of liquid hydrocarbons? (FORM 4)				H. Do you or will you inject at this facility fluids for special processes such as mining of sulfur by the Frasch process, solution mining of minerals, in situ combustion of fossil fuel, or recovery of geothermal energy? (FORM 4)			
I. Is this facility a proposed stationary source which is one of the 28 industrial categories listed in the instructions and which will potentially emit 100 tons per year of any air pollutant regulated under the Clean Air Act and may affect or be located in an attainment area? (FORM 5)				J. Is this facility a proposed stationary source which is NOT one of the 28 industrial categories listed in the instructions and which will potentially emit 250 tons per year of any air pollutant regulated under the Clean Air Act and may affect or be located in an attainment area? (FORM 5)			

III. NAME OF FACILITY

1 SKIP

IV. FACILITY CONTACT

A. NAME & TITLE (last, first, & title)	B. PHONE (area code & no.)
2	

V. FACILITY MAILING ADDRESS

A. STREET OR P.O. BOX

3

B. CITY OR TOWN	C. STATE	D. ZIP CODE
4		

VI. FACILITY LOCATION

A. STREET, ROUTE NO. OR OTHER SPECIFIC IDENTIFIER

5

B. COUNTY NAME

C. CITY OR TOWN	D. STATE	E. ZIP CODE	F. COUNTY CODE (if known)
6			

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VII. SIC CODES *(4-digit, in order of priority)*

A. FIRST — 7 (specify)

B. SECOND — 7 (specify)

C. THIRD — 7 (specify)

D. FOURTH — 7 (specify)

VIII. OPERATOR INFORMATION

A. NAME — 8

B. Is the name listed in Item VIII-A also the owner? ☐ YES ☐ NO

C. STATUS OF OPERATOR *(Enter the appropriate letter into the answer box; if "Other", specify.)*

F = FEDERAL
S = STATE
P = PRIVATE
M = PUBLIC *(other than federal or state)*
O = OTHER *(specify)*

(specify)

D. PHONE *(area code & no.)* — A

E. STREET OR P.O. BOX

F. CITY OR TOWN — B

G. STATE

H. ZIP CODE

IX. INDIAN LAND

Is the facility located on Indian lands?
☐ YES ☐ NO

X. EXISTING ENVIRONMENTAL PERMITS

A. NPDES *(Discharges to Surface Water)* — 9 N

D. PSD *(Air Emissions from Proposed Sources)* — 9 P

B. UIC *(Underground Injection of Fluids)* — 9 U

E. OTHER *(specify)* — 9 (specify)

C. RCRA *(Hazardous Wastes)* — 9 R

E. OTHER *(specify)* — 9 (specify)

XI. MAP

Attach to this application a topographic map of the area extending to at least one mile beyond property boundaries. The map must show the outline of the facility, the location of each of its existing and proposed intake and discharge structures, each of its hazardous waste treatment, storage, or disposal facilities, and each well where it injects fluids underground. Include all springs, rivers and other surface water bodies in the map area. See instructions for precise requirements.

XII. NATURE OF BUSINESS *(provide a brief description)*

XIII. CERTIFICATION *(see instructions)*

I certify under penalty of law that I have personally examined and am familiar with the information submitted in this application and all attachments and that, based on my inquiry of those persons immediately responsible for obtaining the information contained in the application, I believe that the information is true, accurate and complete. I am aware that there are significant penalties for submitting false information, including the possibility of fine and imprisonment.

A. NAME & OFFICIAL TITLE *(type or print)*

B. SIGNATURE

C. DATE SIGNED

COMMENTS FOR OFFICIAL USE ONLY

C

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Please print or type in the unshaded areas only.
(fill-in areas are spaced for elite type, i.e., 12 characters/inch)

Form Approved OMB No 2040-0086 Approval expires 5-31-92

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EPA

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(Read the "General Instructions" before starting.)

I. EPA I.D. NUMBER

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I. EPA I.D. NUMBER

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V. FACILITY MAILING ADDRESS

PLEASE PLACE LABEL IN THIS SPACE

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1 SKIP

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B. PHONE (area code & no.)

2

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A. STREET OR P.O. BOX

3

B. CITY OR TOWN | C. STATE | D. ZIP CODE

4

VI. FACILITY LOCATION

A. STREET, ROUTE NO. OR OTHER SPECIFIC IDENTIFIER

5

B. COUNTY NAME

C. CITY OR TOWN | D. STATE | E. ZIP CODE | F. COUNTY CODE (if known)

6

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VII. SIC CODES *(4-digit, in order of priority)*

A. FIRST	B. SECOND
7 *(specify)*	7 *(specify)*

C. THIRD	D. FOURTH
7 *(specify)*	7 *(specify)*

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8

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C. STATUS OF OPERATOR *(Enter the appropriate letter into the answer box; if "Other", specify.)*

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S = STATE
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M = PUBLIC *(other than federal or state)*
O = OTHER *(specify)*

(specify)

D. PHONE *(area code & no.)*

A

E. STREET OR P.O. BOX

F. CITY OR TOWN

B

G. STATE

H. ZIP CODE

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A. NPDES *(Discharges to Surface Water)*

9 N

D. PSD *(Air Emissions from Proposed Sources)*

9 P

B. UIC *(Underground Injection of Fluids)*

9 U

E. OTHER *(specify)*

9 *(specify)*

C. RCRA *(Hazardous Wastes)*

9 R

E. OTHER *(specify)*

9 *(specify)*

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XIII. CERTIFICATION *(see instructions)*

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A. NAME & OFFICIAL TITLE *(type or print)*	B. SIGNATURE	C. DATE SIGNED

COMMENTS FOR OFFICIAL USE ONLY

C

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APPENDIX E.2: FORM 2F

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1 0453

EPA I.D. Number (copy from Item 1 of Form 1) | Form Approved OMB No. 2040-0086 | Approval expires 5-31-92

Please print or type in the unshaded areas only

Form 2F NPDES

EPA

United States Environmental Protection Agency
Washington, DC 20460

Application for Permit To Discharge Stormwater Discharges Associated with Industrial Activity

Paperwork Reduction Act Notice

Public reporting burden for this application is estimated to average 28.6 hours per application, including time for reviewing instructions, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing the collection of information. Send comments regarding the burden estimate, any other aspect of this collection of information, or suggestions for improving this form, including suggestions which may increase or reduce this burden to: Chief, Information Policy Branch, PM-223, U.S. Environmental Protection Agency, 401 M St., SW, Washington, DC 20460, or Director, Office of Information and Regulatory Affairs, Office of Management and Budget, Washington, DC 20503.

I. Outfall Location

For each outfall, list the latitude and longitude of its location to the nearest 15 seconds and the name of the receiving water.

A. Outfall Number (list)	B. Latitude			C. Longitude			D. Receiving Water (name)

II. Improvements

A. Are you now required by any Federal, State, or local authority to meet any implementation schedule for the construction, upgrading or operation of wastewater treatment equipment or practices or any other environmental programs which may affect the discharges described in this application? This includes, but is not limited to, permit conditions, administrative or enforcement orders, enforcement compliance schedule letters, stipulations, court orders, and grant or loan conditions.

1. Identification of Conditions, Agreements, Etc.	2. Affected Outfalls		3. Brief Description of Project	4. Final Compliance Date	
	number	source of discharge		a. req.	b. proj.

B. You may attach additional sheets describing any additional water pollution (or other environmental projects which may affect your discharges) you now have under way or which you plan. Indicate whether each program is now under way or planned, and indicate your actual or planned schedules for construction.

III. Site Drainage Map

Attach a site map showing topography (or indicating the outline of drainage areas served by the outfall(s) covered in the application if a topographic map is unavailable) depicting the facility including: each of its intake and discharge structures; the drainage area of each storm water outfall; paved areas and buildings within the drainage area of each storm water outfall, each known past or present areas used for outdoor storage or disposal of significant materials, each existing structural control measure to reduce pollutants in storm water runoff, materials loading and access areas, areas where pesticides, herbicides, soil conditioners and fertilizers are applied; each of its hazardous waste treatment, storage or disposal units (including each area not required to have a RCRA permit which is used for accumulating hazardous waste under 40 CFR 262.34); each well where fluids from the facility are injected underground; springs, and other surface water bodies which receive storm water discharges from the facility.

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Continued from the Front

IV. Narrative Description of Pollutant Sources

A. For each outfall, provide an estimate of the area (include units) of impervious surfaces (including paved areas and building roofs) drained to the outfall, and an estimate of the total surface area drained by the outfall.

Outfall Number	Area of Impervious Surface (provide units)	Total Area Drained (provide units)	Outfall Number	Area of Impervious Surface (provide units)	Total Area Drained (provide units)

B. Provide a narrative description of significant materials that are currently or in the past three years have been treated, stored or disposed in a manner to allow exposure to storm water; method of treatment, storage, or disposal; past and present materials management practices employed, in the last three years, to minimize contact by these materials with storm water runoff; materials loading and access areas; and the location, manner, and frequency in which pesticides, herbicides, soil conditioners, and fertilizers are applied.

C. For each outfall, provide the location and a description of existing structural and nonstructural control measures to reduce pollutants in storm water runoff; and a description of the treatment the storm water receives, including the schedule and type of maintenance for control and treatment measures and the ultimate disposal of any solid or fluid wastes other than by discharge.

Outfall Number	Treatment	List Codes from Table 2F-1

V. Nonstormwater Discharges

A. I certify under penalty of law that the outfall(s) covered by this application have been tested or evaluated for the presence of nonstormwater discharges, and that all nonstormwater discharges from these outfall(s) are identified in either an accompanying Form 2C or Form 2E application for the outfall.

Name and Official Title (type or print)	Signature	Date Signed

B. Provide a description of the method used, the date of any testing, and the onsite drainage points that were directly observed during a test.

VI. Significant Leaks or Spills

Provide existing information regarding the history of significant leaks or spills of toxic or hazardous pollutants at the facility in the last three years, including the approximate date and location of the spill or leak, and the type and amount of material released.

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Continued from Page 2

EPA ID Number (copy from Item 1 of Form 1)

VII. Discharge Information

A,B,C, & D See instructions before proceeding. Complete one set of tables for each outfall. Annotate the outfall number in the space provided. Tables VII-A, VII-B, and VII-C are included on separate sheets numbered VII-1 and VII-2.

E. Potential discharges not covered by analysis - is any pollutant listed in Table 2F-2 a substance or a component of a substance which you currently use or manufacture as an intermediate or final product or byproduct?

☐ Yes *(list all such pollutants below)* ☐ No *(go to Section IX)*

VIII. Biological Toxicity Testing Data

Do you have any knowledge or reason to believe that any biological test for acute or chronic toxicity has been made on any of your discharges or on a receiving water in relation to your discharge within the last 3 years?

☐ Yes *(list all such pollutants below)* ☐ No *(go to Section IX)*

IX. Contract Analysis Information

Were any of the analyses reported in Item V performed by a contract laboratory or consulting firm?

☐ Yes *(list the name, address, and telephone number of, and pollutants analyzed by, each such laboratory or firm below)* ☐ No *(go to Section X)*

A. Name	B. Address	C. Area Code & Phone No.	D. Pollutants Analyzed

X. Certification

I certify under penalty of law that this document and all attachments were prepared under my direction or supervision in accordance with a system designed to assure that qualified personnel properly gather and evaluate the information submitted. Based on my inquiry of the person or persons who manage the system or those persons directly responsible for gathering the information, the information submitted is, to the best of my knowledge and belief, true, accurate, and complete. I am aware that there are significant penalties for submitting false information, including the possibility of fine and imprisonment for knowing violations.

A. Name & Official Title *(type or print)*	B. Area Code and Phone No
C. Signature	D. Date Signed

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VII. Discharge Information (Continued from page 3 of Form 2F)

Part A - You must provide the results of at least one analysis for every pollutant in this table. Complete one table for each outfall. See instructions for additional details.

Pollutant and CAS Number (if available)	Maximum Values (include units)		Average Values (include units)		Number of Storm Events Sampled	Sources of Pollutants
	Grab Sample Taken During First 30 Minutes	Flow-weighted Composite	Grab Sample Taken During First 30 Minutes	Flow-weighted Composite		
Oil and Grease						
Biological Oxygen Demand (BOD5)						
Chemical Oxygen Demand (COD)						
Total Suspended Solids (TSS)						
Total Kjeldahl Nitrogen						
Nitrate plus Nitrite Nitrogen						
Total Phosphorus						
pH	Minimum	Maximum	Minimum	Maximum		

Part B - List each pollutant that is limited in an effluent guideline which the facility is subject to or any pollutant listed in the facility's NPDES permit for its process wastewater (if the facility is operating under an existing NPDES permit). Complete one table for each outfall. See the instructions for additional details and requirements.

Pollutant and CAS Number (if available)	Maximum Values (include units)		Average Values (include units)		Number of Storm Events Sampled	Sources of Pollutants
	Grab Sample Taken During First 30 Minutes	Flow-weighted Composite	Grab Sample Taken During First 30 Minutes	Flow-weighted Composite		

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Continued from the Front

Part C - List each pollutant shown in Tables 2F-2, 2F-3, and 2F-4 that you know or have reason to believe is present. See the instructions for additional details and requirements. Complete one table for each outfall.

Pollutant and CAS Number (if available)	Maximum Values (include units)		Average Values (include units)		Number of Storm Events Sampled	Sources of Pollutants
	Grab Sample Taken During First 30 Minutes	Flow-weighted Composite	Grab Sample Taken During First 30 Minutes	Flow-weighted Composite		

Part D - Provide data for the storm event(s) which resulted in the maximum values for the flow weighted composite sample.

1. Date of Storm Event	2. Duration of Storm (in minutes)	3. Total rainfall during storm event (in inches)	4. Number of hours between beginning of storm measured and end of previous measurable rain event	5. Maximum flow rate during rain event (gallons/minute or specify units)	6. Total flow from rain event (gallons or specify units)	7. Season sample was taken	8. Form of Precipitation (rainfall, snowmelt)

9. Provide a description of the method of flow measurement or estimate.

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Instructions - Form 2F
Application for Permit to Discharge Storm Water Associated with Industrial Activity

Who Must File Form 2F

Form 2F must be completed by operators of facilities which discharge storm water associated with industrial activity or by operators of storm water discharges that EPA is evaluating for designation as a significant contributor of pollutants to waters of the United States, or as contributing to a violation of a water quality standard.

Operators of discharges which are composed entirely of storm water must complete Form 2F (EPA Form 3510-2F) in conjunction with Form 1 (EPA Form 3510-1).

Operators of discharges of storm water which are combined with process wastewater (process wastewater is water that comes into direct contact with or results from the production or use of any raw material, intermediate product, finished product, byproduct, waste product, or wastewater) must complete and submit Form 2F, Form 1, and Form 2C (EPA Form 3510-2C).

Operators of discharges of storm water which are combined with nonprocess wastewater (nonprocess wastewater includes noncontact cooling water and sanitary wastes which are not regulated by effluent guidelines or a new source performance standard, except discharges by educational, medical, or commercial chemical laboratories) must complete Form 1, Form 2F, and Form 2E (EPA Form 3510-2E).

Operators of new sources or new discharges of storm water associated with industrial activity which will be combined with other nonstormwater new sources or new discharges must submit Form 1, Form 2F, and Form 2D (EPA Form 3510-2D).

Where to File Applications

The application forms should be sent to the EPA Regional Office which covers the State in which the facility is located. Form 2F must be used only when applying for permits in States where the NPDES permits program is administered by EPA. For facilities located in States which are approved to administer the NPDES permits program, the State environmental agency should be contacted for proper permit application forms and instructions.

Information on whether a particular program is administered by EPA or by a State agency can be obtained from your EPA Regional Office. Form 1, Table 1 of the "General Instructions" lists the addresses of EPA Regional Offices and the States within the jurisdiction of each Office.

Completeness

Your application will not be considered complete unless you answer every question on this form and on Form 1. If an item does not apply to you, enter "NA" (for not applicable) to show that you considered the question

Public Availability of Submitted Information

You may not claim as confidential any information required by this form or Form 1, whether the information is reported on the forms or in an attachment. Section 402(j) of the Clean Water Act requires that all permit applications will be available to the public. This information will be made available to the public upon request

Any information you submit to EPA which goes beyond that required by this form, Form 1, or Form 2C you may claim as confidential, but claims for information which are effluent data will be denied.

If you do not assert a claim of confidentiality at the time of submitting the information, EPA may make the information public without further notice to you. Claims of confidentiality will be handled in accordance with EPA's business confidentiality regulations at 40 CFR Part 2.

Definitions

All significant terms used in these instructions and in the form are defined in the glossary found in the General Instructions which accompany Form 1.

EPA ID Number

Fill in your EPA Identification Number at the top of each odd-numbered page of Form 2F. You may copy this number directly from item I of Form 1.

Item I

You may use the map you provided for item XI of Form 1 to determine the latitude and longitude of each of your outfalls and the name of the receiving water.

Item II-A

If you check "yes" to this question, complete all parts of the chart, or attach a copy of any previous submission you have made to EPA containing the same information.

Item II-B

You are not required to submit a description of future pollution control projects if you do not wish to or if none is planned.

Item III

Attach a site map showing topography (or indicating the outline of drainage areas served by the outfall(s) covered in the application if a topographic map is unavailable) depicting the facility including:

each of its drainage and discharge structures;

the drainage area of each storm water outfall;

paved areas and building within the drainage area of each storm water outfall, each known past or present areas used for outdoor storage or disposal of significant materials, each existing structural control measure to reduce pollutants in storm water runoff, materials loading and access areas, areas where pesticides, herbicides, soil conditioners and fertilizers are applied;

each of its hazardous waste treatment, storage or disposal facilities (including each area not required to have a RCRA permit which is used for accumulating hazardous waste for less than 90 days under 40 CFR 262.34);

each well where fluids from the facility are injected underground; and

springs, and other surface water bodies which receive storm water discharges from the facility.

Item IV-A

For each outfall, provide an estimate of the area drained by the outfall which is covered by impervious surfaces. For the purpose of this application, impervious surfaces are surfaces where storm water runs off at rates that are significantly higher than background rates (e.g., predevelopment levels) and include paved areas, building roofs, parking lots, and roadways. Include an estimate of the total area (including all impervious and pervious areas) drained by each outfall. The site map required under item III can be used to estimate the total area drained by each outfall.

Item IV-B

Provide a narrative description of significant materials that are currently or in the past three years have been treated, stored, or disposed in a manner to allow exposure to storm water; method of treatment, storage or disposal of these materials; past and present materials management practices employed, in the last three years, to minimize contact by these materials with storm water runoff; materials loading and access areas, and the location, manner, and frequency in which pesticides, herbicides, soil conditioners, and fertilizers are applied. Significant materials should be identified by chemical name, form (e.g., powder, liquid, etc.), and type of container or treatment unit. Indicate any materials treated, stored, or disposed of together. "Significant materials" includes, but is not limited to: raw materials; fuels; materials such as solvents, detergents, and plastic pellets; finished materials such as metallic products; raw materials used in food processing or production, hazardous substances designated under Section 101(14) of CERCLA; any chemical the facility is required to report pursuant to Section 313 of Title III of SARA; fertilizers; pesticides; and waste products such as ashes, slag and sludge that have the potential to be released with storm water discharges.

Item IV-C

For each outfall, structural controls include structures which enclose material handling or storage areas covering materials, berms, dikes, or diversion ditches around manufacturing, production, storage or treatment units, retention ponds, etc. Nonstructural controls include practices such as spill prevention plans employee training, visual inspections, preventive maintenance, and housekeeping measures that are used to prevent or minimize the potential for releases of pollutants.

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Item V

Provide a certification that all outfalls that should contain storm water discharges associated with industrial activity have been tested or evaluated for the presence of non-storm water discharges which are not covered by an NPDES permit. Tests for such non-storm water discharges may include smoke tests, fluorometric dye tests, analysis of accurate schematics, as well as other appropriate tests. Part B must include a description of the method used, the date of any testing, and the onsite drainage points that were directly observed during a test. All non-storm water discharges must be identified in a Form 2C or Form 2E which must accompany this application (see beginning of instructions under section titled "Who Must File Form 2F" for a description of when Form 2C and Form 2E must be submitted).

Item VI

Provide a description of existing information regarding the history of significant leaks or spills of toxic or hazardous pollutants at the facility in the last three years.

Item VII-A, B, and C

These items require you to collect and report data on the pollutants discharged for each of your outfalls. Each part of this item addresses a different set of pollutants and must be completed in accordance with the specific instructions for that part. The following general instructions apply to the entire item.

General Instructions

Part A requires you to report at least one analysis for each pollutant listed. Parts B and C require you to report analytical data in two ways. For some pollutants addressed in Parts B and C, if you know or have reason to know that the pollutant is present in your discharge, you may be required to list the pollutant and test (sample and analyze) and report the levels of the pollutants in your discharge. For all other pollutants addressed in Parts B and C, you must list the pollutant if you know or have reason to know that the pollutant is present in the discharge, and either report quantitative data for the pollutant or briefly describe the reasons the pollutant is expected to be discharged. (See specific instructions on the form and below for Parts A through C.) Base your determination that a pollutant is present in or absent from your discharge on your knowledge of your raw materials, material management practices, maintenance chemicals, history of spills and releases, intermediate and final products and byproducts, and any previous analyses known to you of your effluent or similar effluent.

A. **Sampling:** The collection of the samples for the reported analyses should be supervised by a person experienced in performing sampling of industrial wastewater or storm water discharges. You may contact EPA or your State permitting authority for detailed guidance on sampling techniques and for answers to specific questions. Any specific requirements contained in the applicable analytical methods should be followed for sample containers, sample preservation, holding times, the collection of duplicate samples, etc. The time when you sample should be representative, to the extent feasible, of your treatment system operating properly with no system upsets. Samples should be collected from the center of the flow channel, where turbulence is at a maximum, at a site specified in your present permit, or at any site adequate for the collection of a representative sample.

   For pH, temperature, cyanide, total phenols, residual chlorine, oil and grease, and fecal coliform, grab samples taken during the first 30 minutes (or as soon thereafter as practicable) of the discharge must be used (you are not required to analyze a flow-weighted composite for these parameters). For all other pollutants both a grab sample collected during the first 30 minutes (or as soon thereafter as practicable) of the discharge and a flow-weighted composite sample must be analyzed. However, a minimum of one grab sample may be taken for effluents from holding ponds or other impoundments with a retention period of greater than 24 hours.

   All samples shall be collected from the discharge resulting from a storm event that is greater than 0.1 inches and at least 72 hours from the previously measurable (greater than 0.1 inch rainfall) storm event. Where feasible, the variance in the duration of the event and the total rainfall of the event should not exceed 50 percent from the average or median rainfall event in that area.

   A grab sample shall be taken during the first thirty minutes of the discharge (or as soon thereafter as practicable), and a flow-weighted composite shall be taken for the entire event or for the first three hours of the event.

   Grab and composite samples are defined as follows:

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Grab sample: An individual sample of at least 100 milliliters collected during the first thirty minutes (or as soon thereafter as practicable) of the discharge. This sample is to be analyzed separately from the composite sample.

Flow-Weighted Composite sample: A flow-weighted composite sample may be taken with a continuous sampler that proportions the amount of sample collected with the flow rate or as a combination of a minimum of three sample aliquots taken in each hour of discharge for the entire event or for the first three hours of the event, with each aliquot being at least 100 milliliters and collected with a minimum period of fifteen minutes between aliquot collections. The composite must be flow proportional, either the time interval between each aliquot or the volume of each aliquot must be proportional to either the stream flow at the time of sampling or the total stream flow since the collection of the previous aliquot. Aliquots may be collected manually or automatically. Where GC/MS Volatile Organic Analysis (VOA) is required, aliquots must be combined in the laboratory immediately before analysis. Only one analysis for the composite sample is required.

Data from samples taken in the past may be used, provided that:

All data requirements are met;

Sampling was done no more than three years before submission; and

All data are representative of the present discharge.

Among the factors which would cause the data to be unrepresentative are significant changes in production level, changes in raw materials, processes, or final products, and changes in storm water treatment. When the Agency promulgates new analytical methods in 40 CFR Part 136, EPA will provide information as to when you should use the new methods to generate data on your discharges. Of course, the Director may request additional information, including current quantitative data, if they determine it to be necessary to assess your discharges. The Director may allow or establish appropriate site-specific sampling procedures or requirements, including sampling locations, the season in which the sampling takes place, the minimum duration between the previous measurable storm event and the storm event sampled, the minimum or maximum level of precipitation required for an appropriate storm event, the form of precipitation sampled (snow melt or rainfall), protocols for collecting samples under 40 CFR Part 136 and additional time for submitting data on a case-by-case basis.

B. Reporting: All levels must be reported as concentration and as total mass. You may report some or all of the required data by attaching separate sheets of paper instead of filling out pages VII-1 and VII-2 if the separate sheets contain all the required information in a format which is consistent with pages VII-1 and VII-2 in spacing and in identification of pollutants and columns. Use the following abbreviations in the columns headed "Units."

Concentration		Mass	
ppm	parts per million	lbs	pounds
mg/1	milligrams per liter	ton	tons (English tons)
ppb	parts per billion	mg	milligrams
ug/1	micrograms per liter	g	grams
kg	kilograms	T	tonnes (metric tons)

All reporting of values for metals must be in terms of "total recoverable metal," unless:

(1) An applicable, promulgated effluent limitation or standard specifies the limitation for the metal in dissolved, valent, or total form; or

(2) All approved analytical methods for the metal inherently measure only its dissolved form (e.g. hexavalent chromium); or

(3) The permitting authority has determined that in establishing case-by-case limitations it is necessary to express the limitations on the metal in dissolved, valent, or total form to carry out the provisions of the CWA. If you measure only one grab sample and one flow-weighted composite sample for a given outfall, complete only the "Maximum Values" columns and insert "1" into the "Number of Storm Events Sampled" column. The permitting authority may require you to conduct additional analyses to further characterize your discharges.

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If you measure more than one value for a grab sample or a flow-weighted composite sample for a given outfall and those values are representative of your discharge, you must report them. You must describe your method of testing and data analysis. You also must determine the average of all values within the last year and report the concentration mass under the "Average Values" columns, and the total number of storm events sampled under the "Number of Storm Events Sampled" columns.

C. **Analysis:** You must use test methods promulgated in 40 CFR Part 136; however, if none has been promulgated for a particular pollutant, you may use any suitable method for measuring the level of the pollutant in your discharge provided that you submit a description of the method or a reference to a published method. Your description should include the sample holding time, preservation techniques, and the quality control measures which you used. If you have two or more substantially identical outfalls, you may request permission from your permitting authority to sample and analyze only one outfall and submit the results of the analysis for other substantially identical outfalls. If your request is granted by the permitting authority, on a separate sheet attached to the application form, identify which outfall you did test, and describe why the outfalls which you did not test are substantially identical to the outfall which you did test.

Part VII-A

Part VII-A must be completed by all applicants for all outfalls who must complete Form 2F.

Analyze a grab sample collected during the first thirty minutes (or as soon thereafter as practicable) of the discharge and flow-weighted composite samples for all pollutants in this Part, and report the results except use only grab samples for pH and oil and grease. See discussion in General Instructions to Item VII for definitions of grab sample collected during the first thirty minutes of discharge and flow-weighted composite sample. The "Average Values" column is not compulsory but should be filled out if data are available.

Part VII-B

List all pollutants that are limited in an effluent guideline which the facility is subject to (see 40 CFR Subchapter N to determine which pollutants are limited in effluent guidelines) or any pollutant listed in the facility's NPDES permit for its process wastewater (if the facility is operating under an existing NPDES permit). Complete one table for each outfall. See discussion in General instructions to item VII for definitions of grab sample collected during the first thirty minutes (or as soon thereafter as practicable) of discharge and flow-weighted composite sample. The "Average Values" column is not compulsory but should be filled out if data are available.

Analyze a grab sample collected during the first thirty minutes of the discharge and flow-weighted composite samples for all pollutants in this Part, and report the results, except as provided in the General Instructions.

Part VII-C

Part VII-C must be completed by all applicants for all outfalls which discharge storm water associated with industrial activity, or that EPA is evaluating for designation as a significant contributor of pollutants to waters of the United States, or as contributing to a violation of a water quality standard. Use both a grab sample and a composite sample for all pollutants you analyze for in this part except use grab samples for residual chlorine and fecal coliform. The "Average Values" column is not compulsory but should be filled out if data are available. Part C requires you to address the pollutants in Table 2F-2, 2F-3, and 2F-4 for each outfall. Pollutants in each of these Tables are addressed differently.

Table 2F-2: For each outfall, list all pollutants in Table 2F-2 that you know or have reason to believe are discharged (except pollutants previously listed in Part VII-B). If a pollutant is limited in an effluent guideline limitation which the facility is subject to (e.g., use of TSS as an indicator to control the discharge of iron and aluminum), the pollutant should be listed in Part VII-B. If a pollutant in table 2F-2 is indirectly limited by an effluent guideline limitation through an indicator, you must analyze for it and report data in Part VII-C. For other pollutants listed in Table 2F-2 (those not limited directly or indirectly by an effluent limitation guideline), that you know or have reason to believe are discharges, you must either report quantitative data or briefly describe the reasons the pollutant is expected to be discharged.

Table 2F-3: For each outfall, list all pollutants in Table 2F-3 that you know or have reason to believe are discharged. For every pollutant in Table 2F-3 expected to be discharged in concentrations of 10 ppb or greater, you must submit quantitative data. For acrolein, acrylonitrile, 2,4 dinitrophenol, and 2-methyl-4,6 dinitrophenol, you must submit quantitative data if any of these four pollutants is expected to be discharged

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in concentrations of 100 ppb or greater. For every pollutant expected to be discharged in concentrations less than 10 ppb (or 100 ppb for the four pollutants listed above), then you must either submit quantitative data or briefly describe the reasons the pollutant is expected to be discharged.

Small Business Exemption - If you are a "small business," you are exempt from the reporting requirements for the organic toxic pollutants listed in Table 2F-3. There are two ways in which you can qualify as a "small business". If your facility is a coal mine, and if your probable total annual production is less than 100 000 tons per year, you may submit past production data or estimated future production (such as a schedule of estimated total production under 30 CFR 795.14(c)) instead of conducting analyses for the organic toxic pollutants. If your facility is not a coal mine, and if your gross total annual sales for the most recent three years average less than $100,000 per year (in second quarter 1980 dollars), you may submit sales data for those years instead of conducting analyses for the organic toxic pollutants. The production or sales data must be for the facility which is the source of the discharge. The data should not be limited to production or sales for the process or processes which contribute to the discharge, unless those are the only processes at your facility. For sales data, in situations involving intracorporate transfer of goods and services, the transfer price per unit should approximate market prices for those goods and services as closely as possible. Sales figures for years after 1980 should be indexed to the second quarter of 1980 by using the gross national product price deflator (second quarter of 1980 = 100). This index is available in National Income and Product Accounts of the United States (Department of Commerce, Bureau of Economic Analysis).

Table 2F-4: For each outfall, list any pollutant in Table 2F-4 that you know or believe to be present in the discharge and explain why you believe it to be present. No analysis is required, but if you have analytical data, you must report them. Note: Under 40 CFR 117.12(a)(2), certain discharges of hazardous substances (listed at 40 CFR 177.21 or 40 CFR 302.4) may be exempted from the requirements of section 311 of CWA, which establishes reporting requirements, civil penalties, and liability for cleanup costs for spills of oil and hazardous substances. A discharge of a particular substance may be exempted if the origin, source, and amount of the discharged substances are identified in the NPDES permit application or in the permit, if the permit contains a requirement for treatment of the discharge, and if the treatment is in place. To apply for an exclusion of the discharge of any hazardous substance from the requirements of section 311, attach additional sheets of paper to your form, setting forth the following information:

1. The substance and the amount of each substance which may be discharged.
2. The origin and source of the discharge of the substance.
3. The treatment which is to be provided for the discharge by:
   a. An onsite treatment system separate from any treatment system treating your normal discharge;
   b. A treatment system designed to treat your normal discharge and which is additionally capable of treating the amount of the substance identified under paragraph 1 above; or
   c. Any combination of the above.

See 40 CFR 117.12(a)(2) and (c), published on August 29, 1979, in 44 FR 50766, or contact your Regional Office (Table 1 on Form 1, Instructions), for further information on exclusions from section 311.

Part VII-D

If sampling is conducted during more than one storm event, you only need to report the information requested in Part VII-D for the storm event(s) which resulted in any maximum pollutant concentration reported in Part VII-A, VII-B, or VII-C.

Provide flow measurements or estimates of the flow rate, and the total amount of discharge for the storm event(s) sampled, the method of flow measurement, or estimation. Provide the data and duration of the storm event(s) sampled, rainfall measurements, or estimates of the storm event which generated the sampled runoff and the duration between the storm event sampled and the end of the previous measurable (greater than 0.1 inch rainfall) storm event.

Part VII-E

List any toxic pollutant listed in Tables 2F-2, 2F-3, or 2F-4 which you currently use or manufacture as an intermediate or final product or byproduct. In addition, if you know or have reason to believe that 2,3,7,8-tetrachlorodibenzo-p-dioxin (TCDD) is discharged or if you use or manufacture 2,4,5-trichlorophenoxy acetic

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acid (2,4,5,-T); 2-(2,4,5-trichlorophenoxy) propanoic acid (Silvex, 2,4,5,-TP); 2-(2,4,5-trichlorophenoxy) ethyl 2,2-dichloropropionate (Erbon); O,O-dimethyl O-(2,4,5-trichlorphenyl) phosphorothioate (Ronnel), 2,4,5-trichlorophenol (TCP), or hexachlorophene (HCP); then list TCDD. The Director may waive or modify the requirement if you demonstrate that it would be unduly burdensome to identify each toxic pollutant and the Director has adequate information to issue your permit. You may not claim this information as confidential; however, you do not have to distinguish between use or production of the pollutants or list the amounts.

Item VIII

Self explanatory. The permitting authority may ask you to provide additional details after your application is received.

Item X

The Clean Water Act provides for severe penalties for submitting false information on this application form.

Section 309(c)(4) of the Clean Water Act provides that "Any person who knowingly makes any false material statement, representation, or certification in any application, . . . shall upon conviction, be punished by a fine of not more than $10,000 or by imprisonment for not more than 2 years, or by both. If a conviction of such person is for a violation committed after a first conviction of such person under this paragraph, punishment shall be by a fine of not more than $20,000 per day of violation, or by imprisonment of not more than 4 years, or by both." 40 CFR Part 122.22 requires the certification to be signed as follows:

(A) For a corporation: by a responsible corporate official. For purposes of this section, a responsible corporate official means (i) a president, secretary, treasurer, or vice-president of the corporation in charge of a principal business function, or any other person who performs similar policy- or decision-making functions for the corporation, or (ii) the manager of one or more manufacturing, production, or operating facilities employing more than 250 persons or having gross annual sales or expenditures exceeding $25,000,000 (in second-quarter 1980 dollars), if authority to sign documents has been assigned or delegated to the manager in accordance with corporate procedures.

Note: EPA does not require specific assignments or delegation of authority to responsible corporate officers identified in 122.22(a)(1)(i). The Agency will presume that these responsible corporate officers have the requisite authority to sign permit applications unless the corporation has notified the Director to the contrary. Corporate procedures governing authority to sign permit applications may provide for assignment or delegation to applicable corporate position under 122.22(a)(1)(ii) rather than to specific individuals.

(B) For a partnership or sole proprietorship: by a general partner or the proprietor, respectively; or

(C) For a municipality, State, Federal, or other public agency: by either a principal executive officer or ranking elected official. For purposes of this section, a principal executive officer of a Federal agency includes (i) the chief executive officer of the agency, or (ii) a senior executive officer having responsibility for the overall operations of a principal geographic unit of the agency (e.g., Regional Administrators of EPA).

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Table 2F-1

Codes for Treatment Units

Physical Treatment Processes

1-A	Ammonia Stripping	1-M	Grit Removal
1-B	Dialysis	1-N	Microstraining
1-C	Diatomaceous Earth Filtration	1-O	Mixing
1-D	Distillation	1-P	Moving Bed Filters
1-E	Electrodialysis	1-Q	Multimedia Filtration
1-F	Evaporation	1-R	Rapid Sand Filtration
1-G	Flocculation	1-S	Reverse Osmosis (Hyperfiltration)
1-H	Flotation	1-T	Screening
1-I	Foam Fractionation	1-U	Sedimentation (Settling)
1-J	Freezing	1-V	Slow Sand Filtration
1-K	Gas-Phase Separation	1-W	Solvent Extraction
1-L	Grinding (Comminutors)	1-X	Sorption

Chemical Treatment Processes

2-A	Carbon Adsorption	2-G	Disinfection (Ozone)
2-B	Chemical Oxidation	2-H	Disinfection (Other)
2-C	Chemical Precipitation	2-I	Electrochemical Treatment
2-D	Coagulation	2-J	Ion Exchange
2-E	Dechlorination	2-K	Neutralization
2-F	Disinfection (Chlorine)	2-L	Reduction

Biological Treatment Processes

3-A	Activated Sludge	3-E	Pre-Aeration
3-B	Aerated Lagoons	3-F	Spray Irrigation/Land Application
3-C	Anaerobic Treatment	3-G	Stabilization Ponds
3-D	Nitrification-Denitrification	3-H	Trickling Filtration

Other Processes

4-A	Discharge to Surface Water	4-C	Reuse/Recycle of Treated Effluent
4-B	Ocean Discharge Through Outfall	4-D	Underground Injection

Sludge Treatment and Disposal Processes

5-A	Aerobic Digestion	5-M	Heat Drying
5-B	Anaerobic Digestion	5-N	Heat Treatment
5-C	Belt Filtration	5-O	Incineration
5-D	Centrifugation	5-P	Land Application
5-E	Chemical Conditioning	5-Q	Landfill
5-F	Chlorine Treatment	5-R	Pressure Filtration
5-G	Composting	5-S	Pyrolysis
5-H	Drying Beds	5-T	Sludge Lagoons
5-I	Elutriation	5-U	Vacuum Filtration
5-J	Flotation Thickening	5-V	Vibration
5-K	Freezing	5-W	Wet Oxidation
5-L	Gravity Thickening		

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Table 2F-2

Conventional and Nonconventional Pollutants Required To Be Tested by Existing Discharger if Expected To Be Present

Bromide
Chlorine, Total Residual
Color
Fecal Coliform
Fluoride
Nitrate-Nitrite
Nitrogen, Total Kjedahl
Oil and Grease
Phosphorus, Total Radioactivity
Sulfate
Sulfide
Sulfite
Surfactants
Aluminum, Total
Barium, Total
Boron, Total
Cobalt, Total
Iron, Total
Magnesium, Total
Molybdenum, Total
Magnesium, Total
Tin, Total
Titanium, Total

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Table 2F-3
Toxic pollutants required to be identified by applicant if expected to be present

Toxic Pollutants and Total Phenol

Antimony, Total
Arsenic, Total
Beryllium, Total
Cadmium, Total
Chromium, Total
Copper, Total
Lead, Total
Mercury, Total
Nickel, Total
Selenium, Total
Silver, Total
Thallium, Total
Zinc, Total
Cyanide, Total
Phenols, Total

GC/MS Fraction Volatiles Compounds

Acrolein
Acrylonitrile
Benzene
Bromoform
Carbon Tetrachloride
Chlorobenzene
Chlorodibromomethane
Chloroethane
2-Chloroethylvinyl Ether
Chloroform
Dichlorobromomethane
1,1-Dichloroethane
1,2-Dichloroethane
1,1-Dichloroethylene
1,2-Dichloropropane
1,3-Dichloropropylene
Ethylbenzene
Methyl Bromide
Methyl Chloride
Methylene Chloride
1,1,2,2,-Tetrachloroethane
Tetrachloroethylene
Toluene
1,2-Trans-Dichloroethylene
1,1,1-Trichloroethane
1,1,2-Trichloroethane
Trichloroethylene
Vinyl Chloride

Acid Compounds

2-Chlorophenol
2,4-Dichlorophenol
2,4-Dimethylphenol
4,6-Dinitro-O-Cresol
2,4-Dinitrophenol
2-Nitrophenol
4-Nitrophenol
p-Chloro-M-Cresol
Pentachlorophenol
Phenol
2,4,6-Trichlorophenol

Base/Neutral

Acenaphthene
Acenaphthylene
Anthracene
Benzidine
Benzo(a)anthracene
Benzo(a)pyrene
3,4-Benzofluoranthene
Benzo(ghi)perylene
Benzo(k)fluoranthene
Bis(2-chloroethoxy)methane
Bis(2-chloroethyl)ether
Bis(2-chloroisopropyl)ether
Bis(2-ethylhexyl)phthalate
4-Bromophenyl Phenyl Ether
Butylbenzyl Phthalate
2-Chloronaphthalene
4-Chlorophenyl Phenyl Ether
Chrysene
Dibenzo(a,h)anthracene
1,2-Dichlorobenzene
1,3-Dichlorobenzene
1,4-Dichlorobenzene
3,3'-Dichlorobenzidine
Diethyl Phthalate
Dimethyl Phthalate
Di-N-Butyl Phthalate
2,4-Dinitrotoluene
2,6-Dinitrotoluene
Di-N-Octylphthalate
1,2-Diphenylhydrazine (as Azobenzene)
Fluroranthene
Fluorene
Hexachlorobenzene
Hexachlorobutadiene
Hexachloroethane
Indeno(1,2,3-cd)pyrene
Isophorone
Napthalene
Nitrobenzene
N-Nitrosodimethylamine
N-Nitrosodi-N-Propylamine
N-Nitrosodiphenylamine
Phenanthrene
Pyrene
1,2,4-Trichlorobenzene

Pesticides

Aldrin
Alpha-BHC
Beta-BHC
Gamma-BHC
Delta-BHC
Chlordane
4,4'-DDT
4,4'-DDE
4,4'-DDD
Dieldrin
Alpha-Endosulfan
Beta-Endosulfan
Endosulfan Sulfate
Endrin
Endrin Aldehyde
Heptachlor
Heptachlor Epoxide
PCB-1242
PCB-1254
PCB-1221
PCB-1232
PCB-1248
PCB-1260
PCB-1016
Toxaphene

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Table 2F-4
Hazardous substances required to be identified by applicant if expected to be present

Toxic Pollutant

Asbestos

Hazardous Substances

Acetaldehyde	Dinitrobenzene	Napthenic acid
Allyl alcohol	Diquat	Nitrotoluene
Allyl chloride	Disulfoton	Parathion
Amyl acetate	Diuron	Phenolsulfonate
Aniline	Epichlorohydrin	Phosgene
Benzonitrile	Ethion	Propargite
Benzyl chloride	Ethylene diamine	Propylene oxide
Butyl acetate	Ethylene dibromide	Pyrethrins
Butylamine	Formaldehyde	Quinoline
Carbaryl	Furfural	Resorcinol
Carbofuran	Guthion	Strontium
Carbon disulfide	Isoprene	Strychnine
Chlorpyrifos	Isopropanolamine	Styrene
Coumaphos	Kelthane	2,4,5-T (2,4,5-Trichlorophenoxyacetic acid)
Cresol	Kepone	TDE (Tetrachlorodiphenyl ethane)
Crotonaldehyde	Malathion	2,4,5-TP [2-(2,4,5-Trichlorophenoxy) propanoic acid]
Cyclohexane	Mercaptodimethur	Trichlorofon
2,4-D (2,4-Dichlorophenoxyacetic acid)	Methoxychlor	Triethylamine
Diazinon	Methyl mercaptan	Trimethylamine
Dicamba	Methyl methacrylate	Uranium
Dichlobenil	Methyl parathion	Vanadium
Dichlone	Mevinphos	Vinyl acetate
2,2-Dichloropropionic acid	Mexacarbate	Xylene
Dichlorvos	Monoethyl amine	Xylenol
Diethyl amine	Monomethyl amine	Zirconium
Dimethyl amine	Naled	

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APPENDIX E.3: FORM 2C

United States Environmental Protection Agency

are obsolete

Permits Division

EPA

Application Form 2C - Wastewater Discharge Information

Consolidated Permits Program

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This form must be completed by all persons applying for an EPA permit to discharge wastewater *(existing manufacturing, commercial, mining, and silvicultural operations)*.

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Application for Permit to Discharge Wastewater
EXISTING MANUFACTURING, COMMERCIAL, MINING, AND SILVICULTURAL OPERATIONS

This form must be completed by all applicants who check "yes" to item II-C in Form 1.

Public Availability of Submitted Information.

Your application will not be considered complete unless you answer every question on this form and on Form 1. If an item does not apply to you, enter "NA" *(for not applicable)* to show that you considered the question.

You may not claim as confidential any information required by this form or Form 1, whether the information is reported on the forms or in an attachment. This information will be made available to the public upon request.

Any information you submit to EPA which goes beyond that required by this form or Form 1 you may claim as confidential, but claims for information which is effluent data will be denied. If you do not assert a claim of confidentiality at the time of submitting the information, EPA may make the information public without further notice to you. Claims of confidentiality will be handled in accordance with EPA's business confidentiality regulations at 40 CFR Part 2.

Definitions

All significant terms used in these instructions and in the form are defined in the glossary found in the General Instructions which accompany Form 1.

EPA ID Number

Fill in your EPA Identification Number at the top of each page of Form 2c. You may copy this number directly from item I of Form 1.

Item I

You may use the map you provided for item XI of Form 1 to determine the latitude and longitude of each of your outfalls and the name of the receiving water.

Item II-A

The line drawing should show generally the route taken by water in your facility from intake to discharge. Show all operations contributing wastewater, including process and production areas, sanitary flows, cooling water, and stormwater runoff. You may group similar operations into a single unit, labeled to correspond to the more detailed listing in item II-B. The water balance should show average flows. Show all significant losses of water to products, atmosphere, and discharge. You should use actual measurements whenever available; otherwise use your best estimate. An example of an acceptable line drawing appears in Figure 2c-1 to these instructions.

Item II-B

List all sources of wastewater to each outfall. Operations may be described in general terms *(for example, "dye-making reactor" or "distillation tower")*. You may estimate the flow contributed by each source if no data are available. For stormwater discharges you may estimate the average flow, but you must indicate the rainfall event upon which the estimate is based and the method of estimation. For each treatment unit, indicate its size, flow rate, and retention time, and describe the ultimate disposal of any solid or liquid wastes not discharged. Treatment units should be listed in order and you should select the proper code from Table 2c-1 to fill in column 3-b for each treatment unit. Insert "XX" into column 3-b if no code corresponds to a treatment unit you list. If you are applying for a permit for a privately owned treatment works, you must also identify all of your contributors in an attached listing.

Item II-C

A discharge is intermittent unless it occurs without interruption during the operating hours of the facility, except for infrequent shutdowns for maintenance, process changes, or other similar activities. A discharge is seasonal if it occurs only during certain parts of the year. Fill in every applicable column in this item for each source of intermittent or seasonal discharges. Base your answers on actual data whenever available; otherwise, provide your best estimate. Report the highest daily value for flow rate and total volume in the "Maximum Daily" columns *(columns 4-a-2 and 4-b-2)*. Report the average of all daily values measured during days when discharge occurred within the last year in the "Long Term Average" columns *(columns 4-a-1 and 4-b-1)*.

Item III-A

All effluent guidelines promulgated by EPA appear in the Federal Register and are published annually in 40 CFR Subchapter N. A guideline applies to you if you have any operations contributing process wastewater in any subcategory covered by a BPT, BCT, or BAT guideline. If you are unsure whether you are covered by a promulgated effluent guideline, check with your EPA Regional office *(Table 1 in the Form 1 instructions)*. You must check "yes" if an applicable effluent guideline has been promulgated, even if the guideline limitations are being contested in court. If you believe that a promulgated effluent guideline has been remanded for reconsideration by a court and does not apply to your operations, you may check "no".

Item III-B

An effluent guideline is expressed in terms of production *(or other measure of operation)* if the limitation is expressed as mass of pollutant per operational parameter, for example, "pounds of BOD per cubic foot of logs from which bark is removed," or "pounds of TSS per megawatt hour of electrical energy consumed by smelting furnace". An example of a guideline not expressed in terms of a measure of operation is one which limits the concentration of pollutants.

Item III-C

This item must be completed only if you checked "yes" to item III-B. The production information requested here is necessary to apply effluent guidelines to your facility and you cannot claim it as confidential. However, you do not have to indicate how the reported information was calculated. Report quantities in the units of measurement used in the applicable effluent guideline. The production figures provided must be based on actual daily production and not on design capacity or on predictions of future operations. To obtain alternate limits under 40 CFR 122.45(b)(2)(ii), you must define your maximum production capability and demonstrate to the Director that your actual production is substantially below maximum production capability and that there is a reasonable potential for an increase above actual production during the duration of the permit.

Item IV-A

If you check "yes" to this question, complete all parts of the chart, or attach a copy of any previous submission you have made to EPA containing same information.

Item IV-B

You are not required to submit a description of future pollution control projects if you do not wish to or if none is planned.

Item V-A, B, C, and D

The items require you to collect and report data on the pollutants discharged for each of your outfalls. Each part of this item addresses a different set of pollutants and must be completed in accordance with the specific instructions for that part. The following general instructions apply to the entire item.

General Instructions

Part A requires you to report at least one analysis for each pollutant listed. Parts B and C require you to report analytical data in two ways. For some pollutants, you may be required to mark "X" in the "Testing Required" column *(column 2-a, Part C)*, and test *(sample and analysis)* and report the levels of the pollutants in your discharge whether or not you expect them to be present in your discharge. For all others, you must mark "X" in either the "Believe Present" column or the "Believe Absent" column *(columns 2-a or 2-b, Part B, and columns 2-b or 2-c, Part C)* based on your best estimate, and test for those which you believe to be present. *(See specific instructions on the form and below for Parts A through D.)* Base your determination that a pollutant is present in or absent from your discharge on your knowledge of your raw materials, maintenance chemicals, inter-

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ITEM V — A, B, C, and D *(continued)*

mediate and final products and byproducts, and any previous analyses known to you of your effluent or similar effluent. *(For example, if you manufacture pesticides, you should expect those pesticides to be present in contaminated stormwater runoff.)* If you would expect a pollutant to be present solely as a result of its presence in your intake water, you must mark "Believe Present" but you are not required to analyze for that pollutant. Instead, mark an "X" in the "Intake" column.

A. Reporting. All levels must be reported as concentration and as total mass. You may report some or all of the required data by attaching separate sheets of paper instead of filling out pages V-1 to V-9 if the separate sheets contain all the required information in a format which is consistent with pages V-1 to V-9 in spacing and in identification of pollutants and columns. *(For example, the data system used in your GC/MS analysis may be able to print data in the proper format.)* Use the following abbreviations in the columns headed "Units" *(column 3, Part A, and column 4, Parts B and C).*

Concentration	Mass
ppm .... parts per million	lbs .... pounds
mg/l .... milligrams per liter	ton ...... tons *(English tons)*
ppb .... parts per billion	mg .... milligrams
ug/l .... micrograms per liter	g .... grams
	kg .... kilograms
	T....... tonnes *(metric tons)*

All reporting of values for metals must be in terms of "total recoverable metal," unless:

(1) An applicable, promulgated effluent limitation or standard specifies the limitation for the metal in dissolved, valent, or total form; or

(2) All approved analytical methods for the metal inherently measure only its dissolved form (e.g., hexavalent chromium); or

(3) The permitting authority has determined that in establishing case-by-case limitations it is necessary to express the limitations on the metal in dissolved, valent, or total form to carry out the provisions of the CWA.

If you measure only one daily value, complete only the "Maximum Daily Values" columns and insert "1" into the "Number of Analyses" column *(columns 2-a and 2-d, Part A, and columns 3-a, 3-d, Parts B and C).* The permitting authority may require you to conduct additional analyses to further characterize your discharges. For composite samples, the daily value is the total mass or average concentration found in a composite sample taken over the operating hours of the facility during a 24-hour period; for grab samples, the daily value is the arithmetic or flow-weighted total mass or average concentration found in a series of at least four grab samples taken over the operating hours of the facility during a 24-hour period.

If you measure more than one daily value for a pollutant and those values are representative of your wastestream, you must report them. You must describe your method of testing and data analysis. You also must determine the average of all values within the last year and report the concentration and mass under the "Long Term Average Values" columns *(column 2-c, Part A, and column 3-c, Parts B and C),* and the total number of daily values under the "Number of Analyses" columns *(column 2-d, Part A, and columns 3-d, Parts B and C).* Also, determine the average of all daily values taken during each calendar month, and report the highest average under the "Maximum 30-day Values" columns *(column 2-c, Part A, and column 3-b, Parts B and C).*

B. Sampling: The collection of the samples for the reported analyses should be supervised by a person experienced in performing sampling of industrial wastewater. You may contact your EPA or State permitting authority for detailed guidance on sampling techniques and for answers to specific questions. Any specific requirements contained in the applicable analytical methods should be followed for sample containers, sample preservation, holding times, the collection of duplicate samples, etc. The time when you sample should be representative of your normal operation, to the extent feasible, with all processes which contribute wastewater in normal operation, and with your treatment system operating properly with no system upsets. Samples should be collected from the center of the flow channel, where turbulence is at a maximum, at a site specified in your present permit, or at any site adequate for the collection of a representative sample.

For pH, temperature, cyanide, total phenols, residual chlorine, oil and grease, and fecal coliform, grab samples must be used. For all other pollutants 24-hour composite samples must be used. However, a minimum of one grab sample may be taken for effluents from holding ponds or other impoundments with a retention period of greater than 24 hours. For stormwater discharges a minimum of one to four grab samples may be taken, depending on the duration of the discharge. One grab must be taken in the first hour *(or less)* of discharge, with one additional grab *(up to a minimum of four)* taken in each succeeding hour of discharge for discharges lasting four or more hours. The Director may waive composite sampling for any outfall for which you demonstrate that use of an automatic sampler is infeasible and that a minimum of four grab samples will be representative of your discharge.

Grab and composite samples are defined as follows:

Grab sample: An individual sample of at least 100 milliliters collected at a randomly-selected time over a period not exceeding 15 minutes.

Composite sample: A combination of at least 8 sample aliquots of at least 100 milliliters, collected at periodic intervals during the operating hours of a facility over a 24 hour period. The composite must be flow proportional; either the time interval between each aliquot or the volume of each aliquot must be proportional to either the stream flow at the time of sampling or the total stream flow since the collection of the previous aliquot. Aliquots may be collected manually or automatically. For GC/MS Volatile Organic Analysis (VOA), aliquots must be combined in the laboratory immediately before analysis. Four (4) *(rather than eight)* aliquots or grab samples should be collected for VOA. These four samples should be collected during actual hours of discharge over a 24 hour period and need not be flow proportioned. Only one analysis is required.

The Agency is currently reviewing sampling requirements in light of recent research on testing methods. Upon completion of its review, the Agency plans to propose changes to the sampling requirements.

Data from samples taken in the past may be used, provided that:

All data requirements are met;

Sampling was done no more than three years before submission; and

All data are representative of the present discharge.

Among the factors which would cause the data to be unrepresentative are significant changes in production level, changes in raw materials, processes, or final products, and changes in wastewater treatment. When the Agency promulgates new analytical methods in 40 CFR Part 136, EPA will provide information as to when you should use the new methods to generate data on your discharges. Of course, the Director may request additional information, including current quantitative data, if she or he determines it to be necessary to assess your discharges.

C. Analysis: You must use test methods promulgated in 40 CFR Part 136; however, if none has been promulgated for a particular pollutant, you may use any suitable method for measuring the level of the pollutant in your discharge provided that you submit a description of the method or a reference to a published method. Your description should include the sample holding time, preservation techniques, and the quality control measures which you used. If you have two or more substantially identical outfalls, you may request permission from your permitting authority to sample and analyze only one outfall and submit the results of the analysis

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ITEM V — A. B. C. and D *(continued)*

for other substantially identical outfalls. If your request is granted by the permitting authority, on a separate sheet attached to the application form, identify which outfall you did test, and describe why the outfalls which you did not test are substantially identical to the outfall which you did test.

D. Reporting of Intake Data: You are not required to report data under the "Intake" columns unless you wish to demonstate your eligibility for a "net" effluent limitation for one or more pollutants, that is, an effluent limitation adjusted by subtracting the average level of the pollutant(s) present in your intake water. NPDES regulations allow net limitations only in certain circumstances. To demonstrate your eligibility, under the "Intake" columns report the average of the results of analyses on your intake water *(if your water is treated before use, test the water after it is treated)*, and discuss the requirements for a net limitation with your permitting authority.

Part V-A

Part V-A must be completed by all applicants for all outfalls, including outfalls containing only noncontact cooling water or storm runoff. However, at your request, the Director may waive the requirement to test for one or more of these pollutants, upon a determination that available information is adequate to support issuance of the permit with less stringent reporting requirements for these pollutants. You also may request a waiver for one or more of these pollutants for your category or subcategory from the Director, Office of Water Enforcement and Permits. See discussion in General Instructions to item V for definitions of the columns in Part A. The "Long Term Average Values" column *(column 2-c)* and "Maximum 30-day Values" column *(column 2-b)* are not compulsory but should be filled out if data are available.

Use composite samples for all pollutants in this Part, except use grab samples for pH and temperature. See discussion in General Instructions to Item V for definitions of the columns in Part A. The "Long Term Average Values" column *(column 2-c)* and "Maximum 30-Day Values" column *(column 2-b)* are not compulsory but should be filled out if data are available.

Part V-B

Part V-B must be completed by all applicants for all outfalls, including outfalls containing only noncontact cooling water or storm runoff. You must report quantitative data if the pollutant(s) in question is limited in an effluent limitations guideline either directly, or indirectly but expressly through limitation on an indicator *(e.g., use of TSS as an indicator to control the discharge of iron and aluminum)*. For other discharged pollutants you must provide quantitative data or explain their presence in your discharge. EPA will consider requests to the Director of the Office of Water Enforcement and Permits to eliminate the requirement to test for pollutants for an industrial category or subcategory. Your request must be supported by data representative of the industrial category or subcategory in question. The data must demonstrate that individual testing for each applicant is unnecessary, because the facilities in the category or subcategory discharge substantially identical levels of the pollutant or discharge the pollutant uniformly at sufficiently low levels. Use composite samples for all pollutants you analyze for in this part, except use grab samples for residual chlorine, oil and grease, and fecal coliform. The "Long Term Average Values" column *(column 3-c)* and "Maximum 30-day Values" column *(column 3-b)* are not compulsory but should be filled out if data are available.

Part V-C

Table 2c-2 lists the 34 "primary" industry categories in the left-hand column. For each outfall, if any of your processes which contribute wastewater falls into one of those categories, you must mark "X" in "Testing Required" column *(column 2-a)* and test for (1) all of the toxic metals, cyanide, and total phenols, and (2) the organic toxic pollutants contained in Table 2c-2 as applicable to your category, unless you qualify as a small business *(see below)*. The organic toxic pollutants are listed by GC/MS fractions on pages V-4 to V-9 in Part V-C. For example, the Organic Chemicals Industry has an asterisk in all four fractions; therefore, applicants in this category must test for all organic toxic pollutants in Part V-C. The inclusion of total phenols in Part V-C is not intended to classify total phenols as a toxic pollutant. If you are applying for a permit for a privately owned treatment works, determine your testing requirements on the basis of the industry categories of your contributors. When you determine which industry category you are in to find your testing requirements, you are not determining your category for any other purpose and you are not giving up your right to challenge your inclusion in that category *(for example, for deciding whether an effluent guideline is applicable)* before your permit is issued. For all other cases *(secondary industries, nonprocess wastewater outfalls, and non-required GC/MS fractions)*, you must mark "X" in either the "Believed Present" column *(column 2-b)* or the "Believed Absent" column *(column 2-c)* for each pollutant. For every pollutant you know or have reason to believe is present in your discharge in concentrations of 10 ppb or greater, you must report quantitative data. For acrolein, acrylonitrile, 2, 4 dinitrophenol, and 2-methyl-4, 6 dinitrophenol, where you expect these four pollutants to be discharged in concentrations of 100 ppb or greater, you must report quantitative data. For every pollutant expected to be discharged in concentrations less than the thresholds specified above, you must either submit quantitative data or briefly describe the reasons the pollutant is expected to be discharged. At your request the Director, Office of Water Enforcement and Permits, may waive the requirement to test for pollutants for an industrial category or subcategory. Your request must be supported by data representatives of the industrial category or subcategory in question. The data must demonstrate that individual testing for each applicant is unnecessary, because the facilities in question discharge substantially identical levels of the pollutant, or discharge the pollutant uniformly at sufficiently low levels. If you qualify as a small business *(see below)* you are exempt from testing for the organic toxic pollutants, listed on pages V-4 to V-9 in Part C. For pollutants in intake water, see discussion in General Instructions to this item. The "Long Term Average Values" column *(column 3-c)* and "Maximum 30-day Values" column *(column 3-b)* are not compulsory but should be filled out if data are available. You are required to mark "Testing Required" for dioxin if you use or manufacture one of the following compounds:

(a) 2,4,5-trichlorophenoxy acetic acid, (2,4,5-T);

(b) 2-(2,4,5-trichlorophenoxy) propanoic acid, (Silvex, 2,4,5-TP);

(c) 2-(2,4,5-trichlorophenoxy) ethyl 2,2-dichloropropionate, (Erbon);

(d) 0,0-dimethyl 0-(2,4,5-trichlorophenyl) phosphorothioate, (Ronnel);

(e) 2,4,5,-trichlorophenol, (TCP); or

(f) hexachlorophene, (HCP).

If you mark "Testing Required" or "Believed Present," you must perform a screening analysis for dioxins, using gas chromatography with an electron capture detector. A TCDD standard for quantitation is not required. Describe the results of this analysis in the space provided; for example, "no measurable baseline deflection at the retention time of TCDD" or "a measurable peak within the tolerances of the retention time of TCDD." The permitting authority may require you to perform a quantitative analysis if you report a positive result. The Effluent Guidelines Division of EPA has collected and analyzed samples from some plants for the pollutants listed in Part C in the course of its BAT guidelines development program. If your effluents are sampled and analyzed as part of this program in the last three years, you may use these data to answer Part C provided that the permitting authority approves, and provided that no process change or change in raw materials or operating practices has occurred since the samples were taken that would make the analyses unrepresentative of your current discharge.

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ITEM V — A, B, C, and D ***(continued)***

Small Business Exemption: If you qualify as a "small business," you are exempt from the reporting requirements for the organic toxic pollutants, listed on pages V-4 to V-9 in Part C. There are two ways in which you can qualify as a "small business." If your facility is a coal mine, and if your probable total annual production is less than 100,000 tons per year, you may submit past production data or estimated future production *(such as a schedule of estimated total production under 30 CFR § 795.14(c))* instead of conducting analyses for the organic toxic pollutants. If your facility is not a coal mine, and if your gross total annual sales for the most recent three years average less than $100,000 per year *(in second quarter 1980 dollars)*, you may submit sales data for those years instead of conducting analyses for the organic toxic pollutants. The production or sales data must be for the facility which is the source of the discharge. The data should not be limited to production or sales for the process or processes which contribute to the discharge, unless those are the only processes at your facility. For sales data, in situations involving intracorporate transfer of goods and services, the transfer price per unit should approximate market prices for those goods and services as closely as possible. Sales figures for years after 1980 should be indexed to the second quarter of 1980 by using the gross national product price deflator *(second quarter of 1980 = 100)*. This index is available in *National Income and Product Accounts of the United States (Department of Commerce, Bureau of Economic Analysis)*.

Part V-D

List any pollutants in Table 2c-3 that you believe to be present and explain why you believe them to be present. No analysis is required, but if you have analytical data, you must report it.

Note: Under 40 CFR 117.12(a)(2), certain discharges of hazardous substances *(listed in Table 2c-4 of these instructions)* may be exempted from the requirements of section 311 of CWA, which establishes reporting requirements, civil penalties and liability for cleanup costs for spills of oil and hazardous substances. A discharge of a particular substance may be exempted if the origin, source, and amount of the discharged substances are identified in the NPDES permit application or in the permit, if the permit contains a requirement for treatment of the discharge, and if the treatment is in place. To apply for an exclusion of the discharge of any hazardous substance from the requirements of section 311, attach additional sheets of paper to your form, setting forth the following information:

1. The substance and the amount of each substance which may be discharged.
2. The origin and source of the discharge of the substance.
3. The treatment which is to be provided for the discharge by:
   a. An onsite treatment system separate from any treatment system treating your normal discharge;
   b. A treatment system designed to treat your normal discharge and which is additionally capable of treating the amount of the substance identified under paragraph 1 above; or
   c. Any combination of the above.

See 40 CFR §117.12(a)(2) and (c), published on August 29, 1979, in 44 FR 50766, or contact your Regional Office *(Table 1 on Form 1, Instructions)*, for further information on exclusions from section 311.

Item VI

This requirement applies to current use or manufacture of a toxic pollutant as an intermediate or final product or byproduct. The Director may waive or modify the requirement if you demonstrate that it would be unduly burdensome to identify each toxic pollutant and the Director has adequate information to issue your permit. You may not claim this information as confidential; however, you do not have to distinguish between use or production of the pollutants or list the amounts.

Item VII

Self explanatory. The permitting authority may ask you to provide additional details after your application is received.

Item IX

The Clean Water Act provides for severe penalties for submitting false information on this application form.

Section 309(c)(2) of the Clean Water Act provides that "Any person who knowingly makes any false statement, representation, or certification in any application, ... shall upon conviction, be punished by a fine of not more than $10,000 or by imprisonment for not more than six months, or by both."

40 CFR Part 122.22 requires the certification to be signed as follows:

(A) *For a corporation:* by a responsible corporate official. For purposes of this section, a responsible corporate official means (i) a president, secretary, treasurer, or vice-president of the corporation in charge of a principal business function, or any other person who performs similar policy- or decision-making functions for the corporation, or (ii) the manager of one or more manufacturing, production, or operating facilities employing more than 250 persons or having gross annual sales or expenditures exceeding $25,000,000 *(in second-quarter 1980 dollars)*, if authority to sign documents has been assigned or delegated to the manager in accordance with corporate procedures.

Note: EPA does not require specific assignments or delegation of authority to responsible corporate officers identified in §122.22(a)(1)(i). The Agency will presume that these responsible corporate officers have the requisite authority to sign permit applications unless the corporation has notified the director to the contrary. Corporate procedures governing authority to sign permit applications may provide for assignment or delegation to applicable corporate position under §122.22(a)(1)(ii) rather than to specific individuals.

(B) *For a partnership or sole proprietorship:* by a general partner or the proprietor, respectively; or

(C) *For a municipality, State, Federal, or other public agency:* by either a principal executive officer or ranking elected official. For purposes of this section, a principal executive officer of a Federal Agency includes (i) the chief executive officer of the Agency, or (ii) a senior executive officer having responsibility for the overall operations of a principal geographic unit of the Agency *(e.g., Regional Administrators of EPA)*. Applications for Group II stormwater dischargers may be signed by a duly authorized representative *(as defined in 40 CFR 122.22(b))* of the individuals identified above.

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CODES FOR TRE[illegible]

PHYSICAL TREATMENT PROCESSES

- 1—A . . . . .Ammonia Stripping
- 1—B. . . . . .Dialysis
- 1—C. . . . . .Diatomaceous Earth Filtration
- 1—D . . . . .Distillation
- 1—E. . . . . .Electrodialysis
- 1—F . . . . .Evaporation
- 1—G . . . . .Flocculation
- 1—H . . . . .Flotation
- 1—I . . . . .Foam Fractionation
- 1—J. . . . . .Freezing
- 1—K . . . . .Gas—Phase Separation
- 1—L. . . . . .Grinding *(Comminutors)*
- 1—M . . . . .Grit Removal
- 1—N . . . . .Microstraining
- 1—O . . . . .Mixing
- 1—P . . . . .Moving Bed Filters
- 1—Q . . . . .Multimedia Filtration
- 1—R . . . . .Rapid Sand Filtration
- 1—S . . . . .Reverse Osmosis *(Hyperfiltration)*
- 1—T. . . . . .Screening
- 1—U . . . . .Sedimentation *(Settling)*
- 1—V . . . . .Slow Sand Filtration
- 1—W . . . . .Solvent Extraction
- 1—X . . . . .Sorption

CHEMICAL TREATMENT PROCESSES

- 2—A . . . . .Carbon Adsorption
- 2—B. . . . . .Chemical Oxidation
- 2—C. . . . . .Chemical Precipitation
- 2—D . . . . .Coagulation
- 2—E. . . . . .Dechlorination
- 2—F. . . . . .Disinfection *(Chlorine)*
- 2—G . . . . .Disinfection *(Ozone)*
- 2—H . . . . .Disinfection *(Other)*
- 2—I . . . . .Electrochemical Treatment
- 2—J. . . . . .Ion Exchange
- 2—K . . . . .Neutralization
- 2—L. . . . . .Reduction

BIOLOGICAL TREATMENT PROCESSES

- 3—A . . . . .Activated Sludge
- 3—B. . . . . .Aerated Lagoons
- 3—C. . . . . .Anaerobic Treatment
- 3—D . . . . .Nitrification—Denitrification
- 3—E. . . . . .Pre—Aeration
- 3—F. . . . . .Spray Irrigation/Land Application
- 3—G . . . . .Stabilization Ponds
- 3—H . . . . .Trickling Filtration

OTHER PROCESSES

- 4—A . . . . .Discharge to Surface Water
- 4—B. . . . . .Ocean Discharge Through Outfall
- 4—C. . . . . .Reuse/Recycle of Treated Effluent
- 4—D . . . . .Underground Injection

SLUDGE TREATMENT AND DISPOSAL PROCESSES

- 5—A . . . . .Aerobic Digestion
- 5—B. . . . . .Anaerobic Digestion
- 5—C. . . . . .Belt Filtration
- 5—D . . . . .Centrifugation
- 5—E. . . . . .Chemical Conditioning
- 5—F. . . . . .Chlorine Treatment
- 5—G . . . . .Composting
- 5—H . . . . .Drying Beds
- 5—I . . . . .Elutriation
- 5—J. . . . . .Flotation Thickening
- 5—K . . . . .Freezing
- 5—L. . . . . .Gravity Thickening
- 5—M . . . . .Heat Drying
- 5—N . . . . .Heat Treatment
- 5—O . . . . .Incineration
- 5—P. . . . . .Land Application
- 5—Q . . . . .Landfill
- 5—R . . . . .Pressure Filtration
- 5—S. . . . . .Pyrolysis
- 5—T. . . . . .Sludge Lagoons
- 5—U . . . . .Vacuum Filtration
- 5—V . . . . .Vibration
- 5—W . . . . .Wet Oxidation

TABLE 2C-1

INDUSTRY CATEGORY	GC/MS FRACTION[1]			
	Volatile	Acid	Base/Neutral	Pesticide
Adhesives and sealants	X	X	X	—
Aluminum forming	X	X	X	—
Auto and other laundries	X	X	X	X
Battery manufacturing	X	—	X	—
Coal mining	X	X	X	X
Coil coating	X	X	X	—
Copper forming	X	X	X	—
Electric and electronic compounds	X	X	X	X
Electroplating	X	X	X	—
Explosives manufacturing	—	X	X	—
Foundries	X	X	X	—
Gum and wood chemicals	X	X	X	X
Inorganic chemicals manufacturing	X	X	X	—
Iron and steel manufacturing	X	X	X	—
Leather tanning and finishing	X	X	X	X
Mechanical products manufacturing	X	X	X	—
Nonferrous metals manufacturing	X	X	X	X
Ore mining	X	X	X	X
Organic chemicals manufacturing	X	X	X	X
Paint and ink formulation	X	X	X	X
Pesticides	X	X	X	X
Petroleum refining	X	X	X	X
Pharmaceutical preparations	X	X	X	—
Photographic equipment and supplies	X	X	X	X
Plastic and synthetic materials manufacturing	X	X	X	X
Plastic processing	X	—	—	—
Porcelain enameling	X	—	X	X
Printing and publishing	X	X	X	X
Pulp and paperboard mills	X	X	X	X
Rubber processing	X	X	X	—
Soap and detergent manufacturing	X	X	X	—
Steam electric power plants	X	X	X	—
Textile mills	X	X	X	X
Timber products processing	X	X	X	X

*See note at conclusion of 40 CFR Part 122, Appendix D (1983) for explanation of effect of suspensions on testing requirements for primary industry categories.

[1]The pollutants in each fraction are listed in Item V—C.

X = Testing required.

— = Testing not required.

TABLE 2C-2

TOXIC POLLUTANTS AND HAZARDOUS SUBSTANCES REQUIRED TO

[illegible]

TOXIC POLLUTANT

Asbestos

HAZARDOUS SUBSTANCES

Acetaldehyde
Allyl alcohol
Allyl chloride
Amyl acetate
Aniline
Benzonitrile
Benzyl chloride
Butyl acetate
Butylamine
Captan
Carbaryl
Carbofuran
Carbon disulfide
Chlorpyrifos
Coumaphos
Cresol
Crotonaldehyde
Cyclohexane
2,4-D (2,4-Dichlorophenoxyacetic acid)
Diazinon
Dicamba
Dichlobenil
Dichlone
2,2-Dichloropropionic acid

HAZARDOUS SUBSTANCES

Dichlorvos
Diethyl amine
Dimethyl amine
Dinitrobenzene
Diquat
Disulfoton
Diuron
Epichlorohydrin
Ethion
Ethylene diamine
Ethylene dibromide
Formaldehyde
Furfural
Guthion
Isoprene
Isopropanolamine
Kelthane
Kepone
Malathion
Mercaptodimethur
Methoxychlor
Methyl mercaptan
Methyl methacrylate
Methyl parathion
Mevinphos
Mexacarbate
Monoethyl amine
Monomethyl amine

HAZARDOUS SUBSTANCES

Naled
Napthenic acid
Nitrotoluene
Parathion
Phenolsulfonate
Phosgene
Propargite
Propylene oxide
Pyrethrins
Quinoline
Resorcinol
Strontium
Strychnine
Styrene
2,4,5-T (2,4,5-Trichlorophenoxyacetic acid)
TDE (Tetrachlorodiphenyl ethane)
2,4,5-TP (2-(2,4,5-Trichlorophenoxy) propanoic acid)
Trichlorofon
Triethanolamine
Triethylamine
Trimethylamine
Uranium
Vanadium
Vinyl acetate
Xylene
Xylenol
Zirconium

TABLE 2C-3

R0043784

VOL 12

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1. Acetaldehyde
2. Acetic acid
3. Acetic anhydride
4. Acetone cyanohydrin
5. Acetyl bromide
6. Acetyl chloride
7. Acrolein
8. Acrylonitrile
9. Adipic acid
10. Aldrin
11. Allyl alcohol
12. Allyl chloride
13. Aluminum sulfate
14. Ammonia
15. Ammonium acetate
16. Ammonium benzoate
17. Ammonium bicarbonate
18. Ammonium bichromate
19. Ammonium bifluoride
20. Ammonium bisulfite
21. Ammonium carbamate
22. Ammonium carbonate
23. Ammonium chloride
24. Ammonium chromate
25. Ammonium citrate
26. Ammonium fluoroborate
27. Ammonium fluoride
28. Ammonium hydroxide
29. Ammonium oxalate
30. Ammonium silicofluoride
31. Ammonium sulfamate
32. Ammonium sulfide
33. Ammonium sulfite
34. Ammonium tartrate
35. Ammonium thiocyanate
36. Ammonium thiosulfate
37. Amyl acetate
38. Aniline
39. Antimony pentachloride
40. Antimony potassium tartrate
41. Antimony tribromide
42. Antimony trichloride
43. Antimony trifluoride
44. Antimony trioxide
45. Arsenic disulfide
46. Arsenic pentoxide
47. Arsenic trichloride
48. Arsenic trioxide
49. Arsenic trisulfide
50. Barium cyanide
51. Benzene
52. Benzoic acid
53. Benzonitrile
54. Benzoyl chloride
55. Benzyl chloride
56. Beryllium chloride
57. Beryllium fluoride
58. Beryllium nitrate
59. Butylacetate
60. n-Butylphthalate
61. Butylamine
62. Butyric acid
63. Cadmium acetate
64. Cadmium bromide
65. Cadmium chloride
66. Calcium arsenate
67. Calcium arsenite
68. Calcium carbide
69. Calcium chromate
70. Calcium cyanide
71. Calcium dodecylbenzenesulfonate
72. Calcium hypochlorite
73. Captan
74. Carbaryl
75. Carbofuran
76. Carbon disulfide
77. Carbon tetrachloride
78. Chlordane
79. Chlorine
80. Chlorobenzene
81. Chloroform
82. Chloropyrifos
83. Chlorosulfonic acid
84. Chromic acetate
85. Chromic acid
86. Chromic sulfate
87. Chromous chloride
88. Cobaltous bromide
89. Cobaltous formate
90. Cobaltous sulfamate
91. Coumaphos
92. Cresol
93. Crotonaldehyde
94. Cupric acetate
95. Cupric acetoarsenite
96. Cupric chloride
97. Cupric nitrate
98. Cupric oxalate
99. Cupric sulfate
100. Cupric sulfate ammoniated
101. Cupric tartrate
102. Cyanogen chloride
103. Cyclohexane
104. 2,4-D acid (2,4-Dichlorophenoxyacetic acid)
105. 2,4-D esters (2,4-Dichlorophenoxyacetic acid esters)
106. DDT
107. Diazinon
108. Dicamba
109. Dichlobenil
110. Dichlone
111. Dichlorobenzene
112. Dichloropropane
113. Dichloropropene
114. Dichloropropene-dichloropropane mix
115. 2,2-Dichloropropionic acid
116. Dichlorvos
117. Dieldrin
118. Diethylamine
119. Dimethylamine
120. Dinitrobenzene
121. Dinitrophenol
122. Dinitrotoluene
123. Diquat
124. Disulfoton
125. Diuron
126. Dodecylbenzesulfonic acid
127. Endosulfan
128. Endrin
129. Epichlorohydrin
130. Ethion
131. Ethylbenzene
132. Ethylenediamine
133. Ethylene dibromide
134. Ethylene dichloride
135. Ethylene diaminetetraacetic acid (EDTA)
136. Ferric ammonium citrate
137. Ferric ammonium oxalate
138. Ferric chloride
139. Ferric fluoride
140. Ferric nitrate
141. Ferric sulfate
142. Ferrous ammonium sulfate
143. Ferrous chloride
144. Ferrous sulfate
145. Formaldehyde
146. Formic acid
147. Fumaric acid
148. Furfural
149. Guthion
150. Heptachlor
151. Hexachlorocyclopentadiene
152. Hydrochloric acid
153. Hydrofluoric acid
154. Hydrogen cyanide
155. Hydrogen sulfide
156. Isoprene
157. Isopropanolamine dodecylbenzenesulfonate
158. Kelthane
159. Kepone
160. Lead acetate
161. Lead arsenate
162. Lead chloride
163. Lead fluoborate
164. Lead fluorite
165. Lead iodide
166. Lead nitrate
167. Lead stearate
168. Lead sulfate
169. Lead sulfide
170. Lead thiocyanate
171. Lindane
172. Lithium chromate
173. Malathion
174. Maleic acid
175. Maleic anhydride
176. Mercaptodimethur
177. Mercuric cyanide
178. Mercuric nitrate
179. Mercuric sulfate
180. Mercuric thiocyanate
181. Mercurous nitrate
182. Methoxychlor
183. Methyl mercaptan
184. Methyl methacrylate
185. Methyl parathion
186. Mevinphos
187. Mexacarbate
188. Monoethylamine
189. Monomethylamine
190. Naled
191. Naphthalene
192. Naphthenic acid
193. Nickel ammonium sulfate
194. Nickel chloride
195. Nickel hydroxide
196. Nickel nitrate
197. Nickel sulfate
198. Nitric acid
199. Nitrobenzene
200. Nitrogen dioxide
201. Nitrophenol
202. Nitrotoluene
203. Paraformaldehyde

TABLE 2C-4

VOL 12

1 0479

204. Parathion
205. Pentachlorophenol
206. Phenol
207. Phosgene
208. Phosphoric acid
209. Phosphorus
210. Phosphorus oxychloride
211. Phosphorus pentasulfide
212. Phosphorus trichloride
213. Polychlorinated biphenyls (PCB)
214. Potassium arsenate
215. Potassium arsenite
216. Potassium bichromate
217. Potassium chromate
218. Potassium cyanide
219. Potassium hydroxide
220. Potassium permanganate
221. Propargite
222. Propionic acid
223. Propionic anhydride
224. Propylene oxide
225. Pyrethrins
226. Quinoline
227. Resorcinol
228. Selenium oxide
229. Silver nitrate
230. Sodium
231. Sodium arsenate
232. Sodium arsenite
233. Sodium bichromate
234. Sodium bifluoride
235. Sodium bisulfite
236. Sodium chromate
237. Sodium cyanide
238. Sodium dodecylbenzenesulfonate
239. Sodium fluoride
240. Sodium hydrosulfide
241. Sodium hydroxide
242. Sodium hypochlorite
243. Sodium methylate
244. Sodium nitrite
245. Sodium phosphate (dibasic)
246. Sodium phosphate (tribasic)
247. Sodium selenite
248. Strontium chromate
249. Strychnine
250. Styrene
251. Sulfuric acid
252. Sulfur monochloride
253. 2,4,5-T acid (2,4,5-Trichlorophenoxyacetic acid)
254. 2,4,5-T amines (2,4,5-Trichlorophenoxy acetic acid amines)
255. 2,4,5-T esters (2,4,5-Trichlorophenoxy acetic acid esters)
256. 2,4,5-T salts (2,4,5-Trichlorophenoxy acetic acid salts)
257. 2,4,5-TP acid (2,4,5-Trichlorophenoxy propenoic acid)
258. 2,4,5-TP acid esters (2,4,5-Trichlorophenoxy propenoic acid esters)
259. TDE (Tetrachlorodiphenyl ethane)
260. Tetraethyl lead
261. Tetraethyl pyrophosphate
262. Thallium sulfate
263. Toluene
264. Toxaphene
265. Trichlorofon
266. Trichloroethylene
267. Trichlorophenol
268. Triethanolamine dodecylbenzenesulfonate
269. Triethylamine
270. Trimethylamine
271. Uranyl acetate
272. Uranyl nitrate
273. Vanadium pentoxide
274. Vanadyl sulfate
275. Vinyl acetate
276. Vinylidene chloride
277. Xylene
278. Xylenol
279. Zinc acetate
280. Zinc ammonium chloride
281. Zinc borate
282. Zinc bromide
283. Zinc carbonate
284. Zinc chloride
285. Zinc cyanide
286. Zinc fluoride
287. Zinc formate
288. Zinc hydrosulfite
289. Zinc nitrate
290. Zinc phenolsulfonate
291. Zinc phosphide
292. Zinc silicofluoride
293. Zinc sulfate
294. Zirconium nitrate
295. Zirconium potassium flouride
296. Zirconium sulfate
297. Zirconium tetrachloride

TABLE 2C-4 *(continued)*

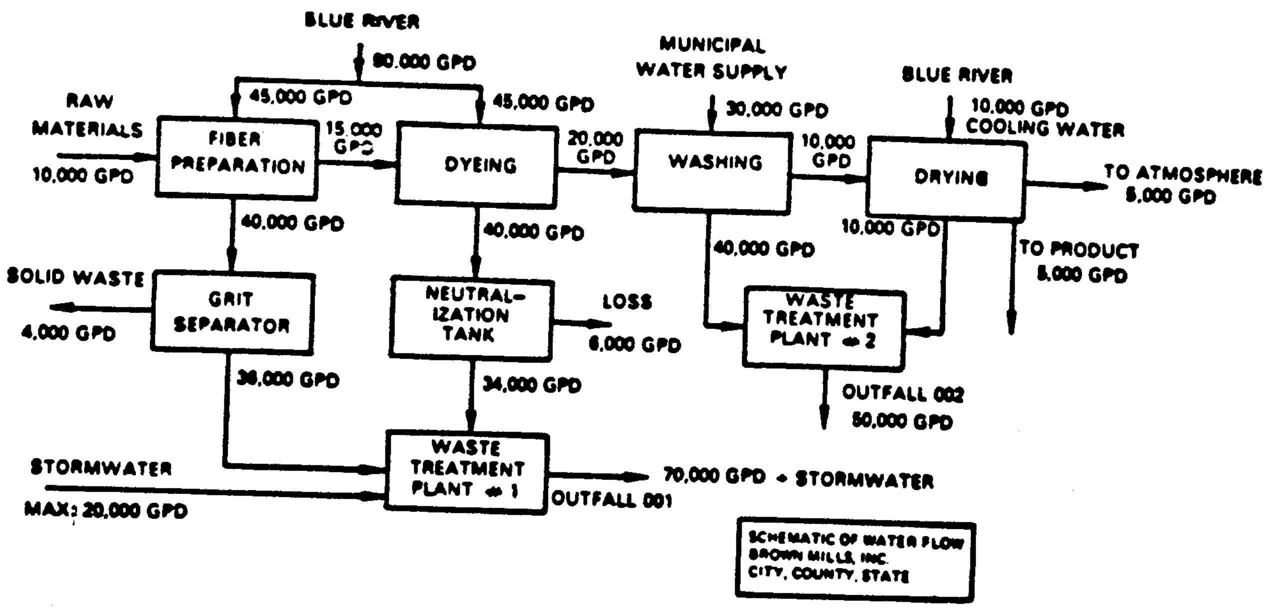
BLUE RIVER
80,000 GPD
45,000 GPD
45,000 GPD
RAW MATERIALS
10,000 GPD
FIBER PREPARATION
15,000 GPD
DYEING
20,000 GPD
MUNICIPAL WATER SUPPLY
30,000 GPD
WASHING
10,000 GPD
BLUE RIVER
10,000 GPD COOLING WATER
DRYING
TO ATMOSPHERE 5,000 GPD
40,000 GPD
40,000 GPD
40,000 GPD
10,000 GPD
TO PRODUCT 5,000 GPD
SOLID WASTE
4,000 GPD
GRIT SEPARATOR
NEUTRALIZATION TANK
LOSS
6,000 GPD
WASTE TREATMENT PLANT #2
OUTFALL 002
50,000 GPD
36,000 GPD
34,000 GPD
STORMWATER
MAX: 20,000 GPD
WASTE TREATMENT PLANT #1
70,000 GPD + STORMWATER
OUTFALL 001
SCHEMATIC OF WATER FLOW
BROWN MILLS, INC.
CITY, COUNTY, STATE

FIGURE 2C-1

Please print or type in the unshaded areas only

EPA I.D. NUMBER (copy from Item 1 of Form 1)

Form Approved
OMB No. 2040-0086
Approval expires 5-31-92

FORM 2C NPDES

EPA

U.S. ENVIRONMENTAL PROTECTION AGENCY

APPLICATION FOR PERMIT TO DISCHARGE WASTEWATER
EXISTING MANUFACTURING, COMMERCIAL, MINING AND SILVICULTURAL OPERATIONS

Consolidated Permits Program

I. OUTFALL LOCATION

For each outfall, list the latitude and longitude of its location to the nearest 15 seconds and the name of the receiving water.

A. OUTFALL NUMBER (list)	B. LATITUDE			C. LONGITUDE			D. RECEIVING WATER (name)
	1. DEG	2. MIN	3. SEC	1. DEG	2. MIN	3. SEC	

II. FLOWS, SOURCES OF POLLUTION, AND TREATMENT TECHNOLOGIES

A. Attach a line drawing showing the water flow through the facility. Indicate sources of intake water, operations contributing wastewater to the effluent, and treatment units labeled to correspond to the more detailed descriptions in Item B. Construct a water balance on the line drawing by showing average flows between intakes, operations, treatment units, and outfalls. If a water balance cannot be determined (e.g., for certain mining activities), provide a pictorial description of the nature and amount of any sources of water and any collection or treatment measures.

B. For each outfall, provide a description of: (1) All operations contributing wastewater to the effluent, including process wastewater, sanitary wastewater, cooling water, and storm water runoff; (2) The average flow contributed by each operation; and (3) The treatment received by the wastewater. Continue on additional sheets if necessary.

1. OUT-FALL NO. (list)	2. OPERATION(S) CONTRIBUTING FLOW		3. TREATMENT		
	a. OPERATION (list)	b. AVERAGE FLOW (include units)	a. DESCRIPTION	b. LIST CODES FROM TABLE 2C-1	

OFFICIAL USE ONLY (effluent guidelines sub-categories)

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CONTINUED FROM PAGE 2

EPA I.D. NUMBER (copy from Item 1 of Form 1)

V. INTAKE AND EFFLUENT CHARACTERISTICS

A, B, & C: See instructions before proceeding – Complete one set of tables for each outfall – Annotate the outfall number in the space provided.
NOTE: Tables V-A, V-B, and V-C are included on separate sheets numbered V-1 through V-9.

D. Use the space below to list any of the pollutants listed in Table 2c-3 of the instructions, which you know or have reason to believe is discharged or may be discharged from any outfall. For every pollutant you list, briefly describe the reasons you believe it to be present and report any analytical data in your possession.

1. POLLUTANT	2. SOURCE	1. POLLUTANT	2. SOURCE

VI. POTENTIAL DISCHARGES NOT COVERED BY ANALYSIS

Is any pollutant listed in Item V-C a substance or a component of a substance which you currently use or manufacture as an intermediate or final product or byproduct?

☐ YES (list all such pollutants below) ☐ NO (go to Item VI-B)

CONTINUE ON REVERSE

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ONTINUED FROM THE FRONT

VII. BIOLOGICAL TOXICITY TESTING DATA

Do you have any knowledge or reason to believe that any biological test for acute or chronic toxicity has been made on any of your discharges or on a receiving water in relation to your discharge within the last 3 years?

☐ YES *(identify the test(s) and describe their purposes below)* ☐ NO *(go to Section VIII)*

ONTRACT ANALYSIS INFORMATION

re any of the analyses reported in Item V performed by a contract laboratory or consulting firm?

☐ YES *(list the name, address, and telephone number of, and pollutants analyzed by, each such laboratory or firm below)* ☐ NO *(go to Section IX)*

A. NAME	B. ADDRESS	C. TELEPHONE (area code & no.)	D. POLLUTANTS ANALYZED (list)

CERTIFICATION

certify under penalty of law that this document and all attachments were prepared under my direction or supervision in accordance with a system designed to assure that qualified personnel properly gather and evaluate the information submitted. Based on my inquiry of the person or persons who manage the system or those persons directly responsible for gathering the information, the information submitted is, to the best of my knowledge and belief, true, accurate, and complete. I am aware that there are significant penalties for submitting false information, including the possibility of fine and imprisonment for knowing violations.

A. NAME & OFFICIAL TITLE *(type or print)*	B. PHONE NO. *(area code & no.)*
C. SIGNATURE	D. DATE SIGNED

VOL 12

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R0043790

PLEASE PRINT OR TYPE IN THE UNSHADED AREAS ONLY. You may report some or all of this information on separate sheets *(use the same format)* instead of completing these pages.
SEE INSTRUCTIONS.

EPA I.D. NUMBER *(copy from Item 1 of Form 1)*

V. INTAKE AND EFFLUENT CHARACTERISTICS *(continued from page 3 of Form 2-C)*

PART A - You must provide the results of at least one analysis for every pollutant in this table. Complete one table for each outfall. See instructions for additional details.

1. POLLUTANT	2. EFFLUENT							3. UNITS *(specify if blank)*		4. INTAKE *(optional)*		
	a. MAXIMUM DAILY VALUE		b. MAXIMUM 30 DAY VALUE *(if available)*		c. LONG TERM AVRG. VALUE *(if available)*		d. NO. OF ANALYSES	a. CONCENTRATION	b. MASS	a. LONG TERM AVERAGE VALUE		b. NO. OF ANALYSES
	(1) CONCENTRATION	(2) MASS	(1) CONCENTRATION	(2) MASS	(1) CONCENTRATION	(2) MASS				(1) CONCENTRATION	(2) MASS	
a. Biochemical Oxygen Demand *(BOD)*												
b. Chemical Oxygen Demand *(COD)*												
c. Total Organic Carbon *(TOC)*												
d. Total Suspended Solids *(TSS)*												
e. Ammonia *(as N)*												
f. Flow	VALUE		VALUE		VALUE					VALUE		
g. Temperature *(winter)*	VALUE		VALUE		VALUE			°C		VALUE		
h. Temperature *(summer)*	VALUE		VALUE		VALUE			°C		VALUE		
i. pH	MINIMUM	MAXIMUM	MINIMUM	MAXIMUM				STANDARD UNITS				

PART B - Mark "X" in column 2-a for each pollutant you know or have reason to believe is present. Mark "X" in column 2-b for each pollutant you believe to be absent. If you mark column 2a for any pollutant which is limited either directly, or indirectly but expressly, in an effluent limitations guideline, you must provide the results of at least one analysis for that pollutant. For other pollutants for which you mark column 2a, you must provide quantitative data or an explanation of their presence in your discharge. Complete one table for each outfall. See the instructions for additional details and requirements.

1. POLLUTANT AND CAS NO. *(if available)*	2. MARK "X"		3. EFFLUENT							4. UNITS		5. INTAKE *(optional)*		
	a. BELIEVED PRESENT	b. BELIEVED ABSENT	a. MAXIMUM DAILY VALUE		b. MAXIMUM 30 DAY VALUE *(if available)*		c. LONG TERM AVRG. VALUE *(if available)*		d. NO. OF ANALYSES	a. CONCENTRATION	b. MASS	a. LONG TERM AVERAGE VALUE		b. NO. OF ANALYSES
			(1) CONCENTRATION	(2) MASS	(1) CONCENTRATION	(2) MASS	(1) CONCENTRATION	(2) MASS				(1) CONCENTRATION	(2) MASS	
a. Bromide (24959-67-9)														
b. Chlorine, Total Residual														
c. Color														
d. Fecal Coliform														
e. Fluoride (16984-48-8)														
f. Nitrate-Nitrite *(as N)*														

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CONTINUE ON REVERSE

ITEM V-B CONTINUED FROM FRONT

1. POLLUTANT AND CAS NO. (if available)	2. MARK 'X'		3. EFFLUENT							4. UNITS		5. INTAKE (optional)	
	a. BELIEVED PRESENT	b. BELIEVED ABSENT	a. MAXIMUM DAILY VALUE (1) CONCENTRATION	(2) MASS	b. MAXIMUM 30 DAY VALUE (if available) (1) CONCENTRATION	(2) MASS	c. LONG TERM AVRG. VALUE (if available) (1) CONCENTRATION	(2) MASS	d. NO. OF ANALYSES	a. CONCENTRATION	b. MASS	a. LONG TERM AVERAGE VALUE (1) CONCENTRATION	(2) MASS
g. Nitrogen, Total Organic (as N)													
h. Oil and Grease													
i. Phosphorus (as P), Total (7723-14-0)													
j. Radioactivity													
(1) Alpha, Total													
(2) Beta, Total													
(3) Radium, Total													
(4) Radium 226, Total													
k. Sulfate (as SO_4) (14808-79-8)													
l. Sulfide (as S)													
m. Sulfite (as SO_3) (14265-45-3)													
n. Surfactants													
o. Aluminum, Total (7429-90-5)													
p. Barium, Total (7440-39-3)													
q. Boron, Total (7440-42-8)													
r. Cobalt, Total (7440-48-4)													
s. Iron, Total (7439-89-6)													
t. Magnesium, Total (7439-95-4)													
u. Molybdenum, Total (7439-98-7)													
v. Manganese, Total (7439-96-5)													
w. Tin, Total (7440-31-5)													
x. Titanium, Total (7440-32-6)													

CONTINUE ON P...

EPA I.D. NUMBER *(copy from Item 1 of Form 1)*	OUTFALL NUMBER

CONTINUED FROM PAGE 3 OF FORM 2-C

PART V

If you are a primary industry and this outfall contains process wastewater, refer to Table 2c-2 in the instructions to determine which of the GC/MS fractions you must test for. Mark "X" in column 2-a for all such GC/MS fractions that apply to your industry and for ALL toxic metals, cyanides, and total phenols. If you are not required to mark column 2-a *(secondary industries, nonprocess wastewater outfalls, and nonrequired GC/MS fractions)*, mark "X" in column 2-b for each pollutant you know or have reason to believe is present. Mark "X" in column 2-c for each pollutant you believe is absent. If you mark column 2a for any pollutant, you must provide the results of at least one analysis for that pollutant. If you mark column 2b for any pollutant, you must provide the results of at least one analysis for that pollutant if you know or have reason to believe it will be discharged in concentrations of 10 ppb or greater. If you mark column 2b for acrolein, acrylonitrile, 2,4 dinitrophenol, or 2-methyl-4, 6 dinitrophenol, you must provide the results of at least one analysis for each of these pollutants which you know or have reason to believe that you discharge in concentrations of 100 ppb or greater. Otherwise, for pollutants for which you mark column 2b, you must either submit at least one analysis or briefly describe the reasons the pollutant is expected to be discharged. Note that there are 7 pages to this part; please review each carefully. Complete one table *(all 7 pages)* for each outfall. See instructions for additional details and requirements.

1. POLLUTANT AND CAS NUMBER *(if available)*	2. MARK "X"			3. EFFLUENT							4. UNITS		5. INTAKE *(optional)*		
	a. TESTING REQUIRED	b. BELIEVED PRESENT	c. BELIEVED ABSENT	a. MAXIMUM DAILY VALUE		b. MAXIMUM 30 DAY VALUE *(if available)*		c. LONG TERM AVRG. VALUE *(if available)*		d. NO. OF ANALYSES	a. CONCENTRATION	b. MASS	a. LONG TERM AVERAGE VALUE		b. NO. OF ANALYSES
				(1) CONCENTRATION	(2) MASS	(1) CONCENTRATION	(2) MASS	(1) CONCENTRATION	(2) MASS				(1) CONCENTRATION	(2) MASS	
METALS, CYANIDE, AND TOTAL PHENOLS															
1M. Antimony, Total (7440-36-0)															
2M. Arsenic, Total (7440-38-2)															
3M. Beryllium, Total, 7440-41-7)															
4M. Cadmium, Total (7440-43-9)															
5M. Chromium, Total (7440-47-3)															
6M. Copper, Total (7440-50-8)															
7M. Lead, Total (7439-92-1)															
8M. Mercury, Total (7439-97-6)															
9M. Nickel, Total (7440-02-0)															
10M. Selenium, Total (7782-49-2)															
11M. Silver, Total (7440-22-4)															
12M. Thallium, Total (7440-28-0)															
13M. Zinc, Total (7440-66-6)															
14M. Cyanide, Total (57-12-5)															
15M. Phenols, Total															
DIOXIN															
2,3,7,8-Tetrachlorodibenzo-P-Dioxin (1764-01-6)				DESCRIBE RESULTS											

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1. POLLUTANT AND CAS NUMBER (if available)	2. MARK 'X' a. testing required	b. believed present	c. believed absent	3. EFFLUENT a. MAXIMUM DAILY VALUE (1) concentration	(2) mass	b. MAXIMUM 30 DAY VALUE (if available) (1) concentration	(2) mass	c. LONG TERM AVRG. VALUE (if available) (1) concentration	(2) mass	d. NO. OF ANALYSES	4. UNITS a. CONCENTRATION	b. MASS	5. INTAKE (optional) a. LONG TERM AVERAGE VALUE (1) concentration	(2) mass	b. NO. OF ANALYSES
GC/MS FRACTION – VOLATILE COMPOUNDS															
1V A… (107-0…)															
2V Ac…nitrile (107-1…)															
3V Ben…ne (71-43-…)															
4V Bis (chloro-methyl) ether (542-88-…)															
5V Bro…form (75-25-…)															
6V Carbon tetrachloride (56-23-…)															
7V Chlorobenzene (108-90-…)															
8V Chlorodi-bromomethane (124-48-…)															
9V Chl…ethane (75-00-…)															
10V 2-Chloro-ethylvinyl ether (110-75-…)															
11V Chl…oform (67-66-…)															
12V Dichloro-bromomethane (75-27-4)															
13V Dichloro-difluoromethane (75-71-8)															
14V 1,1-…chloro-ethane (7…34-3)															
15V 1,2-…chloro-ethane (…06-2)															
16V 1,…chloro-ethylene (…35-4)															
17V 1,…chloro-propane (…87-5)															
18V 1,… …pro-pylene (…75-6)															
[illegible] …enzene															
[illegible] …83-9)															
[illegible] …87-3)															

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CONTINUE ON PAGE V-5

CONTINUED FROM PAGE V-4

EPA I.D. NUMBER (copy from Item 1 of Form 1)	OUTFALL NUMBER

1. POLLUTANT AND CAS NUMBER (if available)	2. MARK 'X'			3. EFFLUENT							4. UNITS		5. INTAKE (optional)	
	a. testing required	b. believed present	c. believed absent	a. MAXIMUM DAILY VALUE		b. MAXIMUM 30 DAY VALUE (if available)		c. LONG TERM AVRG. VALUE (if available)		d. NO. OF ANALYSES	a. CONCENTRATION	b. MASS	a. LONG TERM AVERAGE VALUE	
				(1) CONCENTRATION	(2) MASS	(1) CONCENTRATION	(2) MASS	(1) CONCENTRATION	(2) MASS				(1) CONCENTRATION	(2) MASS
GC/MS FRACTION – VOLATILE COMPOUNDS (continued)														
22V. Methylene Chloride (75-09-2)														
23V. 1,1,2,2-Tetrachloroethane (79-34-5)														
24V. Tetrachloroethylene (127-18-4)														
25V. Toluene (108-88-3)														
26V. 1,2-Trans-Dichloroethylene (156-60-5)														
27V. 1,1,1-Trichloroethane (71-55-6)														
28V. 1,1,2-Trichloroethane (79-00-5)														
29V. Trichloroethylene (79-01-6)														
30V. Trichlorofluoromethane (75-69-4)														
31V. Vinyl Chloride (75-01-4)														
GC/MS FRACTION – ACID COMPOUNDS														
1A. 2-Chlorophenol (95-57-8)														
2A. 2,4-Dichlorophenol (120-83-2)														
3A. 2,4-Dimethylphenol (105-67-9)														
4A. 4,6-Dinitro-O-Cresol (534-52-1)														
5A. 2,4-Dinitrophenol (51-28-5)														
6A. 2-Nitrophenol (88-75-5)														
7A. 4-Nitrophenol (100-02-7)														
8A. P-Chloro-M-Cresol (59-50-7)														
9A. Pentachlorophenol (87-86-5)														
10A. Phenol (108-95-2)														
11A. 2,4,6-Trichlorophenol (88-06-2)														

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CONTINUE ON REVERSE

CONTINUED FROM THE FRONT

1. POLLUTANT AND CAS NUMBER (if available)	2. MARK 'X'			3. EFFLUENT							4. UNITS		5. INTAKE (optional)	
	a. testing required	b. believed present	c. believed absent	a. MAXIMUM DAILY VALUE		b. MAXIMUM 30 DAY VALUE (if available)		c. LONG TERM AVRG. VALUE (if available)		d. NO. OF ANALYSES	a. CONCENTRATION	b. MASS	a. LONG TERM AVERAGE VALUE	
				(1) CONCENTRATION	(2) MASS	(1) CONCENTRATION	(2) MASS	(1) CONCENTRATION	(2) MASS				(1) CONCENTRATION	(2) MASS
GC/MS FRACTION – BASE/NEUTRAL COMPOUNDS														
1B. Acenaphthene (83-32-9)														
2B. Acenaphtylene (208-96-8)														
3B. Anthracene (120-12-7)														
4B. Benzidine (92-87-5)														
5B. Benzo (a) Anthracene (56-55-3)														
6B. Benzo (a) Pyrene (50-32-8)														
7B. 3,4-Benzofluoranthene (205-99-2)														
8B. Benzo (ghi) Perylene (191-24-2)														
9B. Benzo (k) Fluoranthene (207-08-9)														
10B. Bis (2-Chloroethoxy) Methane (111-91-1)														
11B. Bis (2-Chloroethyl) Ether (111-44-4)														
12B. Bis (2-Chloroisopropyl) Ether (102-60-1)														
13B. Bis (2-Ethylhexyl) Phthalate (117-81-7)														
14B. 4-Bromophenyl Phenyl Ether (101-55-3)														
15B. Butyl Benzyl Phthalate (85-68-7)														
16B. 2-Chloronaphthalene (91-58-7)														
17B. 4-Chlorophenyl Phenyl Ether (7005-72-3)														
18B. Chrysene (218-01-9)														
19B. Dibenzo (a,h) Anthracene (53-70-3)														
20B. 1,2-Dichlorobenzene (95-50-1)														
21B. 1,3-Dichlorobenzene (541-73-1)														

CONTINUE ON PAGE V-7

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EPA I.D. NUMBER (copy from Item 1 of Form 1)	OUTFALL NUMBER

1. POLLUTANT AND CAS NUMBER (if available)	2. MARK 'X'			3. EFFLUENT							4. UNITS		5. INTAKE (optional)	
	a. TESTING REQUIRED	b. BELIEVED PRESENT	c. BELIEVED ABSENT	a. MAXIMUM DAILY VALUE		b. MAXIMUM 30 DAY VALUE (if available)		c. LONG TERM AVRG. VALUE (if available)		d. NO. OF ANALYSES	a. CONCENTRATION	b. MASS	a. LONG TERM AVERAGE VALUE	
				(1) CONCENTRATION	(2) MASS	(1) CONCENTRATION	(2) MASS	(1) CONCENTRATION	(2) MASS				(1) CONCENTRATION	(2) MASS
GC/MS FRACTION – BASE/NEUTRAL COMPOUNDS (continued)														
22B. 1,4-Dichlorobenzene (106-46-7)														
23B. 3,3'-Dichlorobenzidine (91-94-1)														
24B. Diethyl Phthalate (84-66-2)														
25B. Dimethyl Phthalate (131-11-3)														
26B. Di-N-Butyl Phthalate (84-74-2)														
27B. 2,4-Dinitrotoluene (121-14-2)														
28B. 2,6-Dinitrotoluene (606-20-2)														
29B. Di-N-Octyl Phthalate (117-84-0)														
30B. 1,2-Diphenylhydrazine (as Azobenzene) (122-66-7)														
31B. Fluoranthene (206-44-0)														
32B. Fluorene (86-73-7)														
33B. Hexachlorobenzene (118-74-1)														
34B. Hexachlorobutadiene (87-68-3)														
35B. Hexachlorocyclopentadiene (77-47-4)														
36B. Hexachloroethane (67-72-1)														
37B. Indeno (1,2,3-cd) Pyrene (193-39-5)														
38B. Isophorone (78-59-1)														
39B. Naphthalene (91-20-3)														
40B. Nitrobenzene (98-95-3)														
41B. N-Nitrosodimethylamine (62-75-9)														
42B. N-Nitrosodi-N-Propylamine (621-64-7)														

CONTINUE ON REVERSE

CONTINUED FROM THE FRONT

1. POLLUTANT AND CAS NUMBER (if available)	2. MARK 'X'			3. EFFLUENT							4. UNITS		5. INTAKE (optional)	
	a. TESTING REQUIRED	b. BELIEVED PRESENT	c. BELIEVED ABSENT	a. MAXIMUM DAILY VALUE		b. MAXIMUM 30 DAY VALUE (if available)		c. LONG TERM AVRG. VALUE (if available)		d. NO. OF ANALYSES	a. CONCENTRATION	b. MASS	a. LONG TERM AVERAGE VALUE	
				(1) CONCENTRATION	(2) MASS	(1) CONCENTRATION	(2) MASS	(1) CONCENTRATION	(2) MASS				(1) CONCENTRATION	(2) MASS
GC/MS FRACTION — BASE/NEUTRAL COMPOUNDS (continued)														
43B. N-Nitro-sodiphenylamine (86-30-6)														
44B. Phenanthrene (85-01-8)														
45B. Pyrene (129-00-0)														
46B. 1,2,4-Tri-chlorobenzene (120-82-1)														
GC/MS FRACTION — PESTICIDES														
1P. Aldrin (309-00-2)														
2P. α-BHC (319-84-6)														
3P. β-BHC (319-85-7)														
4P. γ-BHC (58-89-9)														
5P. δ-BHC (319-86-8)														
6P. Chlordane (57-74-9)														
7P. 4,4'-DDT (50-29-3)														
8P. 4,4'-DDE (72-55-9)														
9P. 4,4'-DDD (72-54-8)														
10P. Dieldrin (60-57-1)														
11P. α-Endosulfan (115-29-7)														
12P. β-Endosulfan (115-29-7)														
13P. Endosulfan Sulfate (1031-07-8)														
14P. Endrin (72-20-8)														
15P. Endrin Aldehyde (7421-93-4)														
16P. Heptachlor (76-44-8)														

CONTINUE ON PAGE V-7

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EPA I.D. NUMBER (copy from Item 1 of Form 1)	OUTFALL NUMBER

1. POLLUTANT AND CAS NUMBER (if available)	2. MARK 'X' a. TESTING REQUIRED	b. BELIEVED PRESENT	c. BELIEVED ABSENT	3. EFFLUENT a. MAXIMUM DAILY VALUE (1) CONCENTRATION	(2) MASS	b. MAXIMUM 30 DAY VALUE (if available) (1) CONCENTRATION	(2) MASS	c. LONG TERM AVRG. VALUE (if available) (1) CONCENTRATION	(2) MASS	d. NO. OF ANALYSES	4. UNITS a. CONCENTRATION	b. MASS	5. INTAKE (optional) a. LONG TERM AVERAGE VALUE (1) CONCENTRATION	(2) MASS
GC/MS FRACTION — PESTICIDES (continued)														
17P. Heptachlor Epoxide (1024-57-3)														
18P. PCB-1242 (53469-21-9)														
19P. PCB-1254 (11097-69-1)														
20P. PCB-1221 (11104-28-2)														
21P. PCB-1232 (11141-16-5)														
22P. PCB-1248 (12672-29-6)														
23P. PCB-1260 (11096-82-5)														
24P. PCB-1016 (12674-11-2)														
25P. Toxaphene (8001-35-2)														

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Please print or type in the unshaded areas only.

EPA I.D. NUMBER (copy from Item 1 of Form 1)

Form Approved
OMB No. 2040-0086
Approval expires 5-31-92

2C

EPA

U.S. ENVIRONMENTAL PROTECTION AGENCY
APPLICATION FOR PERMIT TO DISCHARGE WASTEWATER
EXISTING MANUFACTURING, COMMERCIAL, MINING AND SILVICULTURAL OPERATIONS
Consolidated Permits Program

I. OUTFALL LOCATION

...or each outfall, list the latitude and longitude of its location to the nearest 15 seconds and the name of the receiving water.

A. OUTFALL NUMBER (list)	B. LATITUDE			C. LONGITUDE			D. RECEIVING WATER (name)
	1. deg.	2. min.	3. sec.	1. deg.	2. min.	3. sec.	

...ONS, SOURCES OF POLLUTION, AND TREATMENT TECHNOLOGIES

... wastewater to the effluent, ... drawing by showing average ... mining activities), provide a ...

... water, sanitary wastewater, ... by the wastewater. Continue on additional sheets if ...

OUTFALL NO.	a. OPERATION (list)	b. ... (include units)	TREATMENT a. DESCRIPTION	b. LIST CODES FROM TABLE 2C-1	

OFFICIAL USE ONLY (effluent guidelines sub-categories)

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C. Except for storm runoff, leaks, or spills, are any of the discharges described in Items II-A or B intermittent or seasonal?

☐ YES (complete the following table) ☐ NO (go to Section III)

1. OUTFALL NUMBER (list)	2. OPERATION(s) CONTRIBUTING FLOW (list)	3. FREQUENCY		4. FLOW				
		a. DAYS PER WEEK (specify average)	b. MONTHS PER YEAR (specify average)	a. FLOW RATE (in mgd)		b. TOTAL VOLUME (specify with units)		c. DURATION (in days)
				1. LONG TERM AVERAGE	2. MAXIMUM DAILY	1. LONG TERM AVERAGE	2. MAXIMUM DAILY	

III. PRODUCTION

A. Does an effluent [illegible] the Clean Water Act apply to your facility?

☐ YES (complete Item III-B) ☐ NO (go to Section IV)

B. Are the limitations in the applicable effluent guideline expressed in terms of production (or other measure of operation)?

☐ YES (complete Item III-C) ☐ NO (go to Section IV)

C. If you answered "yes" to Item III-B, list the quantity which represents an actual measurement of your level of production, expressed in the terms and units used in the applicable effluent guideline, and indicate the affected outfalls.

1. AVERAGE DAILY PRODUCTION			2. AFFECTED OUTFALLS (list outfall numbers)
a. QUANTITY PER DAY	b. UNITS OF MEASURE	c. OPERATION, PRODUCT, MATERIAL, ETC. (specify)	

IV. IMPROVEMENTS

A. Are you now required by any Federal, State or local authority to meet any implementation schedule for the construction, upgrading or operation of waste-water treatment equipment or practices or any other environmental programs which may affect the discharges described in this application? This includes, but is not limited to, permit conditions, administrative or enforcement orders, enforcement compliance schedule letters, stipulations, court orders, and grant or loan conditions.

☐ YES (complete the following table) ☐ NO (go to Item IV-B)

1. IDENTIFICATION OF CONDITION, AGREEMENT, ETC.	2. AFFECTED OUTFALLS		3. BRIEF DESCRIPTION OF PROJECT	4. FINAL COMPLIANCE DATE	
	a. NO.	b. SOURCE OF DISCHARGE		a. REQUIRED	b. PROJECTED

[illegible] ☐ MARK "X" IF DESCRIPTION OF ADDITIONAL CONTROL PROGRAMS IS ATTACHED

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EPA I.D. NUMBER *(copy from Item 1 of Form 1)*

V. INTAKE AND EFFLUENT CHARACTERISTICS

A, B, & C: See instructions before proceeding — Complete one set of tables for each outfall — Annotate the outfall number in the space provided.
NOTE: Tables V-A, V-B, and V-C are included on separate sheets numbered V-1 through V-9.

D. Use the space below to list any of the pollutants listed in Table 2c-3 of the instructions, which you know or have reason to believe is discharged or may be discharged from any outfall. For every pollutant you list, briefly describe the reasons you believe it to be present and report any analytical data in your possession.

1. POLLUTANT	2. SOURCE	1. POLLUTANT	2. SOURCE

VI. POTENTIAL DISCHARGES NOT COVERED BY ANALYSIS

[illegible] listed in Item V-C a substance or a component of a substance which [illegible] use or manufacture as an intermediate or final product or [illegible]

☐ YES *(list all such pollutants below)* ☐ NO *(go to Item VI-B)*

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VII. BIOLOGICAL TOXICITY TESTING DATA

Do you have any knowledge or reason to believe that any biological test for acute or chronic toxicity has been made on any of your discharges or on a receiving water in relation to your discharge within the last 3 years?

☐ YES (identify the test(s) and describe their purposes below) ☐ NO (go to Section VIII)

VIII. CONTRACT ANALYSIS INFORMATION

Were any of the analyses reported in Item V performed by a contract laboratory or consulting firm?

☐ YES (list the name, address, and telephone number of, and pollutants analyzed by, each such laboratory or firm below) ☐ NO (go to Section IX)

A. NAME	B. ADDRESS	C. TELEPHONE (area code & no.)	D. POLLUTANTS ANALYZED (list)

IX. CERTIFICATION

I certify under penalty of law that this document and all attachments were prepared under my direction or supervision in accordance with a system designed to assure that qualified personnel properly gather and evaluate the information submitted. Based on my inquiry of the person or persons who manage the system or those persons directly responsible for gathering the information, the information submitted is, to the best of my knowledge and belief, true, accurate, and complete. I am aware that there are significant penalties for submitting false information, including the possibility of fine and imprisonment for knowing violations.

A. NAME & OFFICIAL TITLE (type or print)	B. PHONE NO. (area code & no.)
C. SIGNATURE	D. DATE SIGNED

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PLEASE PRINT OR TYPE IN THE UNSHADED AREAS ONLY. You may report some or all of this information on separate sheets *(use the same format)* instead of completing these pages.
SEE INSTRUCTIONS.

EPA I.D. NUMBER *(copy from Item 1 of Form 1)*

V. INTAKE AND EFFLUENT CHARACTERISTICS *(continued from page 3 of Form 2-C)*

OUTFALL NO.

PART A - You must provide the results of at least one analysis for every pollutant in this table. Complete one table for each outfall. See instructions for additional details.

1. POLLUTANT	2. EFFLUENT: a. MAXIMUM DAILY VALUE (1) CONCENTRATION	(2) MASS	b. MAXIMUM 30 DAY VALUE *(if available)* (1) CONCENTRATION	(2) MASS	c. LONG TERM AVRG. VALUE *(if available)* (1) CONCENTRATION	(2) MASS	d. NO. OF ANALYSES	3. UNITS *(specify if blank)* a. CONCENTRATION	b. MASS	4. INTAKE *(optional)* a. LONG TERM AVERAGE VALUE (1) CONCENTRATION	(2) MASS	b. NO. OF ANALYSES
a. Biochemical Oxygen Demand *(BOD)*												
b. Chemical Oxygen Demand *(COD)*												
c. Total Organic Carbon *(TOC)*												
d. Total Suspended Solids *(TSS)*												
e. Ammonia *(as N)*												
f. Flow	VALUE		VALUE		VALUE					VALUE		
g. Temperature *(winter)*	VALUE		VALUE		VALUE			°C		VALUE		
h. Temperature *(summer)*	VALUE		VALUE		VALUE			°C		VALUE		
i. pH	MINIMUM	MAXIMUM	MINIMUM	MAXIMUM				STANDARD UNITS				

PART B - Mark "X" in column 2-a for each pollutant you know or have reason to believe is present. Mark "X" in column 2-b for each pollutant you believe to be absent. If you mark column 2a for any pollutant which is limited either directly, or indirectly but expressly, in an effluent limitations guideline, you must provide the results of at least one analysis for that pollutant. For other pollutants for which you mark column 2a, you must provide quantitative data or an explanation of their presence in your discharge. Complete one table for each outfall. See the instructions for additional details and requirements.

1. POLLUTANT AND CAS NO. *(if available)*	2. MARK "X" a. BELIEVED PRESENT	b. BELIEVED ABSENT	3. EFFLUENT: a. MAXIMUM DAILY VALUE (1) CONCENTRATION	(2) MASS	b. MAXIMUM 30 DAY VALUE *(if available)* (1) CONCENTRATION	(2) MASS	c. LONG TERM AVRG. VALUE *(if available)* (1) CONCENTRATION	(2) MASS	d. NO. OF ANALYSES	4. UNITS a. CONCENTRATION	b. MASS	5. INTAKE *(optional)* a. LONG TERM AVERAGE VALUE (1) CONCENTRATION	(2) MASS	b. NO. OF ANALYSES
a. Bromide (24959-67-9)														
b. Chlorine, Total Residual														
c. Color														
d. Fecal Coliform														
e. Fluoride (16984-48-8)														
f. Nitrate—Nitrite *(as N)*														

CONTINUE ON REVERSE

ITEM V-B CONTINUED FROM FRONT

1. POLLUTANT AND CAS NO. *(if available)*	2. MARK 'X' a. BELIEVED PRESENT	b. BELIEVED ABSENT	3. EFFLUENT a. MAXIMUM DAILY VALUE (1) CONCENTRATION	(2) MASS	b. MAXIMUM 30 DAY VALUE *(if available)* (1) CONCENTRATION	(2) MASS	c. LONG TERM AVRG. VALUE *(if available)* (1) CONCENTRATION	(2) MASS	d. NO. OF ANALYSES	4. UNITS a. CONCENTRATION	b. MASS	5. INTAKE *(optional)* a. LONG TERM AVERAGE VALUE (1) CONCENTRATION	(2) MASS
g. Nitrogen, Total Organic *(as N)*													
h. Oil and Grease													
i. Phosphorus *(as P)*, Total (7723-14-0)													
j. Radioactivity													
(1) Alpha, Total													
(2) Beta, Total													
(3) Radium, Total													
(4) Radium 226, Total													
k. Sulfate *(as SO_4)* (14808-79-8)													
l. Sulfide *(as S)*													
m. Sulfite *(as SO_3)* (14265-45-3)													
n. Surfactants													
o. Aluminum, Total (7429-90-5)													
p. [illegible], Total (7440-39-3)													
[illegible] Total (744[illegible])													
[illegible] (744[illegible])													
s. Iron, Total (7439-89-6)													
t. Magnesium, Total (7439-95-4)													
u. Molybdenum, Total (7439-98-7)													
v. Manganese, Total (7439-96-5)													
w. Tin, Total (7440-31-5)													
x. Titanium, Total (7440-32-6)													

CONTINUE ON PAGE V-3

EPA I.D. NUMBER (copy from Item 1 of Form 1)	OUTFALL NUMBER

CONTINUED FROM PAGE 3 OF FORM 2-C

PART C - If you are a primary industry and this outfall contains process wastewater, refer to Table 2c-2 in the instructions to determine which of the GC/MS fractions you must test for. Mark "X" in column 2-a for all such GC/MS fractions that apply to your industry and for ALL toxic metals, cyanides, and total phenols. If you are not required to mark column 2-a (*secondary industries, nonprocess wastewater outfalls, and nonrequired GC/MS fractions*), mark "X" in column 2-b for each pollutant you know or have reason to believe is present. Mark "X" in column 2-c for each pollutant you believe is absent. If you mark column 2a for any pollutant, you must provide the results of at least one analysis for that pollutant. If you mark column 2b for any pollutant, you must provide the results of at least one analysis for that pollutant if you know or have reason to believe it will be discharged in concentrations of 10 ppb or greater. If you mark column 2b for acrolein, acrylonitrile, 2,4 dinitrophenol, or 2-methyl-4, 6 dinitrophenol, you must provide the results of at least one analysis for each of these pollutants which you know or have reason to believe that you discharge in concentrations of 100 ppb or greater. Otherwise, for pollutants for which you mark column 2b, you must either submit at least one analysis or briefly describe the reasons the pollutant is expected to be discharged. Note that there are 7 pages to this part; please review each carefully. Complete one table (*all 7 pages*) for each outfall. See instructions for additional details and requirements.

1. POLLUTANT AND CAS NUMBER (*if available*)	2. MARK "X"			3. EFFLUENT							4. UNITS		5. INTAKE (*optional*)		
	a. TESTING REQUIRED	b. BELIEVED PRESENT	c. BELIEVED ABSENT	a. MAXIMUM DAILY VALUE		b. MAXIMUM 30 DAY VALUE (*if available*)		c. LONG TERM AVRG. VALUE (*if available*)		d. NO. OF ANALYSES	a. CONCENTRATION	b. MASS	a. LONG TERM AVERAGE VALUE		[illegible]
				(1) CONCENTRATION	(2) MASS	(1) CONCENTRATION	(2) MASS	(1) CONCENTRATION	(2) MASS				(1) CONCENTRATION	(2) MASS	
METALS, CYANIDE, AND TOTAL PHENOLS															
1M. Antimony, Total (7440-36-0)															
2M. Arsenic, Total (7440-38-2)															
3M. Beryllium, Total, 7440-41-7)															
4M. Cadmium, Total (7440-43-9)															
5M. Chromium, Total (7440-47-3)															
6M. Copper, Total (7440-50-8)															
7M. Lead, Total (7439-92-1)															
8M. Mercury, Total (7439-97-6)															
9M. Nickel, Total (7440-02-0)															
10M. Selenium, Total (7782-49-2)															
11M. Silver, Total (7440-22-4)															
12M. Thallium, Total (7440-28-0)															
13M. Zinc, Total (7440-66-6)															
14M. Cyanide, Total (57-12-5)															
15M. Phenols, Total															
DIOXIN															
2,3,7,8 Tetrachlorodibenzo-P-Dioxin (1764-01-6)				DESCRIBE RESULTS											

CONTINUE ON REVERSE

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CONTINUED FROM THE FRONT

1. POLLUTANT AND CAS NUMBER (if available)	2. MARK 'X'			3. EFFLUENT							4. UNITS		5. INTAKE (optional)	
	a. testing required	b. believed present	c. believed absent	a. MAXIMUM DAILY VALUE		b. MAXIMUM 30 DAY VALUE (if available)		c. LONG TERM AVRG. VALUE (if available)		d. NO. OF ANALYSES	a. CONCENTRATION	b. MASS	a. LONG TERM AVERAGE VALUE	
				(1) concentration	(2) mass	(1) concentration	(2) mass	(1) concentration	(2) mass				(1) concentration	(2) mass
GC/MS FRACTION – VOLATILE COMPOUNDS														
1V. Acrolein (107-02-8)														
2V. Acrylonitrile (107-13-1)														
3V. Benzene (71-43-2)														
4V. Bis (Chloromethyl) Ether (542-88-1)														
5V. Bromoform (75-25-2)														
6V. Carbon Tetrachloride (56-23-5)														
7V. Chlorobenzene (108-90-7)														
8V. Chlorodibromomethane (124-48-1)														
9V. Chloroethane (75-00-3)														
10V. 2-Chloroethylvinyl Ether (110-75-8)														
11V. Chloroform (67-66-3)														
12V. Dichlorobromomethane (75-27-4)														
13V. Dichlorodifluoromethane (75-71-8)														
14V. 1,1-Dichloroethane (75-34-3)														
15V. 1,2-Dichloroethane (107-06-2)														
16V. 1,1-Dichloroethylene (75-35-4)														
17V. 1,2-Dichloropropane (78-87-5)														
18V. 1,3-Dichloropropylene (542-75-6)														
19V. Ethylbenzene (100-41-4)														
20V. Methyl Bromide (74-83-9)														
21V. Methyl Chloride (74-87-3)														

CONTINUE ON PAGE V-5

VOL 12

1 0050 1

CONTINUED FROM PAGE V-4

EPA I.D. NUMBER (copy from Item 1 of Form 1)	OUTFALL NUMBER

1. POLLUTANT AND CAS NUMBER (if available)	2. MARK 'X'			3. EFFLUENT							4. UNITS		5. INTAKE (optional)		
	a. TESTING REQUIRED	b. BELIEVED PRESENT	c. BELIEVED ABSENT	a. MAXIMUM DAILY VALUE (1) CONCENTRATION	a. MAXIMUM DAILY VALUE (2) MASS	b. MAXIMUM 30 DAY VALUE (if available) (1) CONCENTRATION	b. (2) MASS	c. LONG TERM AVRG. VALUE (if available) (1) CONCENTRATION	c. (2) MASS	d. NO. OF ANALYSES	a. CONCENTRATION	b. MASS	a. LONG TERM AVERAGE VALUE (1) CONCENTRATION	a. (2) MASS	b. NO. OF ANALYSES
GC/MS FRACTION — VOLATILE COMPOUNDS (continued)															
22V. Methylene Chloride (75-09-2)															
23V. 1,1,2,2-Tetrachloroethane (79-34-5)															
24V. Tetrachloroethylene (127-18-4)															
25V. Toluene (108-88-3)															
26V. 1,2-Trans-Dichloroethylene (156-60-5)															
27V. 1,1,1-Trichloroethane (71-55-6)															
28V. 1,1,2-Trichloroethane (79-00-5)															
29V. Trichloroethylene (79-01-6)															
30V. Trichlorofluoromethane (75-69-4)															
31V. Vinyl Chloride (75-01-4)															
GC/MS FRACTION — ACID COMPOUNDS															
1A. 2-Chlorophenol (95-57-8)															
2A. 2,4-Dichlorophenol (120-83-2)															
3A. 2,4-Dimethylphenol (105-67-9)															
4A. 4,6-Dinitro-O-Cresol (534-52-1)															
5A. 2,4-Dinitrophenol (51-28-5)															
6A. 2-Nitrophenol (88-75-5)															
7A. 4-Nitrophenol (100-02-7)															
8A. P-Chloro-M-Cresol (59-50-7)															
9A. Pentachlorophenol (87-86-5)															
10A. Phenol (108-95-2)															
11A. 2,4,6-Trichlorophenol (88-06-2)															

CONTINUE ON REVERSE

CONTINUED FROM THE FRONT

1. POLLUTANT AND CAS NUMBER (if available)	2. MARK 'X' a. testing required	b. believed present	c. believed absent	3. EFFLUENT a. MAXIMUM DAILY VALUE (1) concentration	(2) mass	b. MAXIMUM 30 DAY VALUE (if available) (1) concentration	(2) mass	c. LONG TERM AVRG. VALUE (if available) (1) concentration	(2) mass	d. NO. OF ANALYSES	4. UNITS a. CONCENTRATION	b. MASS	5. INTAKE (optional) a. LONG TERM AVERAGE VALUE (1) concentration	(2) mass
GC/MS FRACTION — BASE/NEUTRAL COMPOUNDS														
1B. Acenaphthene (83-32-9)														
2B. Acenaphtylene (208-96-8)														
3B. Anthracene (120-12-7)														
4B. Benzidine (92-87-5)														
5B. Benzo (a) Anthracene (56-55-3)														
6B. Benzo (a) Pyrene (50-32-8)														
7B. 3,4-Benzo-fluoranthene (205-99-2)														
8B. Benzo (ghi) Perylene (191-24-2)														
9B. Benzo (k) Fluoranthene (207-08-9)														
10B. Bis (2-Chloroethoxy) Methane (111-91-1)														
11B. Bis (2-Chloroethyl) Ether (111-44-4)														
12B. Bis (2-Chloroisopropyl) Ether (102-60-1)														
13B. Bis (2-Ethylhexyl) Phthalate (117-81-7)														
14B. 4-Bromophenyl Phenyl Ether (101-55-3)														
15B. Butyl Benzyl Phthalate (85-68-7)														
16B. 2-Chloronaphthalene (91-58-7)														
17B. 4-Chlorophenyl Phenyl Ether (7005-72-3)														
18B. Chrysene (218-01-9)														
19B. Dibenzo (a,h) Anthracene (53-70-3)														
20B. 1,2-Dichlorobenzene (95-50-1)														
21B. 1,3-Dichlorobenzene (541-73-1)														

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VOL 12

CONTINUED FROM PAGE V-6

EPA I.D. NUMBER *(copy from Item 1 of Form 1)*	OUTFALL NUMBER

1. POLLUTANT AND CAS NUMBER *(if available)*	2. MARK 'X'			3. EFFLUENT							4. UNITS		5. INTAKE *(optional)*	
	a. TESTING REQUIRED	b. BELIEVED PRESENT	c. BELIEVED ABSENT	a. MAXIMUM DAILY VALUE (1) CONCENTRATION	a. MAXIMUM DAILY VALUE (2) MASS	b. MAXIMUM 30 DAY VALUE *(if available)* (1) CONCENTRATION	b. MAXIMUM 30 DAY VALUE (2) MASS	c. LONG TERM AVRG. VALUE *(if available)* (1) CONCENTRATION	c. LONG TERM AVRG. VALUE (2) MASS	d. NO. OF ANALYSES	a. CONCENTRATION	b. MASS	a. LONG TERM AVERAGE VALUE (1) CONCENTRATION	a. LONG TERM AVERAGE VALUE (2) MASS
GC/MS FRACTION – BASE/NEUTRAL COMPOUNDS *(continued)*														
22B. 1,4-Dichlorobenzene (106-46-7)														
23B. 3,3'-Dichlorobenzidine (91-94-1)														
24B. Diethyl Phthalate (84-66-2)														
25B. Dimethyl Phthalate (131-11-3)														
26B. Di-N-Butyl Phthalate (84-74-2)														
27B. 2,4-Dinitrotoluene (121-14-2)														
28B. 2,6-Dinitrotoluene (606-20-2)														
29B. Di-N-Octyl Phthalate (117-84-0)														
30B. 1,2-Diphenylhydrazine *(as Azobenzene)* (122-66-7)														
31B. Fluoranthene (206-44-0)														
32B. Fluorene (86-73-7)														
33B. Hexachlorobenzene (118-74-1)														
34B. Hexachlorobutadiene (87-68-3)														
35B. Hexachlorocyclopentadiene (77-47-4)														
36B. Hexachloroethane (67-72-1)														
37B. Indeno *(1,2,3-cd)* Pyrene (193-39-5)														
38B. Isophorone (78-59-1)														
39B. Naphthalene (91-20-3)														
40B. Nitrobenzene (98-95-3)														
41B. N-Nitrosodimethylamine (62-75-9)														
42B. N-Nitrosodi-N-Propylamine (621-64-7)														

EPA Form 3510-2C (6-80)

CONTINUE ON

CONTINUED FROM THE FRONT

1. POLLUTANT AND CAS NUMBER (if available)	2. MARK 'X'			3. EFFLUENT							4. UNITS		5. INTAKE (optional)	
	a. testing required	b. believed present	c. believed absent	a. MAXIMUM DAILY VALUE (1) concentration	(2) mass	b. MAXIMUM 30 DAY VALUE (if available) (1) concentration	(2) mass	c. LONG TERM AVRG. VALUE (if available) (1) concentration	(2) mass	d. NO. OF ANALYSES	a. CONCENTRATION	b. MASS	a. LONG TERM AVERAGE VALUE (1) concentration	(2) mass
GC/MS FRACTION – BASE/NEUTRAL COMPOUNDS (continued)														
43B. N-Nitrosodiphenylamine (86-30-6)														
44B. Phenanthrene (85-01-8)														
45B. Pyrene (129-00-0)														
46B. 1,2,4-Trichlorobenzene (120-82-1)														
GC/MS FRACTION – PESTICIDES														
1P. Aldrin (309-00-2)														
2P. α-BHC (319-84-6)														
3P. β-BHC (319-85-7)														
4P. γ-BHC (58-89-9)														
5P. δ-BHC (319-86-8)														
6P. Chlordane (57-74-9)														
7P. 4,4'-DDT (50-29-3)														
8P. 4,4'-DDE (72-55-9)														
9P. 4,4'-DDD (72-54-8)														
10P. Dieldrin (60-57-1)														
11P. α-Endosulfan (115-29-7)														
12P. β-Endosulfan (115-29-7)														
13P. Endosulfan Sulfate (1031-07-8)														
14P. Endrin (72-20-8)														
15P. Endrin Aldehyde (7421-93-4)														
16P. Heptachlor (76-44-8)														

CONTINUE ON PAGE V 9

CONTINUED FROM PAGE V-8

EPA I.D. NUMBER *(copy from Item 1 of Form 1)*	OUTFALL NUMBER

1. POLLUTANT AND CAS NUMBER *(if available)*	2. MARK 'X'			3. EFFLUENT							4. UNITS		5. INTAKE *(optional)*	
	a. TESTING REQUIRED	b. BELIEVED PRESENT	c. BELIEVED ABSENT	a. MAXIMUM DAILY VALUE		b. MAXIMUM 30 DAY VALUE *(if available)*		c. LONG TERM AVRG. VALUE *(if available)*		d. NO. OF ANALYSES	a. CONCENTRATION	b. MASS	a. LONG TERM AVERAGE VALUE	
				(1) CONCENTRATION	(2) MASS	(1) CONCENTRATION	(2) MASS	(1) CONCENTRATION	(2) MASS				(1) CONCENTRATION	(2) MASS
GC/MS FRACTION — PESTICIDES *(continued)*														
17P. Heptachlor Epoxide (1024-57-3)														
18P. PCB-1242 (53469-21-9)														
19P. PCB-1254 (11097-69-1)														
20P. PCB-1221 (11104-28-2)														
21P. PCB-1232 (11141-16-5)														
22P. PCB-1248 (12672-29-6)														
23P. PCB-1260 (11096-82-5)														
24P. PCB-1016 (12674-11-2)														
25P. Toxaphene (8001-35-2)														

EPA Form 3510-2C (8-90)

ITEM V-B CONTINUED FROM FRONT

1. POLLUTANT AND CAS NO. (if available)	2. MARK 'X'		3. EFFLUENT							4. UNITS		5. INTAKE (optional)		
	a. believed present	b. believed absent	a. MAXIMUM DAILY VALUE		b. MAXIMUM 30 DAY VALUE (if available)		c. LONG TERM AVRG. VALUE (if available)		d. NO. OF ANALYSES	a. CONCENTRATION	b. MASS	a. LONG TERM AVERAGE VALUE		b. NO. OF ANALYSES
			(1) CONCENTRATION	(2) MASS	(1) CONCENTRATION	(2) MASS	(1) CONCENTRATION	(2) MASS				(1) CONCENTRATION	(2) MASS	
g. Nitrogen, Total Organic (as N)														
h. Oil and Grease														
i. Phosphorus (as P), Total (7723-14-0)														
j. Radioactivity														
(1) Alpha, Total														
(2) Beta, Total														
(3) Radium, Total														
(4) Radium 226, Total														
k. Sulfate (as SO_4) (14808-79-8)														
l. Sulfide (as S)														
m. Sulfite (as SO_3) (14265-45-3)														
n. Surfactants														
o. Aluminum, Total (7429-90-5)														
p. Barium, Total (7440-39-3)														
q. Boron, Total (7440-42-8)														
r. Cobalt, Total (7440-48-4)														
s. Iron, Total (7439-89-6)														
t. Magnesium, Total (7439-95-4)														
u. Molybdenum, Total (7439-98-7)														
v. Manganese, Total (7439-96-5)														
w. Tin, Total (7440-31-5)														
x. Titanium, Total (7440-32-6)														

CONTINUE ON PAGE V

CONTINUED FROM PAGE 3 OF FORM 2-C

EPA I.D. NUMBER *(copy from Item 1 of Form 1)*	OUTFALL NUMBER

Form Approved
OMB No. 2040-0086
Approval expires 7-31-88

PART C - If you are a primary industry and this outfall contains process wastewater, refer to Table 2c-2 in the instructions to determine which of the GC/MS fractions you must test for. Mark "X" in column 2-a for all such GC/MS fractions that apply to your industry and for ALL toxic metals, cyanides, and total phenols. If you are not required to mark column 2-a *(secondary industries, nonprocess wastewater outfalls, and nonrequired GC/MS fractions)*, mark "X" in column 2-b for each pollutant you know or have reason to believe is present. Mark "X" in column 2-c for each pollutant you believe is absent. If you mark column 2a for any pollutant, you must provide the results of at least one analysis for that pollutant. If you mark column 2b for any pollutant, you must provide the results of at least one analysis for that pollutant if you know or have reason to believe it will be discharged in concentrations of 10 ppb or greater. If you mark column 2b for acrolein, acrylonitrile, 2,4 dinitrophenol, or 2-methyl-4, 6 dinitrophenol, you must provide the results of at least one analysis for each of these pollutants which you know or have reason to believe that you discharge in concentrations of 100 ppb or greater. Otherwise, for pollutants for which you mark column 2b, you must either submit at least one analysis or briefly describe the reasons the pollutant is expected to be discharged. Note that there are 7 pages to this part; please review each carefully. Complete one table *(all 7 pages)* for each outfall. See instructions for additional details and requirements.

1. POLLUTANT AND CAS NUMBER *(if available)*	2. MARK 'X'			3. EFFLUENT							4. UNITS		5. INTAKE *(optional)*		
	a. TESTING REQUIRED	b. BELIEVED PRESENT	c. BELIEVED ABSENT	a. MAXIMUM DAILY VALUE (1) CONCENTRATION	a. MAXIMUM DAILY VALUE (2) MASS	b. MAXIMUM 30 DAY VALUE *(if available)* (1) CONCENTRATION	b. MAXIMUM 30 DAY VALUE *(if available)* (2) MASS	c. LONG TERM AVRG. VALUE *(if available)* (1) CONCENTRATION	c. LONG TERM AVRG. VALUE *(if available)* (2) MASS	d. NO. OF ANALYSES	a. CONCENTRATION	b. MASS	a. LONG TERM AVERAGE VALUE (1) CONCENTRATION	a. LONG TERM AVERAGE VALUE (2) MASS	b. NO. OF ANALYSES
METALS, CYANIDE, AND TOTAL PHENOLS															
1M. Antimony, Total (7440-36-0)															
2M. Arsenic, Total (7440-38-2)															
3M. Beryllium, Total, 7440-41-7)															
4M. Cadmium, Total (7440-43-9)															
5M. Chromium, Total (7440-47-3)															
6M. Copper, Total (7440-50-8)															
7M. Lead, Total (7439-92-1)															
8M. Mercury, Total (7439-97-6)															
9M. Nickel, Total (7440-02-0)															
10M. Selenium, Total (7782-49-2)															
11M. Silver, Total (7440-22-4)															
12M. Thallium, Total (7440-28-0)															
13M. Zinc, Total (7440-66-6)															
14M. Cyanide, Total (57-12-5)															
15M. Phenols, Total															
DIOXIN															
2,3,7,8 Tetra-chlorodibenzo-P-Dioxin (1764-01-6)				DESCRIBE RESULTS											

CONTINUED FROM THE FRONT

1. POLLUTANT AND CAS NUMBER (if available)	2. MARK 'X' a. TESTING REQUIRED	2. b. BELIEVED PRESENT	2. c. BELIEVED ABSENT	3. EFFLUENT a. MAXIMUM DAILY VALUE (1) CONCENTRATION	3. a. (2) MASS	3. b. MAXIMUM 30 DAY VALUE (if available) (1) CONCENTRATION	3. b. (2) MASS	3. c. LONG TERM AVRG. VALUE (if available) (1) CONCENTRATION	3. c. (2) MASS	3. d. NO. OF ANALYSES	4. UNITS a. CONCENTRATION	4. b. MASS	5. INTAKE (optional) a. LONG TERM AVERAGE VALUE (1) CONCENTRATION	5. a. (2) MASS	5. b. NO. OF ANALYSES
GC/MS FRACTION — VOLATILE COMPOUNDS															
1V. Acrolein (107-02-8)															
2V. Acrylonitrile (107-13-1)															
3V. Benzene (71-43-2)															
4V. Bis (Chloromethyl) Ether (542-88-1)															
5V. Bromoform (75-25-2)															
6V. Carbon Tetrachloride (56-23-5)															
7V. Chlorobenzene (108-90-7)															
8V. Chlorodibromomethane (124-48-1)															
9V. Chloroethane (75-00-3)															
10V. 2-Chloroethylvinyl Ether (110-75-8)															
11V. Chloroform (67-66-3)															
12V. Dichlorobromomethane (75-27-4)															
13V. Dichlorodifluoromethane (75-71-8)															
14V. 1,1-Dichloroethane (75-34-3)															
15V. 1,2-Dichloroethane (107-06-2)															
16V. 1,1-Dichloroethylene (75-35-4)															
17V. 1,2-Dichloropropane (78-87-5)															
18V. 1,3-Dichloropropylene (542-75-6)															
19V. Ethylbenzene (100-41-4)															
20V. Methyl Bromide (74-83-9)															
21V. Methyl Chloride (74-87-3)															

CONTINUE ON PAGE V-5

Form Approved

CONTINUED FROM PAGE V-4

EPA I.D. NUMBER *(copy from Item 1 of Form 1)* | OUTFALL NUMBER

Form Approved
OMB No. 2040-0086
Approval expires 7-31-88

1. POLLUTANT AND CAS NUMBER *(if available)*	2. MARK 'X'			3. EFFLUENT							4. UNITS		5. INTAKE *(optional)*		
	a. TESTING REQUIRED	b. BELIEVED PRESENT	c. BELIEVED ABSENT	a. MAXIMUM DAILY VALUE		b. MAXIMUM 30 DAY VALUE *(if available)*		c. LONG TERM AVRG. VALUE *(if available)*		d. NO. OF ANALYSES	a. CONCENTRATION	b. MASS	a. LONG TERM AVERAGE VALUE		b. NO. OF ANALYSES
				(1) CONCENTRATION	(2) MASS	(1) CONCENTRATION	(2) MASS	(1) CONCENTRATION	(2) MASS				(1) CONCENTRATION	(2) MASS	
GC/MS FRACTION – VOLATILE COMPOUNDS *(continued)*															
22V. Methylene Chloride (75-09-2)															
23V. 1,1,2,2-Tetrachloroethane (79-34-5)															
24V. Tetrachloroethylene (127-18-4)															
25V. Toluene (108-88-3)															
26V. 1,2-Trans-Dichloroethylene (156-60-5)															
27V. 1,1,1-Trichloroethane (71-55-6)															
28V. 1,1,2-Trichloroethane (79-00-5)															
29V. Trichloroethylene (79-01-6)															
30V. Trichlorofluoromethane (75-69-4)															
31V. Vinyl Chloride (75-01-4)															
GC/MS FRACTION – ACID COMPOUNDS															
1A. 2-Chlorophenol (95-57-8)															
2A. 2,4-Dichlorophenol (120-83-2)															
3A. 2,4-Dimethylphenol (105-67-9)															
4A. 4,6-Dinitro-O-Cresol (534-52-1)															
5A. 2,4-Dinitrophenol (51-28-5)															
6A. 2-Nitrophenol (88-75-5)															
7A. 4-Nitrophenol (100-02-7)															
8A. P-Chloro-M-Cresol (59-50-7)															
9A. Pentachlorophenol (87-86-5)															
10A. Phenol (108-95-2)															
11A. 2,4,6-Trichlorophenol (88-06-2)															

CONTINUED FROM THE FRONT

1. POLLUTANT AND CAS NUMBER (if available)	2. MARK 'X'			3. EFFLUENT							4. UNITS		5. INTAKE (optional)		
	a. testing required	b. believed present	c. believed absent	a. MAXIMUM DAILY VALUE		b. MAXIMUM 30 DAY VALUE (if available)		c. LONG TERM AVRG. VALUE (if available)		d. NO. OF ANALYSES	a. CONCENTRATION	b. MASS	a. LONG TERM AVERAGE VALUE		b. NO. OF ANALYSES
				(1) CONCENTRATION	(2) MASS	(1) CONCENTRATION	(2) MASS	(1) CONCENTRATION	(2) MASS				(1) CONCENTRATION	(2) MASS	
GC/MS FRACTION – BASE/NEUTRAL COMPOUNDS															
1B. Acenaphthene (83-32-9)															
2B. Acenaphtylene (208-96-8)															
3B. Anthracene (120-12-7)															
4B. Benzidine (92-87-5)															
5B. Benzo (a) Anthracene (56-55-3)															
6B. Benzo (a) Pyrene (50-32-8)															
7B. 3,4-Benzo-fluoranthene (205-99-2)															
8B. Benzo (ghi) Perylene (191-24-2)															
9B. Benzo (k) Fluoranthene (207-08-9)															
10B. Bis (2-Chloroethoxy) Methane (111-91-1)															
11B. Bis (2-Chloroethyl) Ether (111-44-4)															
12B. Bis (2-Chloroisopropyl) Ether (102-60-1)															
13B. Bis (2-Ethylhexyl) Phthalate (117-81-7)															
14B. 4-Bromophenyl Phenyl Ether (101-55-3)															
15B. Butyl Benzyl Phthalate (85-68-7)															
16B. 2-Chloronaphthalene (91-58-7)															
17B. 4-Chlorophenyl Phenyl Ether (7005-72-3)															
18B. Chrysene (218-01-9)															
19B. Dibenzo (a,h) Anthracene (53-70-3)															
20B. 1,2-Dichlorobenzene (95-50-1)															
21B. 1,3-Dichlorobenzene (541-73-1)															

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EPA I.D. NUMBER (copy from Item 1 of Form 1)	OUTFALL NUMBER

Form Approved
OMB No. 2040-0086
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1. POLLUTANT AND CAS NUMBER (if available)	2. MARK 'X'			3. EFFLUENT							4. UNITS		5. INTAKE (optional)		
	a. TESTING REQUIRED	b. BELIEVED PRESENT	c. BELIEVED ABSENT	a. MAXIMUM DAILY VALUE		b. MAXIMUM 30 DAY VALUE (if available)		c. LONG TERM AVRG. VALUE (if available)		d. NO OF ANALYSES	a. CONCENTRATION	b. MASS	a. LONG TERM AVERAGE VALUE		b. NO OF ANALYSES
				(1) CONCENTRATION	(2) MASS	(1) CONCENTRATION	(2) MASS	(1) CONCENTRATION	(2) MASS				(1) CONCENTRATION	(2) MASS	
GC/MS FRACTION — BASE/NEUTRAL COMPOUNDS (continued)															
22B. 1,4-Dichlorobenzene (106-46-7)															
23B. 3,3'-Dichlorobenzidine (91-94-1)															
24B. Diethyl Phthalate (84-66-2)															
25B. Dimethyl Phthalate (131-11-3)															
26B. Di-N-Butyl Phthalate (84-74-2)															
27B. 2,4-Dinitrotoluene (121-14-2)															
28B. 2,6-Dinitrotoluene (606-20-2)															
29B. Di-N-Octyl Phthalate (117-84-0)															
30B. 1,2-Diphenylhydrazine (as Azobenzene) (122-66-7)															
31B. Fluoranthene (206-44-0)															
32B. Fluorene (86-73-7)															
33B. Hexachlorobenzene (118-74-1)															
34B. Hexachlorobutadiene (87-68-3)															
35B. Hexachlorocyclopentadiene (77-47-4)															
36B. Hexachloroethane (67-72-1)															
37B. Indeno (1,2,3-cd) Pyrene (193-39-5)															
38B. Isophorone (78-59-1)															
39B. Naphthalene (91-20-3)															
40B. Nitrobenzene (98-95-3)															
41B. N-Nitrosodimethylamine (62-75-9)															
42B. N-Nitrosodi-N-Propylamine (621-64-7)															

CONTINUED FROM THE FRONT

1. POLLUTANT AND CAS NUMBER (if available)	2. MARK 'X'			3. EFFLUENT							4. UNITS		5. INTAKE (optional)		
	a. TESTING REQUIRED	b. BELIEVED PRESENT	c. BELIEVED ABSENT	a. MAXIMUM DAILY VALUE		b. MAXIMUM 30 DAY VALUE (if available)		c. LONG TERM AVRG. VALUE (if available)		d. NO. OF ANALYSES	a. CONCENTRATION	b. MASS	a. LONG TERM AVERAGE VALUE		b. NO. OF ANALYSES
				(1) CONCENTRATION	(2) MASS	(1) CONCENTRATION	(2) MASS	(1) CONCENTRATION	(2) MASS				(1) CONCENTRATION	(2) MASS	
GC/MS FRACTION – BASE/NEUTRAL COMPOUNDS (continued)															
43B. N-Nitrosodiphenylamine (86-30-6)															
44B. Phenanthrene (85-01-8)															
45B. Pyrene (129-00-0)															
46B. 1,2,4-Trichlorobenzene (120-82-1)															
GC/MS FRACTION – PESTICIDES															
1P. Aldrin (309-00-2)															
2P. α-BHC (319-84-6)															
3P. β-BHC (319-85-7)															
4P. γ-BHC (58-89-9)															
5P. δ-BHC (319-86-8)															
6P. Chlordane (57-74-9)															
7P. 4,4'-DDT (50-29-3)															
8P. 4,4'-DDE (72-55-9)															
9P. 4,4'-DDD (72-54-8)															
10P. Dieldrin (60-57-1)															
11P. α-Endosulfan (115-29-7)															
12P. β-Endosulfan (115-29-7)															
13P. Endosulfan Sulfate (1031-07-8)															
14P. Endrin (72-20-8)															
15P. Endrin Aldehyde (7421-93-4)															
16P. Heptachlor (76-44-8)															

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EPA I.D. NUMBER *(copy from Item 1 of Form 1)* | OUTFALL NUMBER

Form Approved
OMB No. 2040-0086
Approval expires 7-31-88

1. POLLUTANT AND CAS NUMBER *(if available)*	2. MARK 'X'			3. EFFLUENT							4. UNITS		5. INTAKE *(optional)*		
	a. TESTING REQUIRED	b. BELIEVED PRESENT	c. BELIEVED ABSENT	a. MAXIMUM DAILY VALUE		b. MAXIMUM 30 DAY VALUE *(if available)*		c. LONG TERM AVRG. VALUE *(if available)*		d. NO. OF ANALYSES	a. CONCENTRATION	b. MASS	a. LONG TERM AVERAGE VALUE		b. NO. OF ANALYSES
				(1) CONCENTRATION	(2) MASS	(1) CONCENTRATION	(2) MASS	(1) CONCENTRATION	(2) MASS				(1) CONCENTRATION	(2) MASS	
GC/MS FRACTION — PESTICIDES *(continued)*															
17P. Heptachlor Epoxide (1024-57-3)															
18P. PCB-1242 (53469-21-9)															
19P. PCB-1254 (11097-69-1)															
20P. PCB-1221 (11104-28-2)															
21P. PCB-1232 (11141-16-5)															
22P. PCB-1248 (12672-29-6)															
23P. PCB-1260 (11096-82-5)															
24P. PCB-1016 (12674-11-2)															
25P. Toxaphene (8001-35-2)															

Please print or type in the unshaded areas only.

EPA I.D. NUMBER (copy from Item 1 of Form 1)

Form Approved. OMB No. 2040-0086 Approval expires 7-31-88

FORM 2C NPDES

EPA

U.S. ENVIRONMENTAL PROTECTION AGENCY
APPLICATION FOR PERMIT TO DISCHARGE WASTEWATER
EXISTING MANUFACTURING, COMMERCIAL, MINING AND SILVICULTURAL OPERATIONS
Consolidated Permits Program

I. OUTFALL LOCATION

For each outfall, list the latitude and longitude of its location to the nearest 15 seconds and the name of the receiving water.

A. OUTFALL NUMBER (list)	B. LATITUDE 1. DEG	2. MIN	3. SEC	C. LONGITUDE 1. DEG	2. MIN	3. SEC	D. RECEIVING WATER (name)

II. FLOWS, SOURCES OF POLLUTION, AND TREATMENT TECHNOLOGIES

A. Attach a line drawing showing the water flow through the facility. Indicate sources of intake water, operations contributing wastewater to the effluent, and treatment units labeled to correspond to the more detailed descriptions in Item B. Construct a water balance on the line drawing by showing average flows between intakes, operations, treatment units, and outfalls. If a water balance cannot be determined *(e.g., for certain mining activities)*, provide a pictorial description of the nature and amount of any sources of water and any collection or treatment measures.

B. For each outfall, provide a description of: (1) All operations contributing wastewater to the effluent, including process wastewater, sanitary wastewater, cooling water, and storm water runoff; (2) The average flow contributed by each operation; and (3) The treatment received by the wastewater. Continue on additional sheets if necessary.

1. OUT-FALL NO. (list)	2. OPERATION(S) CONTRIBUTING FLOW a. OPERATION (list)	b. AVERAGE FLOW (include units)	3. TREATMENT a. DESCRIPTION	b. LIST CODES FROM TABLE 2C-1	

OFFICIAL USE ONLY *(effluent guidelines sub-categories)*

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C. Except for storm runoff, leaks, or spills, are any of the discharges described in Items II-A or B intermittent or seasonal?

☐ YES *(complete the following table)* ☐ NO *(go to Section III)*

1. OUTFALL NUMBER *(list)*	2. OPERATION(s) CONTRIBUTING FLOW *(list)*	3. FREQUENCY		4. FLOW				
		a. DAYS PER WEEK *(specify average)*	b. MONTHS PER YEAR *(specify average)*	a. FLOW RATE *(in mgd)*		b. TOTAL VOLUME *(specify with units)*		c. DURATION *(in days)*
				1. LONG TERM AVERAGE	2. MAXIMUM DAILY	1. LONG TERM AVERAGE	2. MAXIMUM DAILY	

III. PRODUCTION

A. Does an effluent guideline limitation promulgated by EPA under Section 304 of the Clean Water Act apply to your facility?

☐ YES *(complete Item III-B)* ☐ NO *(go to Section IV)*

B. Are the limitations in the applicable effluent guideline expressed in terms of production *(or other measure of operation)*?

☐ YES *(complete Item III-C)* ☐ NO *(go to Section IV)*

C. If you answered "yes" to Item III-B, list the quantity which represents an actual measurement of your level of production, expressed in the terms and units used in the applicable effluent guideline, and indicate the affected outfalls.

1. AVERAGE DAILY PRODUCTION			2. AFFECTED OUTFALLS *(list outfall numbers)*
a. QUANTITY PER DAY	b. UNITS OF MEASURE	c. OPERATION, PRODUCT, MATERIAL, ETC. *(specify)*	

IV. IMPROVEMENTS

A. Are you now required by any Federal, State or local authority to meet any implementation schedule for the construction, upgrading or operation of waste-water treatment equipment or practices or any other environmental programs which may affect the discharges described in this application? This includes, but is not limited to, permit conditions, administrative or enforcement orders, enforcement compliance schedule letters, stipulations, court orders, and grant or loan conditions.

☐ YES *(complete the following table)* ☐ NO *(go to Item IV-B)*

1. IDENTIFICATION OF CONDITION, AGREEMENT, ETC.	2. AFFECTED OUTFALLS		3. BRIEF DESCRIPTION OF PROJECT	4. FINAL COMPLIANCE DATE	
	a. NO.	b. SOURCE OF DISCHARGE		a. REQUIRED	b. PROJECTED

B. OPTIONAL: You may attach additional sheets describing any additional water pollution control programs *(or other environmental projects which may affect your discharges)* you now have underway or which you plan. Indicate whether each program is now underway or planned, and indicate your actual or planned schedules for construction. ☐ MARK "X" IF DESCRIPTION OF ADDITIONAL CONTROL PROGRAMS IS ATTACHED

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Approval expires 7-31-88

V. INTAKE AND EFFLUENT CHARACTERISTICS

A, B, & C: See instructions before proceeding — Complete one set of tables for each outfall — Annotate the outfall number in the space provided.
NOTE: Tables V-A, V-B, and V-C are included on separate sheets numbered V-1 through V-9.

D. Use the space below to list any of the pollutants listed in Table 2c-3 of the instructions, which you know or have reason to believe is discharged or may be discharged from any outfall. For every pollutant you list, briefly describe the reasons you believe it to be present and report any analytical data in your possession.

1. POLLUTANT	2. SOURCE	1. POLLUTANT	2. SOURCE

VI. POTENTIAL DISCHARGES NOT COVERED BY ANALYSIS

Is any pollutant listed in Item V-C a substance or a component of a substance which you currently use or manufacture as an intermediate or final product or byproduct?

☐ YES (list all such pollutants below) ☐ NO (go to Item VI-B)

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VII. BIOLOGICAL TOXICITY TESTING DATA

Do you have any knowledge or reason to believe that any biological test for acute or chronic toxicity has been made on any of your discharges or on a receiving water in relation to your discharge within the last 3 years?

☐ YES *(identify the test(s) and describe their purposes below)* ☐ NO *(go to Section VIII)*

VIII. CONTRACT ANALYSIS INFORMATION

Were any of the analyses reported in Item V performed by a contract laboratory or consulting firm?

☐ YES *(list the name, address, and telephone number of, and pollutants analyzed by, each such laboratory or firm below)* ☐ NO *(go to Section IX)*

A. NAME	B. ADDRESS	C. TELEPHONE (area code & no.)	D. POLLUTANTS ANALYZED (list)

IX. CERTIFICATION

I certify under penalty of law that this document and all attachments were prepared under my direction or supervision in accordance with a system designed to assure that qualified personnel properly gather and evaluate the information submitted. Based on my inquiry of the person or persons who manage the system or those persons directly responsible for gathering the information, the information submitted is, to the best of my knowledge and belief, true, accurate, and complete. I am aware that there are significant penalties for submitting false information, including the possibility of fine and imprisonment for knowing violations.

A. NAME & OFFICIAL TITLE *(type or print)*	B. PHONE NO. *(area code & no.)*
C. SIGNATURE	D. DATE SIGNED

PLEASE PRINT OR TYPE IN THE UNSHADED AREAS ONLY. You may report some or all of this information on separate sheets *(use the same format)* instead of completing these pages.
SEE INSTRUCTIONS

EPA I.D. NUMBER *(copy from Item 1 of Form 1)*

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Approval expires 12-31-85

OUTFALL NO.

V. INTAKE AND EFFLUENT CHARACTERISTICS *(continued from page 3 of Form 2-C)*

PART A - You must provide the results of at least one analysis for every pollutant in this table. Complete one table for each outfall. See instructions for additional details.

1. POLLUTANT	2. EFFLUENT: a. MAXIMUM DAILY VALUE (1) CONCENTRATION	(2) MASS	b. MAXIMUM 30 DAY VALUE *(if available)* (1) CONCENTRATION	(2) MASS	c. LONG TERM AVRG. VALUE *(if available)* (1) CONCENTRATION	(2) MASS	d. NO. OF ANALYSES	3. UNITS *(specify if blank)* a. CONCENTRATION	b. MASS	4. INTAKE *(optional)* a. LONG TERM AVERAGE VALUE (1) CONCENTRATION	(2) MASS	b. NO. OF ANALYSES
a. Biochemical Oxygen Demand *(BOD)*												
b. Chemical Oxygen Demand *(COD)*												
c. Total Organic Carbon *(TOC)*												
d. Total Suspended Solids *(TSS)*												
e. Ammonia *(as N)*												
f. Flow	VALUE		VALUE		VALUE					VALUE		
g. Temperature *(winter)*	VALUE		VALUE		VALUE			°C		VALUE		
h. Temperature *(summer)*	VALUE		VALUE		VALUE			°C		VALUE		
i. pH	MINIMUM	MAXIMUM	MINIMUM	MAXIMUM				STANDARD UNITS				

PART B - Mark "X" in column 2-a for each pollutant you know or have reason to believe is present. Mark "X" in column 2-b for each pollutant you believe to be absent. If you mark column 2a for any pollutant which is limited either directly, or indirectly but expressly, in an effluent limitations guideline, you must provide the results of at least one analysis for that pollutant. For other pollutants for which you mark column 2a, you must provide quantitative data or an explanation of their presence in your discharge. Complete one table for each outfall. See the instructions for additional details and requirements.

1. POLLUTANT AND CAS NO. *(if available)*	2. MARK "X" a. BELIEVED PRESENT	b. BELIEVED ABSENT	3. EFFLUENT: a. MAXIMUM DAILY VALUE (1) CONCENTRATION	(2) MASS	b. MAXIMUM 30 DAY VALUE *(if available)* (1) CONCENTRATION	(2) MASS	c. LONG TERM AVRG. VALUE *(if available)* (1) CONCENTRATION	(2) MASS	d. NO. OF ANALYSES	4. UNITS a. CONCENTRATION	b. MASS	5. INTAKE *(optional)* a. LONG TERM AVERAGE VALUE (1) CONCENTRATION	(2) MASS	b. NO. OF ANALYSES
a. Bromide (24959-67-9)														
b. Chlorine, Total Residual														
c. Color														
d. Fecal Coliform														
e. Fluoride (16984-48-8)														
f. Nitrate–Nitrite *(as N)*														

CONTINUE ON REVERSE

ITEM V-B CONTINUED FROM FRONT

1. POLLUTANT AND CAS NO. *(if available)*	2. MARK "X"		3. EFFLUENT							4. UNITS		5. INTAKE *(optional)*		
	a. BELIEVED PRESENT	b. BELIEVED ABSENT	a. MAXIMUM DAILY VALUE (1) CONCENTRATION	(2) MASS	b. MAXIMUM 30 DAY VALUE *(if available)* (1) CONCENTRATION	(2) MASS	c. LONG TERM AVRG. VALUE *(if available)* (1) CONCENTRATION	(2) MASS	d. NO. OF ANALYSES	a. CONCENTRATION	b. MASS	a. LONG TERM AVERAGE VALUE (1) CONCENTRATION	(2) MASS	b. NO. OF ANALYSES
g. Nitrogen, Total Organic *(as N)*														
h. Oil and Grease														
i. Phosphorus *(as P)*, Total (7723-14-0)														
j. Radioactivity														
(1) Alpha, Total														
(2) Beta, Total														
(3) Radium, Total														
(4) Radium 226, Total														
k. Sulfate *(as SO_4)* (14808-79-8)														
l. Sulfide *(as S)*														
m. Sulfite *(as SO_3)* (14265-45-3)														
n. Surfactants														
o. Aluminum, Total (7429-90-5)														
p. Barium, Total (7440-39-3)														
q. Boron, Total (7440-42-8)														
r. Cobalt, Total (7440-48-4)														
s. Iron, Total (7439-89-6)														
t. Magnesium, Total (7439-95-4)														
u. Molybdenum, Total (7439-98-7)														
v. Manganese, Total (7439-96-5)														
w. Tin, Total (7440-31-5)														
x. Titanium, Total (7440-32-6)														

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EPA I.D. NUMBER *(copy from Item 1 of Form 1)*	OUTFALL NUMBER

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PART C - If you are a primary industry and this outfall contains process wastewater, refer to Table 2c-2 in the instructions to determine which of the GC/MS fractions you must test for. Mark "X" in column 2-a for all such GC/MS fractions that apply to your industry and for ALL toxic metals, cyanides, and total phenols. If you are not required to mark column 2-a *(secondary industries, nonprocess wastewater outfalls, and nonrequired GC/MS fractions)*, mark "X" in column 2-b for each pollutant you know or have reason to believe is present. Mark "X" in column 2-c for each pollutant you believe is absent. If you mark column 2a for any pollutant, you must provide the results of at least one analysis for that pollutant. If you mark column 2b for any pollutant, you must provide the results of at least one analysis for that pollutant if you know or have reason to believe it will be discharged in concentrations of 10 ppb or greater. If you mark column 2b for acrolein, acrylonitrile, 2,4 dinitrophenol, or 2-methyl-4, 6 dinitrophenol, you must provide the results of at least one analysis for each of these pollutants which you know or have reason to believe that you discharge in concentrations of 100 ppb or greater. Otherwise, for pollutants for which you mark column 2b, you must either submit at least one analysis or briefly describe the reasons the pollutant is expected to be discharged. Note that there are 7 pages to this part; please review each carefully. Complete one table *(all 7 pages)* for each outfall. See instructions for additional details and requirements.

1. POLLUTANT AND CAS NUMBER *(if available)*	2. MARK 'X'			3. EFFLUENT							4. UNITS		5. INTAKE *(optional)*		
	a. TESTING REQUIRED	b. BELIEVED PRESENT	c. BELIEVED ABSENT	a. MAXIMUM DAILY VALUE (1) CONCENTRATION	a. MAXIMUM DAILY VALUE (2) MASS	b. MAXIMUM 30 DAY VALUE *(if available)* (1) CONCENTRATION	b. MAXIMUM 30 DAY VALUE (2) MASS	c. LONG TERM AVRG. VALUE *(if available)* (1) CONCENTRATION	c. LONG TERM AVRG. VALUE (2) MASS	d. NO. OF ANALYSES	a. CONCENTRATION	b. MASS	a. LONG TERM AVERAGE VALUE (1) CONCENTRATION	a. LONG TERM AVERAGE VALUE (2) MASS	b. NO. OF ANALYSES
METALS, CYANIDE, AND TOTAL PHENOLS															
1M. Antimony, Total (7440-36-0)															
2M. Arsenic, Total (7440-38-2)															
3M. Beryllium, Total, 7440-41-7)															
4M. Cadmium, Total (7440-43-9)															
5M. Chromium, Total (7440-47-3)															
6M. Copper, Total (7440-50-8)															
7M. Lead, Total (7439-92-1)															
8M. Mercury, Total (7439-97-6)															
9M. Nickel, Total (7440-02-0)															
10M. Selenium, Total (7782-49-2)															
11M. Silver, Total (7440-22-4)															
12M. Thallium, Total (7440-28-0)															
13M. Zinc, Total (7440-66-6)															
14M. Cyanide, Total (57-12-5)															
15M. Phenols, Total															
DIOXIN															
2,3,7,8 Tetra-chlorodibenzo-P-Dioxin (1764-01-6)				DESCRIBE RESULTS											

CONTINUED FROM THE FRONT

1. POLLUTANT AND CAS NUMBER (if available)	2. MARK 'X'			3. EFFLUENT							4. UNITS		5. INTAKE (optional)		
	a. TESTING REQUIRED	b. BELIEVED PRESENT	c. BELIEVED ABSENT	a. MAXIMUM DAILY VALUE		b. MAXIMUM 30 DAY VALUE (if available)		c. LONG TERM AVRG. VALUE (if available)		d. NO. OF ANALYSES	a. CONCENTRATION	b. MASS	a. LONG TERM AVERAGE VALUE		b. NO. OF ANALYSES
				(1) CONCENTRATION	(2) MASS	(1) CONCENTRATION	(2) MASS	(1) CONCENTRATION	(2) MASS				(1) CONCENTRATION	(2) MASS	
GC/MS FRACTION — VOLATILE COMPOUNDS															
1V. Acrolein (107-02-8)															
2V. Acrylonitrile (107-13-1)															
3V. Benzene (71-43-2)															
4V. Bis (Chloromethyl) Ether (542-88-1)															
5V. Bromoform (75-25-2)															
6V. Carbon Tetrachloride (56-23-5)															
7V. Chlorobenzene (108-90-7)															
8V. Chlorodibromomethane (124-48-1)															
9V. Chloroethane (75-00-3)															
10V. 2-Chloroethylvinyl Ether (110-75-8)															
11V. Chloroform (67-66-3)															
12V. Dichlorobromomethane (75-27-4)															
13V. Dichlorodifluoromethane (75-71-8)															
14V. 1,1-Dichloroethane (75-34-3)															
15V. 1,2-Dichloroethane (107-06-2)															
16V. 1,1-Dichloroethylene (75-35-4)															
17V. 1,2-Dichloropropane (78-87-5)															
18V. 1,3-Dichloropropylene (542-75-6)															
19V. Ethylbenzene (100-41-4)															
20V. Methyl Bromide (74-83-9)															
21V. Methyl Chloride (74-87-3)															

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EPA I.D. NUMBER (copy from Item 1 of Form 1) | OUTFALL NUMBER

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Approval expires 7-31-88

1. POLLUTANT AND CAS NUMBER (if available)	2. MARK 'X' a. TESTING REQUIRED	b. BELIEVED PRESENT	c. BELIEVED ABSENT	3. EFFLUENT a. MAXIMUM DAILY VALUE (1) CONCENTRATION	(2) MASS	b. MAXIMUM 30 DAY VALUE (if available) (1) CONCENTRATION	(2) MASS	c. LONG TERM AVRG. VALUE (if available) (1) CONCENTRATION	(2) MASS	d. NO. OF ANALYSES	4. UNITS a. CONCENTRATION	b. MASS	5. INTAKE (optional) a. LONG TERM AVERAGE VALUE (1) CONCENTRATION	(2) MASS	b. NO. OF ANALYSES
GC/MS FRACTION — VOLATILE COMPOUNDS (continued)															
22V. Methylene Chloride (75-09-2)															
23V. 1,1,2,2-Tetrachloroethane (79-34-5)															
24V. Tetrachloroethylene (127-18-4)															
25V. Toluene (108-88-3)															
26V. 1,2-Trans-Dichloroethylene (156-60-5)															
27V. 1,1,1-Trichloroethane (71-55-6)															
28V. 1,1,2-Trichloroethane (79-00-5)															
29V. Trichloroethylene (79-01-6)															
30V. Trichlorofluoromethane (75-69-4)															
31V. Vinyl Chloride (75-01-4)															
GC/MS FRACTION — ACID COMPOUNDS															
1A. 2-Chlorophenol (95-57-8)															
2A. 2,4-Dichlorophenol (120-83-2)															
3A. 2,4-Dimethylphenol (105-67-9)															
4A. 4,6-Dinitro-O-Cresol (534-52-1)															
5A. 2,4-Dinitrophenol (51-28-5)															
6A. 2-Nitrophenol (88-75-5)															
7A. 4-Nitrophenol (100-02-7)															
8A. P-Chloro-M-Cresol (59-50-7)															
9A. Pentachlorophenol (87-86-5)															
10A. Phenol (108-95-2)															
11A. 2,4,6-Trichlorophenol (88-06-2)															

CONTINUE ON REVERSE

CONTINUED FROM THE FRONT

1. POLLUTANT AND CAS NUMBER (if available)	2. MARK 'X'			3. EFFLUENT							4. UNITS		5. INTAKE (optional)		
	a. TESTING REQUIRED	b. BELIEVED PRESENT	c. BELIEVED ABSENT	a. MAXIMUM DAILY VALUE		b. MAXIMUM 30 DAY VALUE (if available)		c. LONG TERM AVRG. VALUE (if available)		d. NO. OF ANALYSES	a. CONCENTRATION	b. MASS	a. LONG TERM AVERAGE VALUE		b. NO. OF ANALYSES
				(1) CONCENTRATION	(2) MASS	(1) CONCENTRATION	(2) MASS	(1) CONCENTRATION	(2) MASS				(1) CONCENTRATION	(2) MASS	
GC/MS FRACTION — BASE/NEUTRAL COMPOUNDS															
1B. Acenaphthene (83-32-9)															
2B. Acenaphtylene (208-96-8)															
3B. Anthracene (120-12-7)															
4B. Benzidine (92-87-5)															
5B. Benzo (a) Anthracene (56-55-3)															
6B. Benzo (a) Pyrene (50-32-8)															
7B. 3,4-Benzo-fluoranthene (205-99-2)															
8B. Benzo (ghi) Perylene (191-24-2)															
9B. Benzo (k) Fluoranthene (207-08-9)															
10B. Bis (2-Chloro-ethoxy) Methane (111-91-1)															
11B. Bis (2-Chloro-ethyl) Ether (111-44-4)															
12B. Bis (2-Chloroiso-propyl) Ether (102-60-1)															
13B. Bis (2-Ethyl-hexyl) Phthalate (117-81-7)															
14B. 4-Bromo-phenyl Phenyl Ether (101-55-3)															
15B. Butyl Benzyl Phthalate (85-68-7)															
16B. 2-Chloro-naphthalene (91-58-7)															
17B. 4-Chloro-phenyl Phenyl Ether (7005-72-3)															
18B. Chrysene (218-01-9)															
19B. Dibenzo (a,h) Anthracene (53-70-3)															
20B. 1,2-Dichloro-benzene (95-50-1)															
21B. 1,3-Dichloro-benzene (541-73-[illegible])															

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EPA I.D. NUMBER (copy from Item 1 of Form 1) | OUTFALL NUMBER

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1. POLLUTANT AND CAS NUMBER (if available)	2. MARK 'X'			3. EFFLUENT							4. UNITS		5. INTAKE (optional)		
	a. TESTING REQUIRED	b. BELIEVED PRESENT	c. BELIEVED ABSENT	a. MAXIMUM DAILY VALUE		b. MAXIMUM 30 DAY VALUE (if available)		c. LONG TERM AVRG. VALUE (if available)		d. NO. OF ANALYSES	a. CONCENTRATION	b. MASS	a. LONG TERM AVERAGE VALUE		b. NO. OF ANALYSES
				(1) CONCENTRATION	(2) MASS	(1) CONCENTRATION	(2) MASS	(1) CONCENTRATION	(2) MASS				(1) CONCENTRATION	(2) MASS	
GC/MS FRACTION — BASE/NEUTRAL COMPOUNDS (continued)															
22B. 1,4-Dichlorobenzene (106-46-7)															
23B. 3,3'-Dichlorobenzidine (91-94-1)															
24B. Diethyl Phthalate (84-66-2)															
25B. Dimethyl Phthalate (131-11-3)															
26B. Di-N-Butyl Phthalate (84-74-2)															
27B. 2,4-Dinitrotoluene (121-14-2)															
28B. 2,6-Dinitrotoluene (606-20-2)															
29B. Di-N-Octyl Phthalate (117-84-0)															
30B. 1,2-Diphenylhydrazine (as Azobenzene) (122-66-7)															
31B. Fluoranthene (206-44-0)															
32B. Fluorene (86-73-7)															
33B. Hexachlorobenzene (118-74-1)															
34B. Hexachlorobutadiene (87-68-3)															
35B. Hexachlorocyclopentadiene (77-47-4)															
36B. Hexachloroethane (67-72-1)															
37B. Indeno (1,2,3-cd) Pyrene (193-39-5)															
38B. Isophorone (78-59-1)															
39B. Naphthalene (91-20-3)															
40B. Nitrobenzene (98-95-3)															
41B. N-Nitrosodimethylamine (62-75-9)															
42B. N-Nitrosodi-N-Propylamine (621-64-7)															

CONTINUE ON REVERSE

CONTINUED FROM THE FRONT

1. POLLUTANT AND CAS NUMBER (if available)	2. MARK 'X'			3. EFFLUENT							4. UNITS		5. INTAKE (optional)		
	a. TESTING REQUIRED	b. BELIEVED PRESENT	c. BELIEVED ABSENT	a. MAXIMUM DAILY VALUE		b. MAXIMUM 30 DAY VALUE (if available)		c. LONG TERM AVRG. VALUE (if available)		d. NO. OF ANALYSES	a. CONCENTRATION	b. MASS	a. LONG TERM AVERAGE VALUE		b. NO. OF ANALYSES
				(1) CONCENTRATION	(2) MASS	(1) CONCENTRATION	(2) MASS	(1) CONCENTRATION	(2) MASS				(1) CONCENTRATION	(2) MASS	
GC/MS FRACTION — BASE/NEUTRAL COMPOUNDS (continued)															
43B. N-Nitrosodiphenylamine (86-30-6)															
44B. Phenanthrene (85-01-8)															
45B. Pyrene (129-00-0)															
46B. 1,2,4-Trichlorobenzene (120-82-1)															
GC/MS FRACTION — PESTICIDES															
1P. Aldrin (309-00-2)															
2P. α-BHC (319-84-6)															
3P. β-BHC (319-85-7)															
4P. γ-BHC (58-89-9)															
5P. δ-BHC (319-86-8)															
6P. Chlordane (57-74-9)															
7P. 4,4'-DDT (50-29-3)															
8P. 4,4'-DDE (72-55-9)															
9P. 4,4'-DDD (72-54-8)															
10P. Dieldrin (60-57-1)															
11P. α-Endosulfan (115-29-7)															
12P. β-Endosulfan (115-29-7)															
13P. Endosulfan Sulfate (1031-07-8)															
14P. Endrin (72-20-8)															
15P. Endrin Aldehyde (7421-93-4)															
16P. Heptachlor (76-44-8)															

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EPA I.D. NUMBER *(copy from Item 1 of Form 1)* | OUTFALL NUMBER

Form Approved
OMB No. 2040-0086
Approval expires 7-31-88

1. POLLUTANT AND CAS NUMBER *(if available)*	2. MARK 'X'			3. EFFLUENT							4. UNITS		5. INTAKE *(optional)*		
	a. TESTING REQUIRED	b. BELIEVED PRESENT	c. BELIEVED ABSENT	a. MAXIMUM DAILY VALUE (1) CONCENTRATION	(2) MASS	b. MAXIMUM 30 DAY VALUE *(if available)* (1) CONCENTRATION	(2) MASS	c. LONG TERM AVRG. VALUE *(if available)* (1) CONCENTRATION	(2) MASS	d. NO. OF ANALYSES	a. CONCENTRATION	b. MASS	a. LONG TERM AVERAGE VALUE (1) CONCENTRATION	(2) MASS	b. NO. OF ANALYSES
GC/MS FRACTION — PESTICIDES *(continued)*															
17P. Heptachlor Epoxide (1024-57-3)															
18P. PCB-1242 (53469-21-9)															
19P. PCB-1254 (11097-69-1)															
20P. PCB-1221 (11104-28-2)															
21P. PCB-1232 (11141-16-5)															
22P. PCB-1248 (12672-29-6)															
23P. PCB-1260 (11096-82-5)															
24P. PCB-1016 (12674-11-2)															
25P. Toxaphene (8001-35-2)															

EPA Form 3510-2C (Rev. 2-85)

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United States
Environmental Protection
Agency

Office of Water
Enforcement and Permits
Washington, DC 20460

EPA Form 3510-2D
August 1990

Permits Division

EPA

Application Form 2D —

New Sources and New Dischargers:

Application for Permit to Discharge Process Wastewater

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Form 2D Instructions

Form 2D must be completed in conjunction with EPA Form 3510-1 (Form 1).

This form must be completed by all applicants who checked "yes" to Item II-D in Application Form 1. However, facilities which discharge only nonprocess wastewater that is not regulated by an effluent limitations guideline or new source performance standard may use EPA Form 3510-2E (Form 2E). Educational, medical, and commercial chemical laboratories should use this form or EPA Form 3510-2C (Form 2C). To further determine if you are a new source or a new discharger, see §122.2 and §122.29. This form should not be used for discharges of stormwater runoff.

Public Availability of Submitted Information

You may not claim as confidential any information required by this form or Form 1, whether the information is reported on the forms or in an attachment. Section 402(j) of the CWA requires that all permit applications shall be available to the public. This information will therefore be made available to the public upon request.

You may claim as confidential any information you submit to EPA which goes beyond that required by this form and Form 1. Confidentiality claims for effluent data must be denied. If you do not assert a claim of confidentiality at the time of submitting the information, EPA may make the information public without further notice. Claims of confidentiality will be handled in accordance with EPA's business confidentiality regulations in 40 CFR Part 2.

Completeness

Your application will not be considered complete unless you answer every question on this form and on Form 1 (except as instructed below). If an item does not apply to you, enter "NA" (for "not applicable") to show that you considered the question.

Followup Requirements

Although you are now required to submit estimated data on this form (Form 2D), please note that no later than two years after you begin discharging from the proposed facility, you must complete and submit Items V and VI of NPDES application Form 2C (EPA Form 3510-2C). How-ever, you need not complete those portions of Item V requiring tests which you have already performed under the discharge monitoring requirements of your NPDES permit. In addition, the permitting authority may waive requirements of Items V-A and VI if the permittee makes the demonstrations required under 40 CFR §122.22(g)(7)(i)(B) and 122.21(g)(9).

Definitions

All significant terms used in these instructions and in the form are defined in the glossary found in the General Instructions which accompany Form 1.

Item I

You may use the map you provided for Item XI of Form 1 to determine the latitude and longitude (to the nearest 15 seconds) of each of your outfalls and the name of the receiving water. You should name all waters to which discharge is made and which flow into significant receiving waters. For example, if the discharge is made to a ditch which flows into an unnamed tributary which in turn flows into a named river, you should provide the name or description (if no name is available) of the ditch, the tributary, and the river.

Item II

This item requires your best estimate of the date on which your facility or new outfall will begin to discharge.

Item III-A

List all outfalls, their source (operations contributing to the flow), and estimate an average flow from each source. Briefly describe the planned treatment for these wastewaters prior to discharge. Also describe the ultimate disposal of any solid or liquid wastes not discharged. You should describe the treatment in either a narrative form or list the proper code for the treatment unit from a list provided in Table 2D-1.

Item III-B

An example of an acceptable line drawing appears in Figure 2D-1 to these instructions. The line drawing should show the route taken by water in your proposed facility from intake to discharge. Show all sources of wastewater, including process and production areas, sanitary flows, cooling water, and storm water runoff. You may group similar operations into a single unit, labeled to correspond to the more detailed listing in Item III-A. The water balance should show estimates of anticipated average flows. Show all significant losses of water to production, atmosphere, and discharge. You should use your best estimates.

Item III-C

Fill in every applicable column in this item for each source of intermittent or seasonal discharge. Base your answers on your best estimate. A discharge is intermittent if it occurs with interruptions during the operating hours of the facility. Discharges caused by routine maintenance shutdowns, process changes, or other similar activities are not considered to be intermittent. A discharge is seasonal if it occurs only during certain parts of the year. The reported flow rate is the highest daily value and should be measured in gallons per day. Maximum total volume means the total volume of any one discharge within 24 hours and is measured in units such as gallons.

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Item IV

"Production" in this question refers to those goods which the proposed facility will produce, not to "wastewater" production. This information is only necessary where production-based new source performance standards (NSPS) or effluent guidelines apply to your facility. Your estimated production figures should be based on a realistic projection of actual daily production level (not design capacity) for each of the first three operating years of the facility. This estimate must be a long-term-average estimate (e.g., average production on an annual basis). If production will vary depending on long-term shifts in operating schedule or capacity, the applicant may report alternate production estimates and the basis for the alternate estimates.

If known, report quantities in the units of measurement used in the applicable NSPS or effluent guideline. For example, if the applicable NSPS is expressed as "grams of pollutant discharged per kilogram of unit production," then report maximum "Quantity Per Day" in kilograms. If you do not know whether any NSPS or effluent guideline applies to your facility, report quantities in any unit of measurement known to you. If an effluent guideline or NSPS specifies a method for estimating production, that method must be followed.

There is no need to conduct new studies to obtain these figures, only data already on hand are required. You are not required to indicate how the reported information was calculated.

Items V-A, B, and C

These items require you to estimate and report data on the pollutants expected to be discharged from each of your outfalls. Where there is more than one outfall, you should submit a separate Item V for each outfall. For Part C only a list is required. Sampling and analysis are not required at this time. If, however, data from such analyses are available, then those data should be reported. Each part of this item addresses a different set of pollutants or parameters and must be completed in accordance with the specific instructions for that part. The following are the general and specific instructions for Items V-A through V-C.

Item V — General Instructions

Each part of this item requires you to provide an estimated maximum daily and average daily value for each pollutant or parameter listed (see Table 2D-2), according to the specific instructions below. The source of the data is also required.

For Parts A through C, base your determination of whether a pollutant will be present in your discharge on your knowledge of the proposed facility's raw materials, maintenance chemicals, intermediate and final products, byproducts, and any analyses of your effluent or of any similar effluent. You may also provide the determination and the estimates based on available in-house or contractor's engineering reports or any other studies performed on the proposed facility (see Item VI of the form). If you expect a pollutant to be present solely as a result of its presence in your intake water, please state this information on the form.

Please note that no later than 2 years after you begin discharging from the proposed facility, you must complete and submit Items V and VI of NPDES application Form 2C (followup data).

Reporting Intake Data. You are not required to report pollutants or parameters present in intake water unless you wish to demonstrate your eligibility for a "net" effluent limitation for these pollutants or parameters, that is, an effluent limitation adjusted to provide allowance for the pollutants or parameters present in your intake water. If you wish to obtain credits for pollutants or parameters present in your intake water, please insert a separate sheet, with a short statement of why you believe you are eligible (see §122.45 (g)), under Item VII (Other Information). You will then be contacted by the permitting authority for further instructions.

All estimated pollutant or parameter levels must be reported as concentration and as total mass, except for discharge flow, temperature, and pH. Total mass is the total weight of pollutants or parameters discharged over a day.

Use the following abbreviations for units:

Concentration	Mass
ppm .... parts per million	lbs...... pounds
mg/1 ... milligrams per liter	ton ..... tons (English tons)
ppb ..... parts per billion	mg ..... milligrams
Ug/1 ... micrograms per liter	g .... grams
kg ...... kilograms	T .... Tonnes (metric tons)

Source

In providing the estimates, use the codes in the following table to indicate the source of such information in column 4 of Parts V — A and — B.

	Code
Engineering study	1
Actual data from pilot plants	1
Estimates from other engineering studies	2
Data from other similar plants	3
Best professional estimates	4
Others	specify on the form

Item V-A

Estimates of data on pollutants or parameters in Group A must be reported by all applicants for all outfalls, including outfalls

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containing only noncontact cooling water or nonprocess wastewater

To request a waiver from reporting any of these pollutants or parameters, the applicant must submit to the permitting authority a written request specifying which pollutants or parameters should be waived and the reasons for requesting such a waiver. This request should be submitted to the permitting authority before or with the permit application. The permitting authority may waive the requirements for information about these pollutants or parameters if he or she determines that less stringent reporting requirements are adequate to support issuance of the permit. No extensive documentation will normally be needed, but the applicant should contact the permitting authority if she or he wishes to receive instructions on what his or her particular request should contain.

Item V-B

Estimates of data on pollutants in Group B must be reported by all applicants for all outfalls, including outfalls containing only noncontact cooling water or nonprocess wastewater. You are merely required to report estimates for those pollutants which you know or have reason to believe will be discharged or which are limited directly by an effluent limitations guideline (or NSPS) or indirectly through promulgated limitations on an indicator pollutant. The priority pollutants in Group B are divided into the following three sections.

1) Metal toxic pollutants, total cyanide, and total phenols
2) 2,3,7,8-Tetrachlorodibenzo-P-Dioxin (TCDD) (CAS # 1764-016)
3) Organic Toxic Pollutants (Gas Chromatography/-Mass Spectrometry Fractions)
   a) Volatile compounds
   b) Acid compounds
   c) Base/neutral compounds
   d) Pesticides

For pollutants listed in Sections 1 and 3, you must report estimates as instructed above.

For Section 2, you are required to report that TCDD may be discharged if you will use or manufacture one of the following compounds, or if you know or have reason to believe that TCDD is or may be present in an effluent:

A. 2,4,5-trichlorophenoxy acetic acid (2,4,5-T) (CAS # 93-765);
B. 2-(2,4,5-trichlorophenoxy) propanoic acid (Silvex, 2,4, 5TP) (CAS # 93-72-1);
C. 2-(2,4,5-trichlorophenoxy) ethyl 2,2-dichloropropionate (Erbon) (CAS # 136-25-4);
D. 0,0-dimethyl 0-(2,4,5-trichlorophenyl) phosphorothioate (Ronnel) (CAS # 299-84-3);
E. 2,4,5-trichlorophenol (TCP)(CAS # 95-95-4), or
F. Hexachlorophene (HCP) (CAS # 70-30-4)

Small Business Exemption

If you are a "small business," you are exempt from the reporting requirement for Item V-B (section 3). You may qualify as a "small business" if you fit one of the following definitions:

1) Your expected gross sales will total less than $100,000 per year for the next three years, or
2) in the case of coal mines, your average production will be less than 100,000 tons of coal per year.

If you are a "small business," you may submit projected sales or production figures to qualify for this exemption. The sales or production figures you submit must be for the facility which is the source of the discharge. The data should not be limited only to production or sales for the process or processes which contribute to the discharge, unless those are the only processes at your facility. For sales data, where intracorporate transfers of goods and services are involved, the transfer price per unit should approximate market prices for those goods and services as closely as possible. If necessary, you may index your sales figures to the second quarter of 1980 to demonstrate your eligibility for a small business exemption. This may be done by using the gross national product price deflator (second quarter of 1980 = 100), an index available in "National Income and Product Accounts of the United States" (Department of Commerce, Bureau of Economic Analysis).

The small business exemption applies to the GC/MS fractions (Section 3) of Item V-B only. Even if you are eligible for a small business exemption, you are still required to provide information on metals, cyanide, total phenols, and dioxin in Item V-B, as well as all of Items V-A and C.

Item V-C

List any pollutants in Table 2D-3 that you believe will be present in any outfalls and briefly explain why you believe they will be present. No estimate of the pollutant's quantity is required, unless you already have quantitative data.

Note: The discharge of pollutants listed in Table 2D-4 may subject you to the additional requirements of section 311 of the CWA (Oil and Hazardous Substance Liability). These requirements are not administered through the NPDES program. However, if you wish an exemption under 40 CFR 117.12(a)(2) from these requirements, attach additional sheets of paper to this form providing the following information:

A. The substance and the amount of each substance which may be discharged;

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B The origin and source of the discharge of the substance.

C The treatment which is to be provided for the discharge by

1. An onsite treatment system separate from any treatment system which will treat your normal discharge.
2. A treatment system designed to treat your normal discharge and which is additionally capable of treating the amount of the substance identified under paragraph 1 above, or
3. Any combination of the above.

An exemption from the section 311 reporting requirements pursuant to 40 CFR Part 117 for pollutants on Table 2D does not exempt you from the section 402 reporting requirements pursuant to 40 CFR Part 122 (Item V-C) for pollutants listed on Table 2D-3.

For further information on exclusions from Section 311, see 40 CFR Section 117.12(a)(2) and (c), or contact your EPA Regional office (Table 1 in the Form 1 instructions).

Item VI-A

If an engineering study was conducted, check the box labeled "report available." If no study was done, check the box labeled "no report."

Item VI-B

Report the name and location of any existing plant(s) which (to the best of your knowledge) resembles your planned operation with respect to items produced, production process, wastewater constituents, or wastewater treatment. No studies need be conducted to respond to this item. Only data which are already available need be submitted.

This information will be used to inform the permit writer of appropriate treatment methods and their associated permit conditions and limits.

Item VII

A space is provided for additional information which you believe would be useful in setting permit limits, such as additional sampling. Any response is optional.

Item VIII

The Clean Water Act provides for severe penalties for submitting false information on this application form.

Section 309(c)(2) of the Clean Water Act provides that "Any person who knowingly makes any false statement, representation, or certification in any application, . . . shall upon conviction, be punished by a fine of no more than $10,000 or by imprisonment for not more than six months, or both."

40 CFR Part 122.22 Requires the Certification To Be Signed as Follows:

A. For a corporation: by a responsible corporate officer.

A responsible corporate officer means (i) a president, secretary, treasurer, or vice-president of the corporation in charge of a principal business function, or any other person who performs similar policy or decision-making functions for the corporation, or (ii) the manager of one or more manufacturing, production or operating facilities employing more than 250 persons or having gross annual sales or expenditures exceeding $25,000,000 (in second-quarter 1980 dollars), if authority to sign documents has been assigned or delegated to the manager in accordance with corporate procedures.

B. For a partnership or sole proprietorship: by a general partner or the proprietor, respectively, or

C. For a municipality, State, Federal, or other public agency: by either a principal executive officer or ranking elected official. For purposes of this section, a principal executive officer of a Federal agency includes (i) the chief executive officer of the agency, or (ii) a senior executive officer having responsibility for the overall operations of a principal geographic unit of the agency (e.g., Regional Administrators of EPA).

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PHYSICAL TREATMENT PROCESSES

1—A ....Ammonia Stripping
1—B ....Dialysis
1—C ....Diatomaceous Earth Filtration
1—D ....Distillation
1—E ....Electrodialysis
1—F ....Evaporation
1—G ....Flocculation
1—H ....Flotation
1—I ....Foam Fractionation
1—J ....Freezing
1—K ....Gas-Phase Separation
1—L ....Grinding *(Comminutors)*
1—M ....Grit Removal
1—N ....Microstraining
1—O ....Mixing
1—P ....Moving Bed Filters
1—Q ....Multimedia Filtration
1—R ....Rapid Sand Filtration
1—S ....Reverse Osmosis *(Hyperfiltration)*
1—T ....Screening
1—U ....Sedimentation *(Settling)*
1—V ....Slow Sand Filtration
1—W ....Solvent Extraction
1—X ....Sorption

CHEMICAL TREATMENT PROCESSES

2—A ....Carbon Adsorption
2—B ....Chemical Oxidation
2—C ....Chemical Precipitation
2—D ....Coagulation
2—E ....Dechlorination
2—F ....Disinfection *(Chlorine)*
2—G ....Disinfection *(Ozone)*
2—H ....Disinfection *(Other)*
2—I ....Electrochemical Treatment
2—J ....Ion Exchange
2—K ....Neutralization
2—L ....Reduction

BIOLOGICAL TREATMENT PROCESSES

3—A ....Activated Sludge
3—B ....Aerated Lagoons
3—C ....Anaerobic Treatment
3—D ....Nitrification-Denitrification
3—E ....Preaeration
3—F ....Spray Irrigation/Land Application
3—G ....Stabilization Ponds
3—H ....Trickling Filtration

OTHER PROCESSES

4—A ....Discharge to Surface Water
4—B ....Ocean Discharge Through Outfall
4—C ....Reuse/Recycle of Treated Effluent
4—D ....Underground Injection

SLUDGE TREATMENT AND DISPOSAL PROCESSES

5—A ....Aerobic Digestion
5—B ....Anaerobic Digestion
5—C ....Belt Filtration
5—D ....Centrifugation
5—E ....Chemical Conditioning
5—F ....Chlorine Treatment
5—G ....Composting
5—H ....Drying Beds
5—I ....Elutriation
5—J ....Flotation Thickening
5—K ....Freezing
5—L ....Gravity Thickening
5—M ....Heat Drying
5—N ....Heat Treatment
5—O ....Incineration
5—P ....Land Application
5—Q ....Landfill
5—R ....Pressure Filtration
5—S ....Pyrolysis
5—T ....Sludge Lagoons
5—U ....Vacuum Filtration
5—V ....Vibration
5—W ....Wet Oxidation

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Table 2D-1

GROUP A

Biochemical Oxygen Demand (BOD)
Chemical Oxygen Demand (COD)
Total Organic Carbon (TOC)
Total Suspended Solids (TSS)
Flow
Ammonia (as N)
Temperature (winter)
Temperature (summer)
pH

GROUP B

Bromide
Total Residual Chlorine
Color
Fecal Coliform
Fluoride
Nitrate-Nitrite (as N)
Oil and Grease
Phosphorus (as P) Total
Radioactivity
(1) Alpha, Total
(2) Beta, Total
(3) Radium, Total
(4) Radium 226, Total
Sulfate (as SO_4)
Sulfide (as S)
Sulfite (as SO_3)
Surfactants
Aluminum, Total
Barium, Total
Boron, Total
Cobalt, Total
Iron, Total
Magnesium, Total
Molybdenum, Total
Manganese, Total
Tin, Total
Titanium, Total

Section 1

Antimony, Total
Beryllium, Total
Chromium, Total
Lead, Total
Nickel, Total
Silver, Total
Zinc, Total
Phenols, Total
Arsenic, Total
Cadmium, Total
Copper, Total
Mercury, Total
Selenium, Total
Thallium, Total
Cyanide, Total

Section 2

2,3,7,8,Tetrachlorodibenzo-P-Dioxin

Section 3

GC/MS FRACTION* — VOLATILE COMPOUNDS

Acrolein
Benzene
Carbon Tetrachloride
Chlorodibramomethane
2-Chloroethylvinyl Ether
Dichlorobomomethane
1,2-Dichloroethane
1,2-Dichloropropane
Ethylbenzene
Methyl Chloride
1,1,2,2-Tetrachloroethane
Toluene
1,1,1-Trichloroethane
Trichloroethylene
Vinyl Chloride
Acrylonitirle
Bromoform
Chlorobenzene
Chloroethane
Chloroform
1,1-Dichloroethane
1,1-Dichloroethane
1,3-Dichloropropylene
Methyl Bromide
Methylene chloroethane
Tetrachloroethylene
1,2-Trans-Dichloroethylene
1,1,2-Trichloroethane

Table 2D-2

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GS/MS FRACTION — ACID COMPOUNDS

2-Chlorophenol
2,4-Dimethylphenol
2,4-Dinitro-phenol
4-Nitrophenol
Pentachlorophenol
2,4,6-Trichlorophenol
2,4-Dichlorophenol
4,6-Dinitro-O-Cresol
2-Nitrophenol
P-Chloro-M-Cresol
Phenol

GC/MS FRACTION — BASE/NEUTRAL COMPOUNDS

Acenaphthene
Anthracene
Benzo (a) Anthracene
3,5-Benzofluoranthene
Benzo (k) Fluoranthene
Bis (2-Chloroethyl) Ether Bis
Bis (2-Ethylhexyl) Phthalate
Butyl Benzyl Phthalate
4-Chlorophenyl Phenyl Ether
Dibenzo (a, h) Anthracene
1,3-Dichlorobenzene
3,3-Dichlorobenzidine
Dimethyl Phthalate
2,4-Dinitrotoluene
Di-N-Octyl Phthalate
Fluoranthene
Hexachlorobenzene
Hexachlorocyclopentadiene
Indeno (1,2,3-cd) Pyrene
Naphthalene
N-Nitro-sodimethylamine
N-Nitro-sodiphenylamine
Pyrene
Acenaphtylene
Benzidine
Benzo (a) Pyrene
Benzo (ghi) Perylene
Bis (2 Chloroethoxy) Methane
(2-Chloroisopropyl) Ether
4-Bromophenyl Phenyl Ether
2-Chloronaphthalene
Chrysene
1,2-Dichlorobenzene
1,4-Dichlorobenzene
Diethyl Phthalate
Di-N-Butyl Phthalate
2,6-Dinitrotoluene
1,2, Diphenylhydrazine (as Azobenzen)
Fluorene
Hexachlorobutadiene
Hexachloroethane
Isophorone
Nitrobenzene
N-Nitrosodi-N-Propylamine
Phenanthrene
1,2,4-Trichlorobenzene

GC/MS FRACTION — PESTICIDES

Aldrin
Alpha-BHC
Beta-BHC
4,4' DDT
4,4'-DDD
Alpha-Endosulfan
Endosulfan Sulfate
Endrin Aldehyde
Heptachlor Epoxide
PCB-1254
PCB-1232
PCB-1260
Toxaphene
Gamma-BHC
Delta-BHC
Chlordane
4,4' DDE
Dieldrin
Beta-Endosulfan
Endrin
Heptachlor
PCB-1242
PCB-1221
PCB-1248
PCB-1016

*fractions defined in 40 CFR Part 136

Table 2D-2

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TOXIC POLLUTANTS AND HAZARDOUS SUBSTANCES REQUIRED TO BE IDENTIFIED BY APPLICANTS IF EXPECTED TO BE PRESENT

TOXIC POLLUTANT

Asbestos

HAZARDOUS SUBSTANCES

Aceltaldehyde
Allyl alcohol
Allyl chloride
Amyl acetate
Aniline
Benzonitrile
Benzyl chloride
Butyl acetate
Butylamine
Captan
Carbaryl
Carbofuran
Carbon disulfide
Chlorpyrifos
Coumpahos
Cresol
Crotonaldehyde
Cyclohexane
2,4-D (2,4-Dichlorophinoxyacetic acid)
Diazinon
Dicamba
Dichlobenil
Dichlone
2,2 Dichloropropionic acid
Dichlorvos
Diethyl amine
Dimethyl amine
Dintrobenzene
Diquat
Disulfoton
Diuron
Epichlorohydrin
Ethion
Ethylene diamine
Formaldehyde
Furfural
Guthion
Isoprene
Isopropanolamine dodecylbenzenesulfonate
Kelthane
Kepone
Malathion
Mercaptodimethur
Methoxychlor

HAZARDOUS SUBSTANCES

Methyl mercaptan
Methyl methacrylate
Methyl parathion
Mevinphos
Mexacarbate
Monoethyl amine
Monomethyl amine
Naled
Naphthenic acid
Nitrotoluene
Parathion
Phenolsulfonate
Phosgene
Propargite
Propylene oxide
Pyrethrins
Quinoline
Resorcinol
Strontium
Strychnine
2,4,5-T (2,4,5-Trichlorophenoxyacetic acid)
TDE (Tetrochlorodiphenyl ethane)
2,4,5-TP [2-(2,4,5-Trichlorophenoxy) propanic acid]
Trichlorofon
Triethanolamine dodecylbenzenesulfonate
Triethylamine
Uranium
Vanadium
Vinyl acetate
Xylene
Xylenol
Zirconium

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TABLE 2D-3

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HAZARDOUS SUBSTANCES

Acetaldehyde
Acetic acid
Acetic anhydride
Acetone cyanohydrin
Acetyl bromide
Acetyl chloride
Acrolein
Acrylonitrile
Adipic acid
Aldrin
Allyl alcohol
Allyl chloride
Aluminum sulfate
Ammmonia
Ammonium acetate
Ammonium benzoate
Ammonium bicarbonate
Ammonium bichromate
Ammonium bifluoride
Ammonium bisulfite
Ammonium carbamate
Ammonium carbonate
Ammonium chloride
Ammonium chromate
Ammonium citrate
Ammonium flouroborate
Ammonium fluoride
Ammonium hydroxide
Ammonium oxalate
Ammonium silicofluoride
Ammonium sulfamate
Ammonium sulfide
Ammonium sulfite
Ammonium tartrate
Ammonium thiocyanate
Ammonium thiosulfate
Amyl acetate
Aniline
Antimony pentachloride
Antimony potassium tartrate
Antimony tribromide
Antimony trichloride
Antimony trifluoride
Antimony trioxide
Arsenic disulfide
Arsenic trichloride
Arsenic trioxide
Arsenic trisulfide
Barium cyanide
Benzene
Benzoic acid
Benzonitrite
Benzoyl chloride
Benzyl chloride
Beryllium chloride
Beryllium fluoride
Beryllium nitrate
Butylacetate
n-Butylphthalate
Butylamine
Butyric acid
Cadmium acetate
Cadmium bromide
Cadmium chloride
Calcium arsenate
Calcium arsenite
Calcium carbide
Calcium chromate
Calcium cyanide
Calcium dodecylbenzenesulfonate
Calcium hypochlorite
Captan
Carbaryl
Carbofuran
Carbon disulfide
Carbon tetrachloride
Chlordane
Chlorine
Chlorobenzene
Chloroform
Chloropyrifos
Chlorosulfonic acid
Chromic acetate
Chromic acid
Chromic sulfate
Chromous chloride
Cobaltous bromide
Cobaltous formate
Cobaltous sulfamate
Coumaphos
Cresol
Crotonaldehyde
Cupric acetate
Cupric acetoarsenite
Cupric chloride
Cupric nitrate
Cupric oxalate
Cupric sulfate
Cupric sulfate ammoniated
Cupric tartrate
Cyanogen chloride
Cyclohexane
2,4-D acid
(2,4-Dichlorophenoxyacetic acid)
2,4-D esters
(2,4-Dichlorophenoxyacetic acid esters)
DDT
Diazinon
Dicamba
Dichlobenil
Dichlone
Dichlorobenzene
Dichloropropane
Dichloropropene
Dichloropropene-Dichloropropane mix
2.2-Dichloropropionic acid
Dichlorvos
Dieldrin
Diethylamine
Dimethylamine
Dinitrobenzene
Dinitrophenol
Dinitrotoluene
Diquat
Disulfoton
Diuron
Dodecylbenzesulfonic acid
Endosulfan
Endrin
Epichlorohydrin
Ethion
Ethylbenzene
Ethylenediamine
Ethylene dibromide
Ethylene dichloride
Ethylene diaminetetracetic acid (EDTA)
Ferric ammonium citrate
Ferric ammonium oxalate
Ferric chloride
Ferric fluoride
Ferric nitrate
Ferric sulfate
Ferrous chloride
Ferrous sulfate
Formaldehyde
Formic acid
Fumaric acid
Furfural
Guthion
Heptachlor
Hexachlorocyclopentadiene
Hydrochloric acid
Hydrofluoric acid
Hydrogen cyanide
Hydrogen sulfide
Isoprene
Isopropanolamine dodecylbenzenesulfonate
Kelthane
Kepone
Lead acetate
Lead arsenate
Lead chloride
Lead fluoborate
Lead fluorite
Lead iodide
Lead nitrate
Lead stearate
Lead sulfate
Lead sulfide
Lead thiocyanate
Lindane
Lithium chromate
Malathion

TABLE 2D-4

HAZARDOUS SUBSTANCES *(Continued)*

Maleic acid
Maleic anhydride
Mercaptodimethur
Mercuric cyanide
Mercuric nitrate
Mercuric sulfate
Mercuric thiocyanate
Mercurous nitrate
Methoxychlor
Methyl mercaptan
Methyl methacrylate
Methyl parathion
Mevinphos
Mexacarbate
Monoethylamine
Monomethylamine
Naled
Naphthalene
Naphthenic acid
Nickel ammonium sulfate
Nickel chloride
Nickel hydroxide
Nickel nitrate
Nickel sulfate
Nitric acid
Nitrobenezene
Nitrogen dioxide
Nitrophenil
Nitrotoluene
Paraformaldehyde
Parathion
Pentachlorophenol
Phenol
Phosoene
Phosphoric acid
Phosphorus
Phosphorus oxychloride
Phosphorus pentasulfide
Phosphorus trichloride
Polychlorinated biphenyls (PCB)
Potassium arsenate
Potassium arsenite
Potassium bichromate
Potassium cyanide
Potassium hydroxide
Potassium permanganate
Propargite
Propionic acid
Propionic anhydride
Propylene oxide
Pyrethrins
Quinoline
Resorcinol
Selenium oxide
Silver nitrate
Sodium
Sodium arsenate
Sodium arsenite
Sodium bichromate
Sodium bifluoride
Sodium bisulfite
Sodium chromate
Sodium cyanide
Sodium dodecylbenzenesulfonate
Sodium fluoride
Sodium hydrosulfide
Sodium hydroxide
Sodium hypochlorite
Sodium methylate
Sodium nitrate
Sodium phospate (dibasic)
Sodium phosphate (tribasic)
Sodium selenite
Strontium chromate
Strychnine
Styrene
Sulfuric acid
Sulfur monochloride
2,4,5-T acid (2,4,5-Trichlorophenoxy acetic acid)
2,4,5-Tamines (2,4,5-Trichlorophenoxy acetic acid amines)
2,4,5-T esters (2,4,5-Trichlorophenoxy acetic acid esters)
2,4,5-T salts (2,4,5-Trichlorophenoxy acetic acid salts)
2,4,5-TP acid (2,4,5-Trichlorophenoxy propanoic acid)
2,4,5-TP acid esters (2,4,5-Trichlorophenoxy propanoic acid esters)
TDE (Tetrachlorodiphenyl ethane)
Tetraethyl lead
Tetraethyl pyrophosphate
Thallium sulfate
Toluene
Toxaphene
Trichlorofon
Trichloroethylene
Trichlorophenol
Triethanolamine dodecylbenzenesulfonate
Triethylamine
Trimethylamine
Uranyl acetate
Uranyl nitrate
Vanadium pentoxide
Vanadyl sulfate
Vinyl acetate
Vinylidene chloride
Xylene
Xylenol
Zinc acetate
Zinc ammonium chloride
Zinc borate
Zinc bromide
Zinc carbonate
Zinc chloride
Zinc cyanide
Zinc fluoride
Zinc formate
Zinc hydrosulfite
Zinc nitrate
Zinc phenolsulfonate
Zinc phosphide
Zinc silicofluoride
Zinc sulfate
Zirconium nitrate
Zirconium potassium fluoride
Zirconium sulfate
Zirconium tetrachloride

Table 2D-4

LINE DRAWING

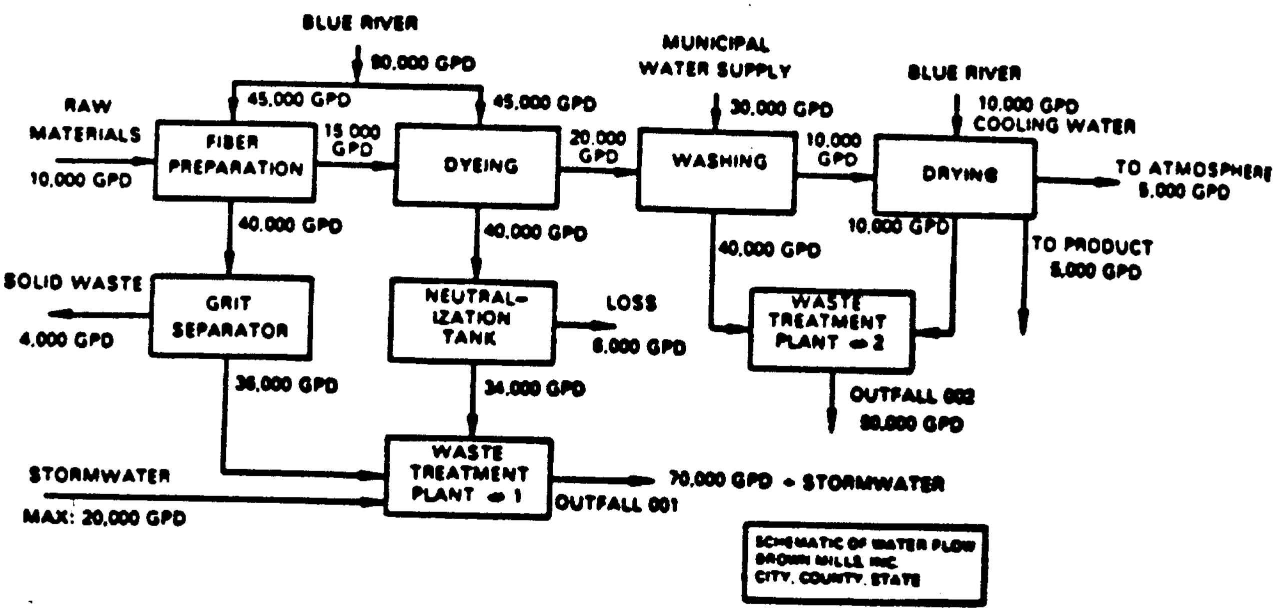

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Figure 2D-1

Form Approved OMB No. 2040-0086 Approval Expires 5-31-92

Please type or print in the unshaded areas only

EPA ID Number (copy from Item 1 of Form 1)

Form 2D NPDES

EPA

New Sources and New Dischargers Application for Permit to Discharge Process Wastewater

I. Outfall Location

For each outfall, list the latitude and longitude, and the name of the receiving water

Outfall Number (list)	Latitude Deg	Latitude Min	Latitude Sec	Longitude Deg	Longitude Min	Longitude Sec	Receiving Water (name)

II. Discharge Date (When do you expect to begin discharging?)

III. Flows, Sources of Pollution, and Treatment Technologies

A. For each outfall, provide a description of (1) All operations contributing wastewater to the effluent, including process wastewater, sanitary wastewater, cooling water, and stormwater runoff, (2) The average flow contributed by each operation, and (3) The treatment received by the wastewater. Continue on additional sheets if necessary

Outfall Number	1. Operations Contributing Flow (list)	2. Average Flow (include units)	3. Treatment (Description or List Codes from Table 2D-1)

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B Attach a line drawing showing the water flow through the facility. Indicate sources of intake water, operations contributing wastewater to the effluent, and treatment units labeled to correspond to the more detailed descriptions in Item III-A. Construct a water balance on the line drawing by showing average flows between intakes, operations, treatment units, and outfalls. If a water balance cannot be determined (e.g., for certain mining activities), provide a pictorial description of the nature and amount of any sources of water and any collection or treatment measures.

C Except for storm runoff, leaks, or spills, will any of the discharges described in item III-A be intermittent or seasonal?

☐ Yes *(complete the following table)* ☐ No *(go to item IV)*

Outfall Number	1. Frequency		2. Flow		
	a. Days Per Week *(specify average)*	b. Months Per Year *(specify average)*	a. Maximum Daily Flow Rate *(in mgd)*	b. Maximum Total Volume *(specify with units)*	c. Duration *(in days)*

IV. Production

If there is an applicable production-based effluent guideline or NSPS, for each outfall list the estimated level of production (projection of actual production level, not design), expressed in the terms and units used in the applicable effluent guideline or NSPS, for each of the first 3 years of operation. If production is likely to vary, you may also submit alternative estimates (attach a separate sheet).

Year	a. Quantity Per Day	b. Units of Measure	c. Operation, Product, Material, etc. *(specify)*

CONTINUE ON NEXT PAGE

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CONTINUED FROM THE FRONT	EPA ID Number (copy from Item 1 of Form 1)	Outfall Number

V. Effluent Characteristics

A, and B. These items require you to report estimated amounts *(both concentration and mass)* of the pollutants to be discharged from each of your outfalls. Each part of this item addresses a different set of pollutants and should be completed in accordance with the specific instructions for that part. Data for each outfall should be on a separate page. Attach additional sheets of paper if necessary.

General Instructions *(See table 2D-2 for Pollutants)*

Each part of this item requests you to provide an estimated daily maximum and average for certain pollutants and the source of information. Data for all pollutants in Group A, for all outfalls, must be submitted unless waived by the permitting authority. For all outfalls, data for pollutants in Group B should be reported only for pollutants which you believe will be present or are limited directly by an effluent limitations guideline or NSPS or indirectly through limitations on an indicator pollutant.

1. Pollutant	2. Maximum Daily Value *(include units)*	3. Average Daily Value *(include units)*	4. Source *(see instructions)*

CONTINUE ON REVERSE

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CONTINUED FROM THE FRONT	EPA I.D. Number (copy from Item 1 of Form 1)	

C. Use the space below to list any of the pollutants listed in Table 2D-3 of the instructions which you know or have reason to believe will be discharged from any outfall. For every pollutant you list, briefly describe the reasons you believe it will be present

1. Pollutant	2. Reason for Discharge

VI. Engineering Report on Wastewater Treatment

A. If there is any technical evaluation concerning your wastewater treatment, including engineering reports or pilot plant studies, check the appropriate box below

☐ Report Available ☐ No Report

B. Provide the name and location of any existing plant(s) which, to the best of your knowledge, resembles this production facility with respect to production processes, wastewater constituents, or wastewater treatments.

Name	Location

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EPA ID Number *(copy from item one of Form 1)*

VII. Other Information *(Optional)*

Use the space below to expand upon any of the above questions or to bring to the attention of the reviewer any other information you feel should be considered in establishing permit limitations for the proposed facility. Attach additional sheets if necessary.

VIII. Certification

I certify under penalty of law that this document and all attachments were prepared under my direction or supervision in accordance with a system designed to assure that qualified personnel properly gather and evaluate the information submitted. Based on my inquiry of the person or persons who manage the system, or those persons directly responsible for gathering the information, the information submitted is, to the best of my knowledge and belief, true, accurate, and complete. I am aware that there are significant penalties for submitting false information, including the possibility of fine and imprisonment for knowing violations.

A. Name and Official Title *(type or print)*	B. Phone No.
C. Signature	D. Date Signed

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Form Approved OMB No. 2040-0086. Approval Expires 5-31-92

Please type or print in the unshaded areas only | EPA I.D. Number (copy from Item 1 of Form 1)

Form **2D** NPDES

EPA New Sources and New Dischargers Application for Permit to Discharge Process Wastewater

I. Outfall Location

For each outfall, list the latitude and longitude, and the name of the receiving water.

Outfall Number (list)	Latitude Deg	Latitude Min	Latitude Sec	Longitude Deg	Longitude Min	Longitude Sec	Receiving Water (name)

II. Discharge Date *(When do you expect to begin discharging?)*

III. Flows, Sources of Pollution, and Treatment Technologies

A. For each outfall, provide a description of (1) All operations contributing wastewater to the effluent, including process wastewater, sanitary wastewater, cooling water, and stormwater runoff, (2) The average flow contributed by each operation, and (3) The treatment received by the wastewater. Continue on additional sheets if necessary.

Outfall Number	1. Operations Contributing Flow *(list)*	2. Average Flow *(include units)*	3. Treatment *(Description or List Codes from Table 2D-1)*

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R0043852

B Attach a line drawing showing the water flow through the facility. Indicate sources of intake water, operations contributing wastewater to the effluent, and treatment units labeled to correspond to the more detailed descriptions in Item III-A. Construct a water balance on the line drawing by showing average flows between intakes, operations, treatment units, and outfalls. If a water balance cannot be determined (e.g., for certain mining activities), provide a pictorial description of the nature and amount of any sources of water and any collection or treatment measures.

C Except for storm runoff, leaks, or spills, will any of the discharges described in item III-A be intermittent or seasonal?

☐ Yes *(complete the following table)* ☐ No *(go to item IV)*

Outfall Number	1. Frequency		2. Flow		
	a. Days Per Week *(specify average)*	b. Months Per Year *(specify average)*	a. Maximum Daily Flow Rate *(in mgd)*	b. Maximum Total Volume *(specify with units)*	c. Duration *(in days)*

IV. Production

If there is an applicable production-based effluent guideline or NSPS, for each outfall list the estimated level of production (projection of actual production level, not design), expressed in the terms and units used in the applicable effluent guideline or NSPS, for each of the first 3 years of operation. If production is likely to vary, you may also submit alternative estimates (attach a separate sheet).

Year	a. Quantity Per Day	b. Units of Measure	c. Operation, Product, Material, etc *(specify)*

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CONTINUE ON NEXT PAGE

CONTINUED FROM THE FRONT	EPA ID Number (copy from Item 1 of Form 1)	Outfall Number

V. Effluent Characteristics

A. and B. These items require you to report estimated amounts *(both concentration and mass)* of the pollutants to be discharged from each of your outfalls. Each part of this item addresses a different set of pollutants and should be completed in accordance with the specific instructions for that part. Data for each outfall should be on a separate page. Attach additional sheets of paper if necessary.

General Instructions *(See table 2D-2 for Pollutants)*

Each part of this item requests you to provide an estimated daily maximum and average for certain pollutants and the source of information. Data for all pollutants in Group A, for all outfalls, must be submitted unless waived by the permitting authority. For all outfalls, data for pollutants in Group B should be reported only for pollutants which you believe will be present or are limited directly by an effluent limitations guideline or NSPS or indirectly through limitations on an indicator pollutant.

1. Pollutant	2. Maximum Daily Value *(include units)*	3. Average Daily Value *(include units)*	4. Source *(see instructions)*

CONTINUE ON REVERSE

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CONTINUED FROM THE FRONT	EPA ID Number (copy from Item 1 of Form 1)	

C Use the space below to list any of the pollutants listed in Table 2D-3 of the instructions which you know or have reason to believe will be discharged from any outfall. For every pollutant you list, briefly describe the reasons you believe it will be present.

1. Pollutant	2. Reason for Discharge

VI. Engineering Report on Wastewater Treatment

A. If there is any technical evaluation concerning your wastewater treatment, including engineering reports or pilot plant studies, check the appropriate box below

☐ Report Available ☐ No Report

B. Provide the name and location of any existing plant(s) which, to the best of your knowledge, resembles this production facility with respect to production processes, wastewater constituents, or wastewater treatments.

Name	Location

CONTINUE ON NEXT PAGE

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VII. Other Information *(Optional)*

Use the space below to expand upon any of the above questions or to bring to the attention of the reviewer any other information you feel should be considered in establishing permit limitations for the proposed facility. Attach additional sheets if necessary.

VIII. Certification

I certify under penalty of law that this document and all attachments were prepared under my direction or supervision in accordance with a system designed to assure that qualified personnel properly gather and evaluate the information submitted. Based on my inquiry of the person or persons who manage the system, or those persons directly responsible for gathering the information, the information submitted is, to the best of my knowledge and belief, true, accurate, and complete. I am aware that there are significant penalties for submitting false information, including the possibility of fine and imprisonment for knowing violations.

A. Name and Official Title *(type or print)*	B. Phone No.
C. Signature	D. Date Signed

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R0043856

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United States Environmental Protection Agency
Permits Division
Office of Water Enforcement and Permits Washington, DC 20460
EPA Form 3510-2E
Revised August 1990

EPA

Application Form 2E —

Facilities Which Do Not Discharge Process Wastewater

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Form 2E Instructions

Who Must File Form 2E

EPA Form 3510-2E must be completed in conjunction with EPA Form 3510-1 (Form 1). This short form may be used only by operators of facilities which discharge only nonprocess wastewater (process wastewater is water that comes into direct contact with or results from the production or use of any raw material, intermediate product, finished product, byproduct, waste product, or wastewater) which is not regulated by effluent limitations guidelines or new source performance standards. The form is intended primarily for use by dischargers (new or existing) of sanitary wastes and noncontact cooling water. It may not be used for discharges of stormwater runoff or by educational, medical, or commercial chemical laboratories or by publicly owned treatment works (POTW's).

Where to File Applications

The application forms should be sent to the EPA Regional Office which covers the State in which the facility is located. Form 2E (the short form) must be used only when applying for permits in States where the NPDES permits program is administered by EPA. For facilities located in States which are approved to administer the NPDES permits program, the State environmental agency should be contacted for proper permit application forms and instructions. Information on whether a particular program is administered by EPA or by a State agency can be obtained from your EPA Regional Office. Form 1, Table 1 of the "General Instructions" lists the addresses of EPA Regional Offices and the States within the jurisdiction of each Office.

Public Availability of Submitted Information

You may not claim as confidential any information required by this form or Form 1, whether the information is reported on the forms or in an attachment. Section 402(j) of the CWA requires that all permit applications shall be available to the public. This information will therefore be made available to the public upon request.

You may claim as confidential any information you submit to EPA which goes beyond that required by this form or Form 1. However, confidentiality claims for effluent data must be denied. If you do not assert a claim of confidentiality at the time of submitting the information, EPA may make the information public without further notice. Claims of confidentiality will be handled in accordance with EPA's business confidentiality regulations in 40 CFR Part 2.

Completeness

Your application will not be considered complete unless you answer every question on this form and Form 1 (except as instructed below). If an item does not apply to you, enter "NA" (for "not applicable") to show that you considered the question.

Followup Requirements for New Dischargers and New Sources

Please note that no later than 2 years after commencement of discharge from the proposed facility, you must complete and submit Item IV of this form (NPDES Form 2E). At that time you must test and report actual rather than estimated data for the pollutants or parameters in Item IV, unless waived by the permitting authority.

Definitions

Significant terms used in these instructions and in the form are defined in the Glossary found in the General Instructions accompanying Form 1.

Item I

Under Part A, list an outfall number. Under Part B, list the latitude and longitude to the nearest 15 seconds for this outfall. Under Part C, list the name of the outfall's receiving water. When there is more than one outfall, you must submit a seperate Form 2E (Items I, III, and IV only) for each outfall.

Item II (New Dischargers Only)

This item requires your best estimate of the date on which your facility will begin to discharge.

Item III

In Part A, indicate the general type(s) of wastes to be discharged by placing an "x" in the appropriate box(es). If "other nonprocess wastewater" is marked, it should be identified. If cooling water additives are to be used, they must be listed by name under Part B.

In addition, the composition of the cooling water additives should be listed if this information is available. The composition of cooling water additives may be found on product labels or from manufacturer's data sheets.

Item IV — Reporting

All pollutant levels must be reported as concentration and as total mass (except for discharge flow, pH, and temperature). Total mass is the total weight of pollutants discharged over a day. Use the following abbreviations for units:

Concentration		Mass	
ppm	parts per million	lbs	pounds
mg/1	milligrams per liter	ton	tons (English tons)
ppb	parts per billion	mg	milligrams
Ug/1	micrograms per liter	g	grams
kg	kilograms	T	Tonnes (metric tons)

A. Existing Sources

You are required to provide at least one analysis for each pollutant or parameter listed by filling in the requested information under the applicable column. Data reported must be representative of the facility's current operation (average daily value over the previous 365 days should be reported). Most facilities routinely monitor these pollutants or parameters as part of existing permit requirements.

The pollutants or parameters listed are average flow, biochemical oxygen demand (BOD), total suspended solids (TSS), fecal coliform (if believed present or if sanitary waste is discharged), pH, total residual chlorine (if chlorine is used), temperature (winter and summer), oil and grease, chemical oxygen demand (COD), total organic carbon (TOC) (COD and TOC are only required if noncontact cooling water is discharged), and ammonia (as N). The analysis of these pollutants or parameters must be done in accordance with procedures promulgated in 40 CFR Part 136. Grab samples must be used for pH, temperature, residual chlorine, oil and grease, and fecal coliform. For all other pollutants, 24-hour composite samples must be used. Any further questions on sampling or analysis should be directed to your EPA or State permitting authority. The authority may request that you do additional testing, if appropriate, on a case-by-case basis under Section 308 of the Clean Water Act (CWA).

If you expect a pollutant to be present solely as a result of its presence in your intake water, state this information on Item VII of the form.

B. New Dischargers

You are required to provide an estimated maximum daily and average daily value for each pollutant or parameter (exceptions noted on the form). Please note that followup testing and reporting are required no later than 2 years after the facility starts to discharge. Sampling and analysis are not required at this time. If, however, data from such analyses are available, then such data should be reported. The source of the estimates is also required. Base your determination of whether a pollutant will be present in your discharge on your knowledge of the proposed facility's use of maintenance chemicals, and any analyses of your effluent or of any similar effluent. You may also provide the estimates based on available inhouse or contractor's engineering reports or any other studies performed on the proposed facility. If you expect a pollutant or parameter to be present solely as a result of its presence in your intake water, state this information on Item VII of the form.

In providing the estimates, use the codes in the following table to indicate the source of such information.

Engineering study	Code
Actual data from pilot plants	1
Estimates from other engineering studies	2
Data from other similar plants	3
Best professional estimates	4
Others	specify on the form

C. Testing Waivers

To request a waiver from reporting any of these pollutants or parameters, the applicant (whether a new or existing discharger) must submit to the permitting authority a written request specifying which pollutants or parameters should be waived and the reasons for requesting a waiver. This request should be submitted to the permitting authority before or with the permit application. The permitting authority may waive the requirements for information about any pollutant or parameter if he determines that less stringent reporting requirements are adequate to support issuance of the permit. No extensive documentation of the request will normally be needed, but the applicant should contact the permitting authority if he or she wishes to receive instructions on what his or her particular request should contain.

Item V

Describe the average frequency of flow and duration of any intermittent or seasonal discharge (except for stormwater runoff, leaks, or spills). The frequency of flow means the number of days or months per year there is intermittent discharge. Duration means the number of days or hours per discharge. For new dischargers, base your answers on your best estimate.

Item VI

Describe briefly any treatment system(s) used (or to be used for new dischargers), indicating whether the treatment system is physical, chemical, biological, sludge and disposal, or other. Also give the particular type(s) of process(es) used (or to be used). For example, if a physical treatment system is used (or will be used), specify the processes applied, such as grit removal, ammonia stripping, dialysis, etc.

Item VII

This item is intended for you to provide any additional information (such as sampling results) that you feel should be considered by the reviewer in establishing permit limitations. Any response here is optional. If you wish to demonstrate your eligibility for a "net" effluent limitation, i.e., an effluent limitation adjusted to provide credit for the pollutant(s) present in your intake water, please add a short statement of why you believe you are eligible (see §122.45(g)). You will then be contacted by the permitting authority for further instructions.

Item VIII

The Clean Water Act provides severe penalties for submitting false information on this application form. Section 309(c)(2) of the Clean Water Act provides that "Any person who knowingly makes any false statement,

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representation, or certification in any application, . . . shall upon conviction, be punished by a fine of no more than $10,000 or by imprisonment for not more than six months or both."

40 CFR Part 122.22 requires the certification to be signed as follows:

a. For a corporation: by a responsible corporate officer. A responsible corporate officer means (i) a president, secretary, treasurer, or vice-president of the corporation in charge of of a principal business function, or any other person who performs similar policy or decisionmaking functions for the corporation, or (ii) the manager of one or more manufacturing, production, or operating facilities employing more than 250 persons or having gross annual sales or expenditures exceeding $25,000,000 (in second quarter 1980 dollars), if authority to sign documents has been assigned or delegated to the manager in accordance with corporate procedures.

b. For a partnership or sole proprietorship: by a general partner or the proprietor, respectively; or

c. For a municipality, State, Federal, or other public agency: by either a principal executive officer or ranking elected official. For purposes of this section, a principal executive officer of a Federal agency includes (i) the chief executive officer of the agency, or (ii) a senior executive officer having responsibility for the overall operations of a principal geographic unit of the agency (e.g., Regional Administrators of EPA).

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Please type or print in the unshaded areas only | EPA ID Number *(copy from Item 1 of Form 1)* | Form Approved OMB No 2040-0086 Approval expires 5-31-92

Form **2E** NPDES

EPA Facilities Which Do Not Discharge Process Wastewater

I. Receiving Waters

For this outfall, list the latitude and longitude, and name of the receiving water(s).

Outfall Number *(list)*	Latitude			Longitude			Receiving Water *(name)*
	Deg	Min	Sec	Deg	Min	Sec	

II. Discharge Date *(If a new discharger, the date you expect to begin discharging)*

III. Type of Waste

A. Check the box(es) indicating the general type(s) of wastes discharged

☐ Sanitary Wastes ☐ Restaurant or Cafeteria Wastes ☐ Noncontact Cooling Water ☐ Other Nonprocess Wastewater *(Identify)*

B. If any cooling water additives are used, list them here. Briefly describe their composition if this information is available

IV. Effluent Characteristics

A. **Existing Sources** — Provide measurements for the parameters listed in the left-hand column below, unless waived by the permitting authority *(see instructions)*.

B. **New Dischargers** — Provide estimates for the parameters listed in the left-hand column below, unless waived by the permitting authority. Instead of the number of measurements taken, provide the source of estimated values *(see instructions)*.

Pollutant or Parameter	(1) Maximum Daily Value *(include units)*		(2) Average Daily Value *(last year)* *(include units)*		(3) Number of Measurements Taken *(last year)*	(or) (4) Source of Estimate *(if new discharger)*
	Mass	Concentration	Mass	Concentration		
Biochemical Oxygen Demand (BOD)						
Total Suspended Solids (TSS)						
Fecal Coliform *(if believed present or if sanitary waste is discharged)*						
Total Residual Chlorine *(if chlorine is used)*						
Oil and Grease						
*Chemical oxygen demand (COD)						
*Total organic carbon (TOC)						
Ammonia *(as N)*						
Discharge Flow	Value					
pH *(give range)*	Value					
Temperature *(Winter)*	°C		°C			
Temperature *(Summer)*	°C		°C			

*If noncontact cooling water is discharged

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V. Except for leaks or spills, will the discharge described in this form be intermittent or seasonal?
If yes, briefly describe the frequency of flow and duration ☐ Yes ☐ No

VI. Treatment System *(Describe briefly any treatment system(s) used or to be used)*

VII. Other Information (Optional)

Use the space below to expand upon any of the above questions or to bring to the attention of the reviewer any other information you feel should be considered in establishing permit limitations. Attach additional sheets, if necessary.

VIII. Certification

I certify under penalty of law that this document and all attachments were prepared under my direction or supervision in accordance with a system designed to assure that qualified personnel properly gather and evaluate the information submitted. Based on my inquiry of the person or persons who manage the system, or those persons directly responsible for gathering the information, the information submitted is to the best of my knowledge and belief, true, accurate, and complete. I am aware that there are significant penalties for submitting false information, including the possibility of fine and imprisonment for knowing violations.

A. Name & Official Title	B. Phone No. *(area code & no.)*
C. Signature	D. Date Signed

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Please type or print in the unshaded areas only | EPA ID Number (copy from Item 1 of Form 1) | Form Approved. OMB No. 2040-0086 Approval expires 5-31-92.

Form 2E

EPA Facilities Which Do Not Discharge Process Wastewater

I. Receiving Waters

For this outfall, list the latitude and longitude, and name of the receiving water(s).

Outfall Number (list)	Latitude Deg	Latitude Min	Latitude Sec	Longitude Deg	Longitude Min	Longitude Sec	Receiving Water (name)

II. Discharge Date (If a new discharger, the date you expect to begin discharging)

III. Type of Waste

A. Check the box(es) indicating the general type(s) of wastes discharged.

☐ Sanitary Wastes ☐ Restaurant or Cafeteria Wastes ☐ Noncontact Cooling Water ☐ Other Nonprocess Wastewater (Identify)

B. If any cooling water additives are used, list them here. Briefly describe their composition if this information is available.

IV. Effluent Characteristics

A. Existing Sources — Provide measurements for the parameters listed in the left-hand column below, unless waived by the permitting authority (see instructions).

B. New Dischargers — Provide estimates for the parameters listed in the left-hand column below, unless waived by the permitting authority. Instead of the number of measurements taken, provide the source of estimated values (see instructions).

Pollutant or Parameter	(1) Maximum Daily Value (include units)		(2) Average Daily Value (last year) (include units)		(3) Number of Measurements Taken (last year)	(or) (4) Source of Estimate (if new discharger)
	Mass	Concentration	Mass	Concentration		
Biochemical Oxygen Demand (BOD)						
Total Suspended Solids (TSS)						
Fecal Coliform (if believed present or if sanitary waste is discharged)						
Total Residual Chlorine (if chlorine is used)						
Oil and Grease						
*Chemical oxygen demand (COD)						
*Total organic carbon (TOC)						
Ammonia (as N)						
Discharge Flow	Value					
pH (give range)	Value					
Temperature (Winter)	°C		°C			
Temperature (Summer)	°C		°C			

*If noncontact cooling water is discharged

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V. Except for leaks or spills, will the discharge described in this form be intermittent or seasonal?
If yes, briefly describe the frequency of flow and duration. ☐ Yes ☐ No

VI. Treatment System *(Describe briefly any treatment system(s) used or to be used)*

VII. Other Information *(Optional)*

Use the space below to expand upon any of the above questions or to bring to the attention of the reviewer any other information you feel should be considered in establishing permit limitations. Attach additional sheets, if necessary.

VIII. Certification

I certify under penalty of law that this document and all attachments were prepared under my direction or supervision in accordance with a system designed to assure that qualified personnel properly gather and evaluate the information submitted. Based on my inquiry of the person or persons who manage the system, or those persons directly responsible for gathering the information, the information submitted is to the best of my knowledge and belief, true, accurate, and complete. I am aware that there are significant penalties for submitting false information, including the possibility of fine and imprisonment for knowing violations.

A. Name & Official Title	B. Phone No. *(area code & no.)*
C. Signature	D. Date Signed

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United States
Environmental Protection
Agency

Office Of Water
(WH-547)

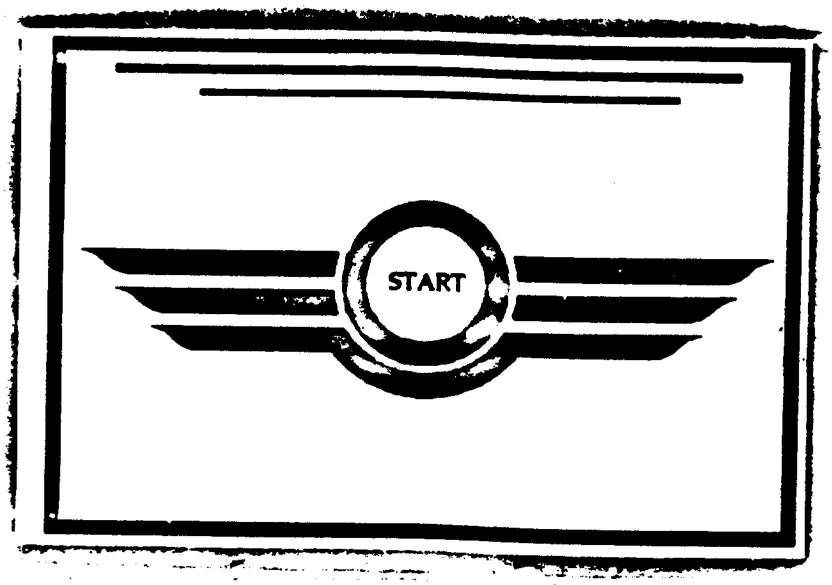
EPA [illegible]
September [illegible]

ⓔEPA

Storm Water Management For Industrial Activities

Item 42

Developing Pollution Prevention Plans And Best Management Practices



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FOREWORD

This manual provides industrial facilities with comprehensive guidance on the development of storm water pollution prevention plans and identification of appropriate Best Management Practices (BMPs). It provides technical assistance and support to all facilities subject to pollution prevention requirements established under National Pollutant Discharge Elimination System (NPDES) permits for storm water point source discharges.

EPA's storm water program significantly expands the scope and application of the existing NPDES permit system for municipal and industrial process wastewater discharges. It emphasizes pollution prevention and reflects a heavy reliance on BMPs to reduce pollutant loadings and improve water quality. This manual provides essential guidance in both of these areas.

This document was issued in support of EPA regulations and policy initiatives involving the development and implementation of a National storm water program. This document is Agency guidance only. It does not establish or affect legal rights or obligations. Agency decisions in any particular case will be made applying the laws and regulations on the basis of specific facts when permits are issued or regulations promulgated.

This document will be revised and expanded periodically to reflect additional pollution prevention information and data on treatment effectiveness of BMPs. Comments from users will be welcomed. Send comments to U.S. EPA, Office of Wastewater Enforcement and Compliance, 401 M Street, SW, Mail Code EN-336, Washington, DC 20460.

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CHAPTER 1

INTRODUCTION

Storm water runoff is part of a natural hydrologic process. However, human activities, particularly urbanization, can alter natural drainage patterns and add pollutants to the rainwater and snowmelt that runs off the earth's surface and enters our Nation's rivers, lakes, streams, and coastal waters. A number of recent studies by the U.S. Environmental Protection Agency (EPA), State water pollution control authorities, and various universities have shown that storm water runoff is a major source of water pollution, declines in fisheries, restrictions on swimming, and these conditions limit our ability to enjoy many of the other benefits that the Nation's waters provide.

In response to this problem, the States and many municipalities have been taking the initiative to manage storm water more effectively. In acknowledgement of the importance of the storm water problem, the Congress has directed EPA to undertake a wide range of activities, including providing technical and financial assistance to States and other jurisdictions to help them improve their storm water management programs. In addition, through recent amendments to the Clean Water Act, the Congress has instructed EPA to develop a regulatory program for certain high priority storm water sources.

In carrying out its responsibilities, EPA is committed to promoting the concept and the practice of preventing pollution at the source, before it can cause environmental problems costing the public and private sector in terms of lost resources and the funding it takes to remediate or correct environmental damage.

1.1 PURPOSE OF THIS GUIDANCE MANUAL

This manual provides general guidance on developing and implementing a Storm Water Pollution Prevention Plan for industrial facilities. Owners and operators of industrial facilities will find that putting together a Storm Water Pollution Prevention Plan is a straightforward process that can be accomplished by facility managers and employees.

EPA is publishing this manual for several reasons. The primary purpose of this manual is to provide guidance for industrial facilities that are subject to requirements under EPA's General Permits for storm water discharges associated with industrial activity. Facilities located in the 12 nondelegated States or 6 Territories are subject to these requirements (see Section 1.6 for a list of States and Territories subject to EPA General Permit requirements). EPA anticipates that most storm water discharge permits issued under the Storm Water Program will require a pollution prevention plan. Throughout this manual, specific EPA General Permit pollution prevention requirements are given in the shaded boxes as seen below. Although the requirements for a Storm Water Pollution Prevention Plan may vary from one permit to another, and from State to State, EPA expects that most of the general concepts described in this manual are common to all plan requirements. Please also note that, although this manual presents EPA General Permit requirements that apply to facilities located in nondelegated States and Territories, some of the nondelegated States required modifications or additions to the pollution prevention plan requirements to ensure that the permit complies with State laws and standards. Therefore, it is important that all facilities located in delegated States, as well as nondelegated States, read their permits to determine whether there are any special conditions. This manual is not intended in any way to substitute for binding legal requirements pursuant to National Pollutant Discharge Elimination System (NPDES) permits.

EPA GENERAL PERMIT REQUIREMENTS
Storm Water Pollution Prevention Plans Part IV A Storm Water Pollution Prevention Plan shall be developed for each facility covered by this permit. Storm Water Pollution Prevention Plans shall be prepared in accordance with good engineering practices. The plan shall identify potential sources of pollution which may reasonably be expected to affect the quality of storm water discharges associated with industrial activity from the facility. In addition, the plan shall describe and ensure the implementation of practices which are to be used to reduce the pollutants in storm water discharges associated with industrial activity at the facility and to assure compliance with the terms and conditions of this permit. Facilities must implement the provisions of the Storm Water Pollution Prevention Plan required under this part as a condition of this permit.

In addition to providing guidance for facilities that are subject to storm water permit requirements, this manual contains information that is generally useful for controlling storm water pollution from almost any type of developed site. EPA hopes this manual is widely used in furthering the prevention of pollution at its sources and the adoption of management practices that help us protect the overall quality of the environment.

EPA is also issuing a guidance manual on Best Management Practices (BMPs) for construction activities. If you are subject to requirements under the general permit for storm water discharges associated with construction activities, that manual is designed to help you comply with those somewhat different requirements.

1.2 ORGANIZATION OF THIS GUIDANCE MANUAL

This manual is presented as a user's guide to Storm Water Pollution Prevention Plan requirements. Step-by-step guidelines and accompanying worksheets will walk you through the process of developing and implementing a Storm Water Pollution Prevention Plan. This approach allows you to complete this process in the simplest and most efficient way. The worksheets are designed to help you organize the required information. The remainder of this manual is divided into three sections: Chapter 2 provides information on how to develop a plan; Chapter 3 serves as a resource for selecting activity-specific Best Management Practices (BMPs); and Chapter 4 discusses site-specific BMPs. As you complete each section, you will move through each of the following steps and end up with a fully developed Storm Water Pollution Prevention Plan. Each step is important and should be completed before moving on to the next step. The five major phases involved in developing and implementing your plan are as follows:

Phase 1	-	Planning and Organization
Phase 2	-	Assessment
Phase 3	-	BMP Identification
Phase 4	-	Plan Implementation
Phase 5	-	Evaluation

Chapter 2 provides step-by-step guidance for completing each of these phases. The Organization Phase starts the process by helping you to get organized and by identifying who is going to develop and implement the plan and by identifying site-specific pollution prevention objectives. The Assessment Phase involves gathering information about your site and identifying potential sources of storm water pollution. Using the information collected during the Assessment Phase, you can begin to design the storm water management program that best suits your site. During the BMP Identification Phase, you will evaluate the required baseline BMPs and select other preventive measures. The fourth stage of the Storm Water Pollution Prevention Planning process is the Implementation Phase, during which you put the plan into action. The final step, the Evaluation Phase, allows you to determine if your plan is actually accomplishing your pollution prevention objectives. Periodic reviews, inspections, and evaluations will allow you to keep the plan effective and up-to-date.

In Chapter 3, which details activity-specific BMPs, you will find a number of measures you can use to prevent or reduce the contamination of storm water caused by specific industrial activities. Chapter 4 describes site-specific BMPs. From the list of site-specific BMPs, you can select prevention and control measures that are most appropriate for the physical characteristics of your facility. A combination of these types of BMPs may be most appropriate for your site.

In addition, there are several appendices located at the end of this manual. Appendix A lists the references used to develop this manual. Appendix B includes a glossary of terms. Appendix C provides a model of what a pollution prevention plan might look like for a small industry. Appendix D provides State and Federal storm water and pollution prevention contacts and additional information on pollution prevention. Appendix E provides technical and design fact sheets for some of the storm water BMPs described in Chapter 4. Appendix F describes tests for non-storm water discharges. Appendix G compares Storm Water Pollution Prevention Plan requirements with plan requirements under other environmental programs. Appendix H is a list of reportable quantities for hazardous substances under 40 CFR Parts 117 and 302. Appendix I is the list of water priority chemicals under Emergency Planning and Community Right-to-Know Act (EPCRA), Section 313. Appendix J includes a table of the monitoring requirements that are contained in EPA's General Permits.

1.3 SCOPE OF THIS MANUAL

This manual provides useful information on many pollution prevention and best management practices which you can use to prevent or reduce the discharge of sediment and other pollutants in storm water runoff from your site. This manual describes the practices and controls, tells how, when, and where to use them, and how to maintain them. However, the effectiveness of these controls lies fully in your hands. Although specific recommendations will be offered in the following chapters, keep in mind that careful consideration must be given to selecting the most appropriate control measures based on site-specific features, and on properly installing the controls in a timely manner. Finally, although this manual provides guidelines for maintenance, it is up to you to make sure that your controls are carefully maintained or they will prove to be ineffective.

This manual describes the EPA General Permit requirements for pollution prevention plans. However, requirements may vary from permit to permit. You should read your permit to determine the required components of your pollution prevention plan. Although this manual describes "typical" permit requirements, do not assume that the typical permit requirements described in this manual are the same as your permit requirements even if you are included under an NPDES general permit for storm water discharges associated with industrial activities. Permit conditions may vary between different permits and/or different versions of the permit.

EPA has issued a number of regulations addressing pollution control practices for different environmental media (i.e., land, water, air, and ground water). However, this manual focuses on identifying pollution prevention measures and BMPs specifically for industrial storm water discharges and provides guidance to industrial facilities on how to comply with storm water permits.

Although Storm Water Pollution Prevention Plans primarily focus on storm water, it is important to consider the impacts of selected storm water management measures on other environmental media (i.e., land, air, and ground water). For example, if the water table is unusually high in your area, a retention pond for contaminated storm water may also lead to contamination of a ground water source unless special preventive measures are taken. Permittees must take these issues into consideration in selecting appropriate pollution prevention measures and should make certain that adoption of storm water measures is consistent with other Federal, State, and local environmental laws. For instance, under EPA's July 1991 Ground Water Protection Strategy, States are encouraged to develop Comprehensive State Ground Water Protection Programs. Your facility's efforts to control storm water should be compatible with the ground water protection objectives reflected in your State's program.

1.4 DEFINITIONS

As you use this manual to select pollution prevention approaches, you will see two key phrases used frequently: "pollution prevention plan" and "best management practice." A solid understanding of these terms is very important in meeting the goals of storm water management discussed above.

Pollution Prevention Plan

The first term of importance is "storm water pollution prevention plan." As mentioned in Section 1.1, this manual is designed to help you to prepare and implement a Storm Water Pollution Prevention Plan. As you will learn in Chapter 2, Storm Water Pollution Prevention Plans consist of a series of steps and activities to, first, identify sources of pollution or contamination on your site, and, second, select and carry out actions which prevent or control the pollution of storm water discharges.

Best Management Practice

The other concept used throughout this manual is "Best Management Practice" or BMP. BMPs are measures or practices used to reduce the amount of pollution entering surface water, air, land, or ground waters. BMPs may take the form of a process, activity, or physical structure. Some BMPs are simple and can be put into place immediately, while others are more complicated and require extensive planning or space. They may be inexpensive or costly to implement. Although BMPs are used in many environmental programs, the BMPs presented in this manual are specifically designed to reduce or eliminate pollutants in storm water discharges. Chapter 2 describes the baseline BMP requirements of EPA's General Permit for storm water discharges associated with industrial activity. Chapters 3 and 4 describe numerous specific BMPs that will help you comply with these requirements.

1.5 GOALS OF STORM WATER MANAGEMENT

Federal, State, and local storm water management programs have a common goal:

To Improve Water Quality By Reducing the Pollutants Contained In Storm Water Discharges

Meeting this goal is a difficult challenge for many reasons. For example, the original sources of the pollutants transported in storm water can be diffuse or spread out over a wide area. So, small oil and grease spills at hundreds of different facilities within a single city can collectively represent a major pollution problem. In addition, the nature of storm water is such that the amount of pollutants that enter receiving waters will vary in accordance with the frequency, intensity and duration of rainfall and the nature of local drainage patterns. Considering the wide variety of types of industries in the United States and the wide range of materials and chemical compounds that are used as part of different industrial activities, a site-specific pollution prevention plan tailored for each facility is considered the most effective, flexible, and economically practical approach to achieve effective storm water management.

The pollution prevention plan approach required by EPA gives facilities flexibility to establish a site-specific storm water management program to meet Best Available Technology/Best Control Technology (BAT/BCT) standards required by the Clean Water Act instead of imposing numerical discharge limitations. Yet, the BMP framework established by the pollution prevention plan requirements must be fully implemented to meet these standards.

1.6 SUMMARY OF THE STORM WATER PROGRAM

Storm water discharges have been increasingly identified as a significant source of water pollution in numerous nationwide studies on water quality. To address this problem, the Clean Water Act Amendments of 1987 required EPA to publish regulations to control storm water discharges under NPDES. EPA published storm water regulations on November 16, 1990, which require certain dischargers of storm water to waters of the United States to apply for NPDES permits. "Waters of the United States" is generally defined as surface waters, including lakes, rivers, streams, wetlands, and coastal waters. NPDES storm water discharge permits will allow the States and EPA to track and monitor sources of storm water pollution. According to the November 16, 1990, final rule, facilities with a "storm water discharge associated with industrial activity" are required to apply for a storm water permit. EPA has defined this phrase in terms of 11 categories of industrial activity that include: (1) facilities subject to storm water effluent limitations guidelines, new source performance standards, or toxic pollutant effluent standards under 40 CFR Subchapter N; (2) "heavy" manufacturing facilities; (3) mining and oil and gas operations with "contaminated" storm water discharges; (4) hazardous waste treatment, storage, or disposal facilities; (5) landfills, land application sites, and open dumps; (6) recycling facilities; (7) steam electric generating facilities; (8) transportation facilities, including airports; (9) sewage treatment plants; (10) construction operations disturbing 5 or more acres*; and (11) other industrial facilities where materials are exposed to storm water*. Operators of industrial facilities that are Federally, State, or municipally owned or operated that meet the above description must also submit applications. If you have questions about whether or not your facility needs to seek permit coverage, contact the EPA Storm Water Hotline at (703) 821-4823.

Storm water discharges associated with industrial activity that reach waters of the United States through Municipal Separate Storm Sewer Systems (MS4s) are also required to obtain NPDES storm water permit coverage. Discharges of storm water to a combined sewer system or to a Publicly Owned Treatment Works (POTW) are excluded.

The storm water regulation presents three permit application options for storm water discharges associated with industrial activity. The first option is to submit an individual application consisting of Forms 1 and 2F. The second option is to participate in a group application. The third option is to file a Notice of Intent (NOI) to be covered under a general permit in accordance with the

*On June 4, 1992, the United States Court of Appeals for the Ninth Circuit remanded the exemptions for manufacturing facilities which do not have materials or activities exposed to storm water and for construction sites of less than five acres to the EPA for further rulemaking.

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requirements of an issued general permit. Regardless of the permit application option a facility selects, the resulting storm water discharge permit will most likely contain a requirement to develop and implement a Storm Water Pollution Prevention Plan.

NPDES permits are issued by the State for States that have been delegated NPDES permitting authority or by EPA for States that have not been delegated NPDES permitting authority. Therefore, the specific EPA General Permit requirements discussed in this guidance manual apply only to facilities located in one of the 12 nondelegated States or Territories (Alaska; Arizona; Idaho; Louisiana; Maine; Massachusetts; New Hampshire; New Mexico; Oklahoma; South Dakota; Texas; the District of Columbia; Puerto Rico; Guam; American Samoa; Northern Mariana Islands; Trust Territory of the Pacific Islands; Indian lands in Alabama, California, Georgia, Kentucky, Michigan, Minnesota, Mississippi, Montana, North Carolina, North Dakota, New York, Nevada, South Carolina, Tennessee, Utah, Wisconsin, Wyoming; located within Federal facilities or Indian lands in Colorado and Washington; and located within Federal facilities in Delaware). EPA expects, however, that the Federal general permit will be used as a model by NPDES-authorized States, tailored to meet State-specific conditions. Even though storm water permit requirements will vary from State to State depending on water quality concerns and permitting priorities for the permitting authority, EPA expects that most NPDES storm water discharge permits will contain Storm Water Pollution Prevention Plan requirements similar to the requirements presented in this manual.

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CHAPTER 2

STORM WATER POLLUTION PREVENTION PLAN

Chapter 2 presents a step-by-step guide to help you develop a Storm Water Pollution Prevention Plan for your facility. Figure 2.1 is a flowchart showing each step involved in developing and implementing a successful plan. As shown in this flowchart, the steps have been grouped into five general phases, which are: (1) planning and organization; (2) assessment; (3) BMP identification; (4) implementation; and (5) evaluation/monitoring. In addition, Storm Water Pollution Prevention Plans also must address a number of general requirements, including developing a schedule or deadlines for the accomplishment of tasks, and an identification of signature authority, where required by Federal regulations. Some types of facilities will also have to meet other special requirements. For example, special requirements apply to facilities that discharge through municipal separate storm water systems as well as those facilities that are subject to reporting requirements under EPCRA, Section 313 for water priority chemicals.

Figure 2.1 also identifies a number of worksheets that can help walk you through the planning process. These worksheets are located at the end of Chapter 2. You can pull them out, photocopy them, and simply incorporate the completed forms in your plan.

The five planning phases, general requirements, and special requirements are discussed in turn in the remainder of this chapter. To help you follow along, a simplified version of the flowchart for the entire planning process is shown at the beginning of each section, with a highlighted box showing the particular phase that is being discussed. So, for example, you will find that the Planning and Organization Phase is highlighted on the flowchart at the top of page 2-3, signaling the beginning of our detailed discussion of this first step.

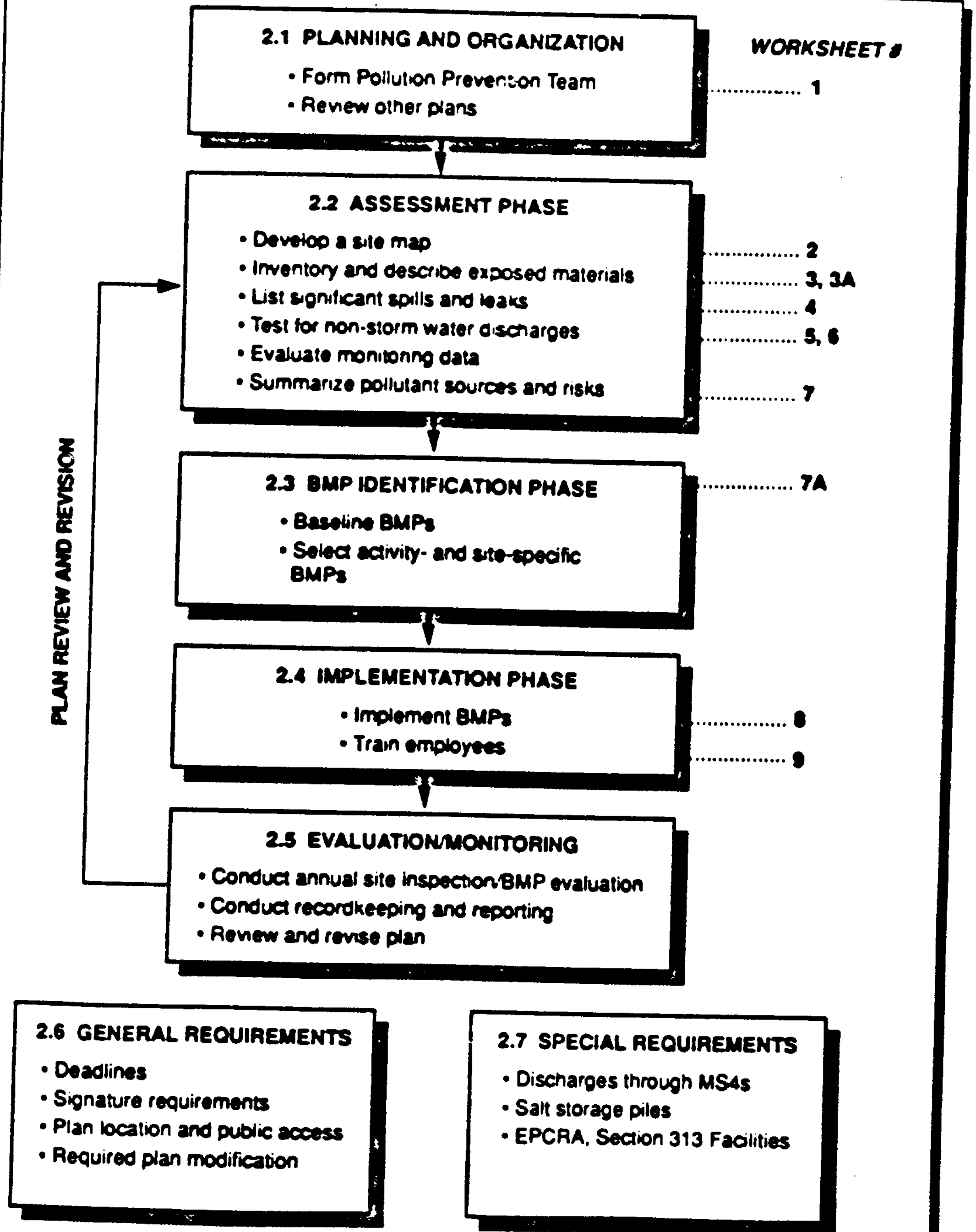
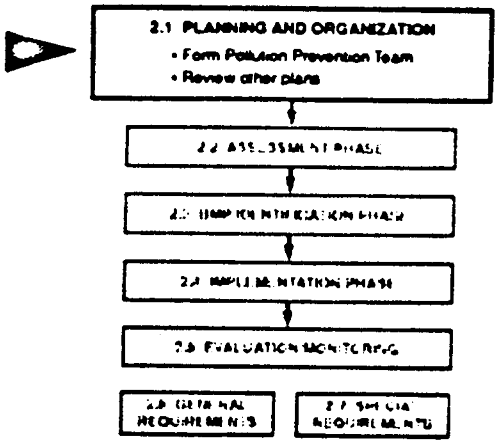


FIGURE 2.1 STORM WATER POLLUTION PREVENTION PLAN FLOWCHART



2.1 PLANNING AND ORGANIZATION PHASE

Before you start putting your Storm Water Pollution Prevention Plan together, there are two tasks to complete to make developing the plan easier. These steps are designed to help you organize your staff and make preliminary decisions:

- Decide who will be responsible for developing and implementing your Storm Water Pollution Prevention Plan
- Look at other existing environmental facility plans for consistency and overlap.

2.1.1 Who Will Develop and Implement Your Plan?

EPA GENERAL PERMIT REQUIREMENTS
Pollution Prevention Team
Part IV.D.1.
Each plan shall identify a specific individual or individuals within the facility organization as members of a storm water pollution prevention team that are responsible for developing the Storm Water Pollution Prevention Plan and assisting the facility or plant manager in its implementation, maintenance, and revision. The plan shall clearly identify the responsibilities of each team member. The activities and responsibilities of the team shall address all aspects of the facility's Storm Water Pollution Prevention Plan.

What is the Purpose of Designating an Individual or a Team?

Designating a specific individual or team who will develop and implement your pollution prevention plan serves several purposes. Naming the individual or team members makes it clear that part of that person's job is to prevent storm water pollution. Identifying a specific individual also provides a point of contact for those outside the facility who may need to discuss aspects of the facility's pollution prevention plan (i.e., regulatory officials, etc.).

Where setting up a pollution prevention team is appropriate, it is important to identify the key people onsite who are most familiar with the facility and its operations, and to provide adequate structure and direction to the facility's entire storm water management program. The pollution prevention team concept is flexible and should be molded to conform to the resources and specific conditions of the facility. Specific activities of the pollution prevention team, the number of members, and their background and experience will vary for each facility.

Effective organization of the pollution prevention team is important in order for the team to be able to accomplish the task of developing and implementing a comprehensive Storm Water Pollution Prevention Plan. There are two important features in organizing a team of this nature: (1) selecting the right individuals to serve on the team; and (2) establishing good channels of communication.

What are the Roles and Responsibilities of the Designated Individual or Team?

The designated individual or team will be the driving force behind the development, implementation, maintenance, and revision of the facility's Storm Water Pollution Prevention Plan. One of the first tasks of those responsible is to define and agree upon a clear and reasonable set of goals for the facility's overall storm water management program. Where a team is involved, the responsibilities or duties of specific team members should be clearly defined.

Areas of responsibilities include initial site assessment, identification of pollutant sources and risks, decision making on appropriate BMPs, directing the actual implementation of the BMPs, and then, regular evaluations to measure the effectiveness of the plan. Details of these procedures are described in the latter part of this chapter.

To ensure that the Storm Water Pollution Prevention Plan remains effective, the person or team responsible for maintaining the pollution prevention plan must be aware of any changes that are made in plant operations to determine if any changes must be made.

While a designated individual or a pollution prevention team can be assigned the job of developing and implementing a Storm Water Pollution Prevention Plan, plant management is ultimately responsible for the implementation of the plan and for compliance with all applicable storm water requirements. Accordingly, the designated individual or team must have a clear line of communication with plant management to ensure that they are able to function in a cooperative partnership.

Who Should be on a Storm Water Pollution Prevention Team?

Any team, by definition, involves decision making and planning in a group setting. This allows for people with different ideas and areas of expertise to share knowledge and collectively figure out what works best for a particular facility. To broaden the base of involvement in the facility's storm water pollution prevention program, team members should represent all phases of the facility's operations.

For example, at a large facility, a team may be comprised of representatives from plant management, all aspects of production operations, engineering, waste handling and treatment (environmental department), and, if applicable, research and development. See Figure 2.2 for an illustration of an example team organizational chart.

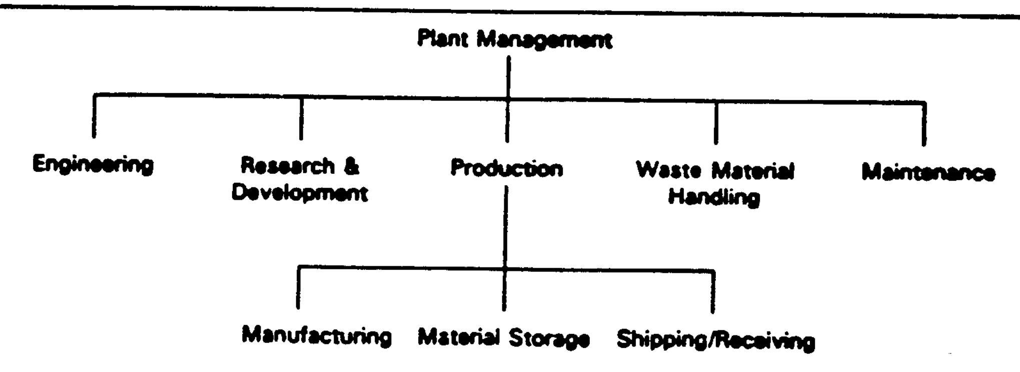


FIGURE 2.2 EXAMPLE POLLUTION PREVENTION TEAM ORGANIZATION CHART

Not all facilities will have or require all of these "team" positions. As mentioned above, team membership depends on the type of operations occurring at a facility. For example, a small trucking operation may find it appropriate to designate a single individual or a very small pollution prevention team with experience in key types of facility operations, such as vehicle maintenance, vehicle washing, fueling, and materials handling.

For a facility that has already designated a spill prevention and response team, the facility may use some of these personnel on the storm water pollution prevention team, thus overlapping the two groups to a certain extent. However, the roles and responsibilities of the pollution prevention team reach beyond the activities of a spill prevention and response team, and consequently, it would not be appropriate for a facility simply to substitute the spill response team for the pollution prevention team without clearly examining the roles and requirements related to storm water management (see Section 2.1.2).

Worksheet #1 (located at the end of Chapter 2) is an example of an appropriate form on which to list the team members. To complete this worksheet, list the pollution prevention team members by name, facility position (title), phone number, and include a brief description of each member's specific responsibilities. This list can be directly incorporated into the Storm Water Pollution Prevention Plan, but it should also be displayed or posted within the facility so that other plant employees are aware of who is responsible for storm water management.

EPCRA, Section 313 Facility Team Requirements

EPA's General Permit contains more specific pollution prevention team requirements for facilities subject to reporting under EPCRA, Section 313 for water priority chemicals [Part IV.D.7.b.(9).]. The team must designate a person who will be accountable for spill prevention at the facility and identify this person in the plan. The designated person is responsible for setting up necessary spill emergency procedures and reporting requirements to isolate, contain, and clean up spills and emergency releases of Section 313 water priority chemicals before a discharge can occur.

2.1.2 Building on Existing Environmental Management Plans

EPA GENERAL PERMIT REQUIREMENTS
Consistency with Other Plans **Part IV.D.6.** Storm Water Pollution Prevention Plans may reflect requirements for Spill Prevention Control and Countermeasure (SPCC) plans developed for the facility under Section 311 of the Clean Water Act or BMP programs otherwise required by an NPDES permit for the facility as long as such requirement is incorporated into the Storm Water Pollution Prevention Plan.

Many industrial facilities may have already incorporated storm water management practices into day-to-day operations as a part of an environmental management plan required by other regulations. Potentially relevant elements of a number of different types of plans are listed in Appendix G at the end of this manual. The plans addressed include: the Preparedness, Prevention and Contingency Plan [40 Code of Federal Regulations (CFR) 264 and 265], the Spill Control and Countermeasures requirements (40 CFR 112), the National Pollutant Discharge Elimination System Toxic Organic Management Plan (40 CFR 413, 433, 469), and the Occupational Safety and Health Administration (OSHA) Emergency Action Plan (29 CFR 1910). It is the responsibility of the pollution prevention team to evaluate these other plans to determine which, if any, provisions may be incorporated into the Storm Water Pollution Prevention Plan.

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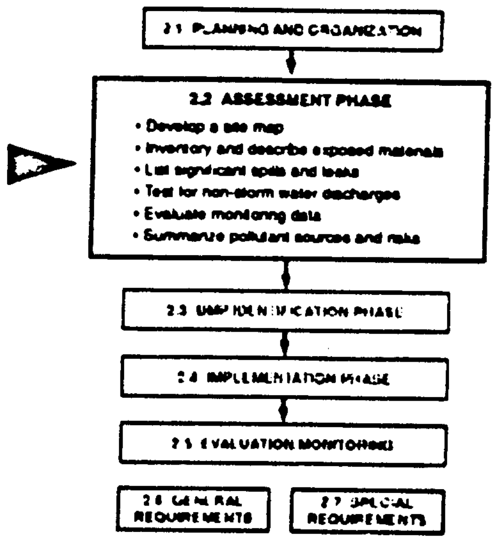
In some cases, it may be possible to build on elements of these plans that are relevant to storm water pollution prevention. For example, if your facility already has in place an effective spill prevention and response plan, elements of that spill prevention strategy may be relevant to your approach for storm water pollution prevention. More specifically, lists of potential pollutants or constituents of concern may provide a starting point for your list of potential storm water pollutants. Although you should build on relevant portions of other environmental plans as appropriate, it is important to note that your Storm Water Pollution Prevention Plan must be a comprehensive, stand-alone document.



2.2 ASSESSMENT PHASE - DESCRIPTION OF POTENTIAL POLLUTANT SOURCES

After identifying who is responsible for developing and implementing your plan and organizing your planning process, you should proceed to this next step—a pollutant source assessment. This is where you take a look at your facility and site and determine what materials or practices are or may be a source of contaminants to the storm water running off your site. To complete this phase, you will:

- Assess the potential sources of storm water pollution at your facility
- Create a map of the facility site to locate pollutant sources and determine storm water management opportunities
- Conduct a material inventory
- Evaluate past spills and leaks
- Identify non-storm water discharges and illicit connections
- Collect or evaluate storm water quality data
- Summarize the findings of this assessment.

EPA GENERAL PERMIT REQUIREMENTS
Description of Potential Pollutant Sources **Part IV.D.2.**
Each plan should provide a description of potential sources which may be reasonably expected to add significant amounts of pollutants to storm water discharges or which may result in the discharge of pollutants during dry weather from separate storm sewers draining the facility. Each plan shall identify all activities and significant materials which may potentially be significant pollutant sources.

This phase is designed to help you to target the most important pollutant sources for corrective and/or preventive action, thus using a "risk-based" approach to environmental protection. Details on how to complete this assessment are provided in the next six subsections of this chapter (see 2.2.1-2.2.6). These sections of the manual will help you discover areas at your facility that have the potential for contributing pollutants to storm water. Within each of the following sections, you will find helpful worksheets and suggestions for accomplishing a complete and accurate assessment of existing and potential problems. Each of the required components builds on the others; therefore, it is very important to perform each step thoroughly.

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2.2.1 Developing a Site Map

EPA GENERAL PERMIT REQUIREMENTS

Site Drainage and Potential Pollutant Sources

Part IV.D.2.a.(1).

The facility site map must include:

- An outline of the drainage area of each storm water outfall
- Location of any existing structural control measures used to reduce pollutants in storm water runoff
- Surface water bodies
- Locations where significant materials are exposed to precipitation
- Locations where major spills or leaks have occurred
- Locations for each of the following activities (where exposed to storm water):
  - Fueling stations
  - Vehicle and equipment maintenance and/or cleaning areas
  - Loading/unloading areas
  - Treatment, storage, or waste disposal areas
  - Liquid storage tanks
  - Processing areas
  - Storage areas.

The facility site map is basically an illustration of the overall site and location, and should indicate property boundaries, buildings and operation or process areas, as well as provide information on drainage, storm water control structures, and receiving streams. Locating these features on the map will help you assess where potential storm water pollutants are located on your site, where they mix with storm water, and where storm water leaves your site. All of this information is essential in identifying the best opportunities for storm water pollution prevention or control. Worksheet #2 (located at the end of Chapter 2) is designed to help you develop an appropriate and useful site map.

Figures 2.3 and 2.4 are good examples of site maps with different layers of information to help locate sources of pollution on your site. When properly drafted, your site map will be a very useful tool to assist in designing the proper pollution prevention controls, thereby preventing further degradation of water quality by reducing additional water pollution.

Outfalls and Drainage Areas

Once boundaries and facility structures have been shown on your site map, you should identify all of the storm water outfalls (also called "discharge points") on your site. A storm water outfall is the point where storm water enters a natural waterway or a separate storm sewer system. If your facility has its own storm water conveyance system, locate where the pipes or conveyances discharge to a stream, river, lake, or other water body. If your facility discharges to a municipal separate storm sewer system, your onsite drainage point into the system is an outfall. However, on many sites, storm water is simply collected in ditches. The discharge points may not be so obvious, particularly when it is not raining. In these cases, it may be necessary to inspect your site

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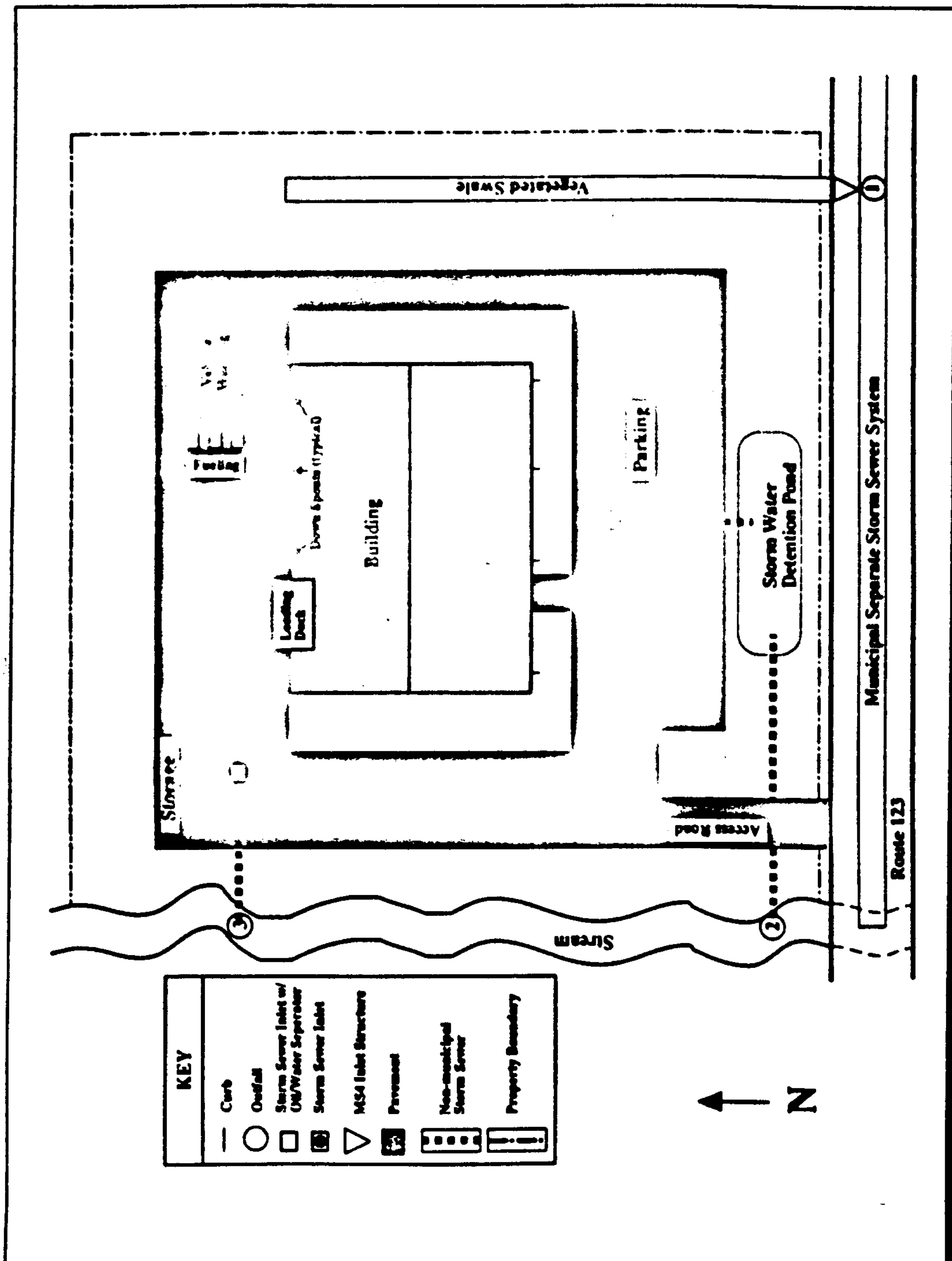

FIGURE 2.3 EXAMPLE SITE MAP

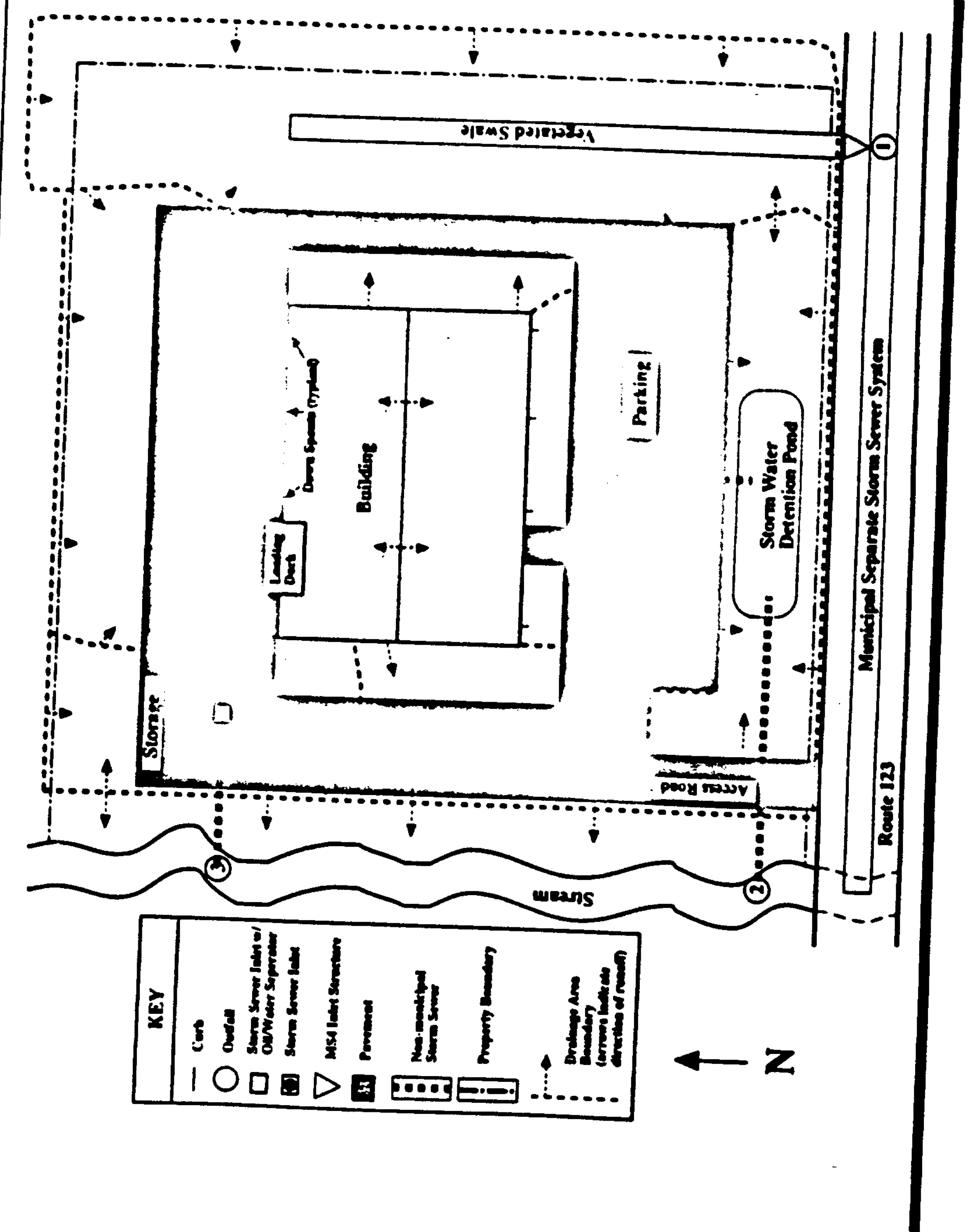

FIGURE 2.4 EXAMPLE SITE MAP WITH DRAINAGE AREAS

particularly when it is not raining. In these cases, it may be necessary to inspect your site during a rain storm to identify your discharge points. Clearly label each outfall either with letters (A, B, C, etc.) or numbers (1, 2, 3, etc.) so that you can easily reference these discharge points in other sections of your Storm Water Pollution Prevention Plan.

Working back from the storm water outfalls you have identified, now determine the drainage areas for each outfall (see Figure 2.4). A topographic map can help with this task if one with the suitable scale is readily available. For larger facilities (greater than 25 acres), 7.5 minute topographic maps, available from the United States Geological Survey (USGS), probably have the level of detail necessary to determine site drainage patterns.

> Maps may be purchased from local commercial dealers or directly from USGS information offices. Check your local yellow pages for commercial dealers. Topographic maps may also be purchased by mail. Standard topographic quadrangles cost $2.50. You can order maps from the following locations:
>
> USGS Map Sales
> Box 25286
> Denver, CO 80225
>
> or
>
> for Alaska maps:
> USGS Map Sales
> 101 12th Ave., #12
> Fairbanks, AK 99701

For smaller sites, examination of a topographic map may not reveal very much about the drainage patterns of the site. A simple alternative is to examine the contours of your site. A visual observation of flows or the use of small floatables or dyes in concentrated flows are simple methods to determine drainage patterns on your facility. Drainage patterns may be very obvious in some cases, such as drainage down a particular hill on the site. In areas where the site appears to be relatively flat, a rough study of storm water flow during a rain event should provide you with a sufficient sense of the flow patterns.

Structural Storm Water Controls

Other features to include on the site map are the locations and identification of any existing structural control measures already in place that are used to control or direct storm water runoff. A structural control measure is any physically constructed feature you have onsite that is used specifically to change the way that storm water flows or that is used to remove pollutants from storm water. Examples of structural controls include: retention/detention ponds, flow diversion structures (including ditches and culverts), vegetative swales, porous pavement, sediment traps, and any soil stabilization or erosion control practices. See Chapter 4 for a more complete description and illustrations of these structures. Each structure should be clearly identified on the site map, as illustrated in Figure 2.3.

Surface Waters

On the site map, you should label all surface water bodies on or next to the site. This includes any stream, river, lake, or other water body (see Figure 2.3 as an example). Each water body should be identified by name. If you do not know the name of the water body, you can check the USGS topographical maps discussed above for the legal name. Your municipal government may also have municipal maps that identify small streams by name. If your storm water runoff flows into a small, unnamed tributary, the name of the downstream water body will be sufficient.

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Potential Pollutant Sources

To develop a useful site map for your facility's Storm Water Pollution Prevention Plan, you must also indicate other items on the map so that you understand what activities are taking place in each drainage area, and therefore, what types of pollutants may be present in storm water from these areas. These features include:

- Topography of site (discussed above)
- Location of exposed significant materials (see Section 2.2.2)
- Locations of past spills and leaks (see Section 2.2.3)
- High-risk waste generating areas and activities common on industrial sites, such as:
  - Fueling stations
  - Vehicle and equipment maintenance
  - Vehicle and equipment washing
  - Loading and unloading areas
  - Above-ground liquid storage tanks
  - Industrial waste management areas and outside manufacturing
  - Outside storage of raw materials, by-products, or finished products.

You will notice that specific BMPs may be applied to control the amount of pollutants in storm water discharges from these areas (see Chapter 3). Now is the time to determine if any of these activities take place onsite, and in which drainage areas they take place.

EPA GENERAL PERMIT REQUIREMENTS
Types of Pollutants and Flow Direction Part IV.D.2.a.(2).
For each area of the facility that generates storm water discharges associated with industrial activity with a reasonable potential for containing significant amounts of pollutants, include a prediction of the direction of flow and identify the types of pollutants which are likely to be present in storm water discharges associated with industrial activity. Factors to consider include the toxicity of the chemical; quantity of chemicals used, produced, or discharged; the likelihood of contact with storm water; and the history of significant leaks or spills of toxic or hazardous pollutants. Flows with a significant potential for causing erosion shall be identified.

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2.2.2 Material Inventory

EPA GENERAL PERMIT REQUIREMENTS
Inventory of Exposed Materials Part IV.D.2.b. Conduct an inventory of materials that may be exposed to storm water at your site, and include a narrative description of: • Significant materials that have been handled, treated, stored, or disposed in a manner to allow exposure to storm water between the time of three years prior to the date of permit issuance and the present • Method(s) and location of onsite storage or disposal • Materials management practices employed to minimize contact of these materials with storm water runoff between the time of three years prior to the date of the issuance of the permit and the present • Existing structural and nonstructural control measures to reduce pollutants in storm water runoff, including their locations • Any treatment of storm water runoff.

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The next step in the Assessment Phase is to conduct a material inventory at your site, specifically looking for materials that have been exposed to storm water and measures you have taken to prevent the contact of these materials with storm water. Maintaining an up-to-date material inventory is an efficient way to identify what materials are handled onsite and which may contribute to storm water contamination problems. As discussed above, these potential pollutant sources should be identified on your facility's site map.

Worksheet #3 (located at the end of Chapter 2) will help guide you through the process of conducting a material inventory for your Storm Water Pollution Prevention Plan. Although an inventory of all materials (exposed and not exposed) is required as part of EPA's General Permits, conducting such an inventory is a good first step in compiling a list of <u>exposed</u> materials. If any of the significant materials on your site have been exposed to storm water in the three years prior to the effective date of your permit, fill out Worksheet #3A and include it in your plan.

Inventory of Exposed Significant Materials

"Significant materials," as defined in 40 CFR 122.26(b)(12), are substances related to industrial activities such as process chemicals, raw materials, fuels, pesticides, and fertilizers (see Glossary in Appendix B for exact definition). When these substances are exposed to storm water runoff, they may be carried to a receiving stream with the storm water flow. Therefore, identification of these materials helps to determine where a potential for contamination exists and is the first step in identifying appropriate BMPs to address this contamination potential.

To inventory the materials on your site, inspect your site carefully. You may wish to use the site checklist (page 2-14) to help you identify exposed materials. Focus on areas where you store, process, transport or transfer any materials used or produced during your industrial processes. Check any storage tanks, pipes or pumping areas and note any leaks or spills. Observe any loading or unloading operations and indicate whether any industrial materials are exposed to storm water during those processes. Look at any unsealed dumpsters or disposal units/areas where you deposit wastes from your industrial activities and document instances where waste materials are exposed to rain. Also pay attention to material handling equipment, including everything from vehicles to pallets, where raw and waste materials from your industrial activities are exposed. Finally, consider areas such as the roof where particles are emitted from air vents and are likely to fall within your drainage areas.

Site Checklist
☐ Does your facility show signs of poor housekeeping (cluttered walkways, unswept floors, uncovered materials, etc.)?
☐ Are there spots, pools, puddles, or other traces of oil, grease, or other chemicals on the ground?
☐ Is there discoloration, residue, or corrosion on the roof or around vents or pipes that ventilate or drain work areas?
☐ Do you see leaking equipment, pipes, containers, or lines?
☐ Are there areas where absorbent materials (kitty litter, saw dust, etc.) are regularly used?
☐ Do you notice signs such as smoke, dirt, or fumes that indicate material losses?
☐ Do you smell strange odors, or experience eye, nose, or throat irritation when you first enter the work area? These are indications of equipment leaks.
☐ Do storage containers show signs of corrosion or leaks?
☐ Are there open containers, stacked drums, shelving too small to properly handle inventory, or other indications of poor storage procedures?
☐ Are containers properly labeled?

These are some basic guidelines meant to help you determine what kinds of things to look out for. This list does not necessarily cover every possible source of pollutants. As the site operator, you are responsible for knowing the particular concerns associated with your activity. Be as detailed as you can in your description of the significant materials exposed at your facility. Discuss what you found in your assessment, the amounts present and their location. Update this inventory whenever new, significant materials are introduced and exposed onsite so that your management practices can be modified to suit any changes.

Next, you should give closer scrutiny to areas where you store or dispose of industrial materials. Inspect your various containers carefully and note whether there are any openings, holes or leaks that allow storm water to contact significant materials in those containers.

Existing Management Measures and Treatment of Storm Water Runoff

Now that you have described the potential pollutant sources in storm water runoff from your site, you should describe what management practices you currently use. Management practices can be as simple as scheduled sweeping of the material transfer area. In this section of your plan you must describe both structural and nonstructural management practices. Structural management practices are those practices that entail construction of manmade structures such as berms, detention ponds, or grassed swales, whereas nonstructural management practices involve regularly scheduled actions (such as sweeping, inspections, or improved materials handling and management practices).

Remember that the purpose of BMPs is to keep the pollutants out of storm water runoff by reducing material exposure to storm water, directing the storm water away from contaminated areas, or reducing the volume of potentially polluting materials on the site.

Finally, you must describe any treatment that you provide for the storm water discharges from your site. The treatment of storm water is often accomplished through holding in a detention pond which allows for settling of inorganic solids and partial removal of organic contaminants. In the case of detention ponds, you should describe the size and average depth of each pond on your site (storage volume). You should also provide any design criteria (i.e., design flow rates, etc.) for the pond that may be available to you from engineering design reports or diagrams. Your site may also direct some of your storm water into your process water treatment system. If so, you should identify what type of treatment is provided, and whether this is allowed under your NPDES or other discharge permit. In any case, be sure to specify areas from which the treated storm water drains.

2.2.3 Identifying Past Spills and Leaks

EPA GENERAL PERMIT REQUIREMENTS
Spills and Leaks **Part IV.D.2.c.** Include a list of significant spills and significant leaks of toxic or hazardous pollutants that occurred at areas that are exposed to precipitation or that otherwise drain to a storm water conveyance at the facility after the date of three years prior to the effective date of this permit. Such list shall be updated as appropriate during the term of this permit.

The next component of the assessment phase of your pollution prevention plan is a list of significant spills and significant leaks of toxic or hazardous materials that have occurred at your facility. This list provides information on potential sources of storm water contamination. The first question that comes to mind is "What is a significant spill or leak?"

EPA has defined "significant spills" to include releases within a 24-hour period of hazardous substances in excess of reportable quantities under Section 311 of the Clean Water Act and Section 102 of the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA). Reportable quantities are set amounts of substances in pounds, gallons, or other units and are listed in 40 CFR Part 117 and 40 CFR Part 302. This list is included as Appendix H in this manual. If your facility releases these listed hazardous substances to the environment in excess of these amounts, you are required to notify the National Response Center at (800) 424-8802 as soon as possible. Releases are defined to include any spilling, leaking, pumping, pouring, emitting, emptying, discharging, injecting, escaping, leaching, dumping, or disposing into the environment.

Worksheet #4 (located at the end of Chapter 2) can help you organize this list of leaks and spills. The areas on your site where significant leaks or spills have occurred are areas on which you should focus very closely when selecting activity-specific or site-specific BMPs.

If several of these events have occurred at your facility, pay special attention to Section 2.3.1, which discusses spill prevention and response procedures. Adequate spill prevention and response

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procedures are one of the BMPs that should be included in your pollution prevention plan. Using the proper procedures will reduce the likelihood of spills or releases in the future, thus reducing the opportunity for spilled pollutants to come into contact with storm water.

The above list of significant leaks and spills, together with the other information gathered to identify pollutants and sources, provides the necessary focus for the BMP Identification Phase of your facility's Storm Water Pollution Prevention Plan. This information is used to target pollution prevention activities such as preventive maintenance, good housekeeping, spill prevention and response procedures, employee training, and storm water management controls such as covering, flow diversion, erosion control and treatment that ultimately will reduce pollutant loadings in storm water discharges.

2.2.4 Identifying Non-Storm Water Discharges

EPA GENERAL PERMIT REQUIREMENTS

Non-Storm Water Discharges

Part IV.D.3.g.(1).

The plan must include a certification that all storm water outfalls have been tested or evaluated for the presence of non-storm water discharges. The certification shall include:

- **Identification of potential non-storm water discharges**
- **A description of the results of any test and/or evaluation for the presence of non-storm water discharges**
- **The evaluation criteria or test method used**
- **The date of testing and/or evaluation**
- **The onsite drainage points that were directly observed during the test and/or evaluation.**

This certification shall be signed in accordance with Section 2.6.2 in this manual and must be included in your Storm Water Pollution Prevention Plan. An example certification form is provided as Worksheet #5.

If this certification is not feasible because you do not have access to an outfall, manhole, or other point of access to the final storm water discharge point(s), you should describe why the certification was infeasible. You also must notify the permitting authority by October 1, 1993 (or 180 days after submitting the Notice of Intent (NOI) for facilities that begin industrial activities after October 1, 1992), of any potential sources of non-storm water discharges to the storm water discharge and why you could not perform the test for non-storm water discharges. This certification must be signed in accordance with Section 2.6.2 of this manual and submitted to the permitting authority. An example Failure to Certify form is provided as Worksheet #6.

Examples of non-storm water discharges include any water used directly in the manufacturing process (process water), air conditioner condensate, non-contact cooling water, vehicle wash water, or sanitary wastes. Connections of non-storm water discharges to a storm water collection system are common yet are often unidentified. Those types of discharges are significant sources of water quality problems. Unless permitted by an NPDES permit, such discharges are illegal. If such connections are discovered, disconnect them or submit an NPDES permit application (Form 2C for process wastewater or 2E for nonprocess wastewater) to your permitting authority. Such interconnections must be disconnected or covered by an NPDES permit.

To check for non-storm water discharges, you may elect to use one of four common dry weather tests described below and in more detail in Appendix F: (1) visual inspection; (2) plant schematic review; and (3) dye testing.

Visual Inspection

The easiest method for detecting non-storm water connections into the storm water collection system is simply to observe all discharge points during dry weather. Inspect each discharge point on three separate occasions. As a rule, the discharge point should be dry during a period of extended dry weather since a storm water collection system should only collect storm water. Keep in mind, however, that drainage of a particular rain event can continue for three days or more after the rain has stopped. In addition, infiltration of ground water into the underground collection system is also common. To be sure about the source of any flow during dry weather, you may need to perform one of the additional tests described below.

Sewer Map

A review of a plant schematic is another simple way to determine if there are any interconnections into the onsite storm water collection system. A sewer map or plant schematic is a map of pipes and drainage systems used to carry process wastewater, non-contact cooling water, air conditioner condensate, and sanitary wastes (bathrooms, sinks, etc.). A common problem, however, is that sites often do not have accurate, up-to-date schematics. If you do have an accurate and reliable plant schematic, you can simply examine the pathways of the different water circuits listed above. Be sure also to investigate where the floor drains discharge. These are commonly connected to the storm sewer system, especially in older buildings.

Dye Testing

Another method for detecting improper connections to the storm water collection system is dye testing. A dye test can be performed by simply releasing a dye into either your sanitary or process wastewater system and examining the discharge points from the storm water collection system for discoloration. A detailed description of the equipment needed and proper procedures for a dye test is included in Appendix F.

Non-Storm Water Discharges

As noted above, unless covered by an NPDES permit, non-storm water discharges are illegal. Generally, non-storm water discharges are issued individual NPDES permits based on application Form 2C (for process wastewater) or Form 2E (for nonprocess wastewater). However, EPA's General Permit authorizes the following types of non-storm water discharges:

- Discharges from fire fighting activities
- Fire hydrant flushings
- Potable water sources including waterline flushings
- Irrigation drainage

- Lawn watering
- Uncontaminated ground water
- Foundation or footing drains where flows are not contaminated with process materials
- Discharges from springs
- Routine exterior building washdown which does not use detergents or other compounds
- Pavement wash waters where spills or leaks of toxic or hazardous materials have not occurred and where detergents are not used
- Air conditioning condensate.

Be sure to examine your facility's storm water permit to determine whether it authorizes any of these or other non-storm water discharges. If your permit does not authorize non-storm water discharges occurring at your facility, you should contact your permitting authority or the Storm Water Hotline for more information about how to address these discharges.

EPA GENERAL PERMIT REQUIREMENTS
Non-Storm Water Discharges
Part IV.D.3.g.(2).
Except for flows from fire fighting activities, sources of non-storm water that are authorized by this permit must be identified in the plan. The plan shall identify and ensure the implementation of appropriate pollution prevention measures for the non-storm water component of the discharge.

Generally, except for flows from fire fighting activities, all non-storm water connections that are identified and that are authorized by your storm water discharge permit should be identified in the Storm Water Pollution Prevention Plan. Where necessary to minimize pollutants in these discharges, pollution prevention measures should be adopted and implemented. The pollution potential from these sources can be significantly reduced where a conscious effort is taken to control them.

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2.2.5 Storm Water Monitoring Data

EPA GENERAL PERMIT REQUIREMENTS
Sampling Data Part IV.D.2.d. Include a summary of any existing discharge sampling data describing pollutants in storm water discharges from the facility and a summary of sampling data collected during the term of this permit.

Storm water sampling data provide information that describes the quality of storm water discharges. These data are valuable because they indicate the potential environmental risk of the discharge by identifying the types and amounts of pollutants present. In addition, these data can be used to identify potential sources of storm water pollution.

During the site assessment phase, permittees should collect and summarize any storm water sampling data that were collected in the past. Historical storm water monitoring data may be very useful in locating areas which have previously contributed pollutants to storm water discharges and identifying what the problem pollutants are. In your summary of these data, describe the sample collection procedures used. Be sure to cross-reference the particular storm water outfall sampled to one of the outfalls designated on your site map.

Although some permittees may not have to conduct storm water sampling under the permit that is issued to that facility, incorporation of these data into the Storm Water Pollution Prevention Plan as it is collected will provide a basis for evaluating the effectiveness of the plan. Under EPA's General Permit, certain classes of facilities are required to conduct storm water sampling either annually or semiannually throughout the term of the permit. Appendix J contains a table summarizing these sampling requirements, including the parameters for which analysis is required and the sampling frequency. State-issued storm water general permits may include similar provisions. Generally, where sampling is required, facilities must collect and analyze grab and composite samples in accordance with the protocol established in 40 CFR Part 136. EPA has published a guidance manual addressing storm water sampling requirements and procedures for NPDES storm water discharge permit applications. Although directed toward application requirements, the guidance manual contains information that would be of assistance to facilities required to sample under a storm water general permit. To obtain a copy of the manual, call the Storm Water Hotline at (703) 821-4823.

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2.2.6 Assessment Summary

EPA GENERAL PERMIT REQUIREMENTS
Risk Identification and Summary of Potential Pollutant Sources Part IV.D.2.e. Include in your plan a narrative description of the potential pollutant sources and identify any pollutant of concern that may be generated by the following activities at your facility: • Loading and unloading operations • Outdoor storage activities • Outdoor manufacturing or processing activities • Significant dust or particulate generating activities • Onsite waste disposal practices.

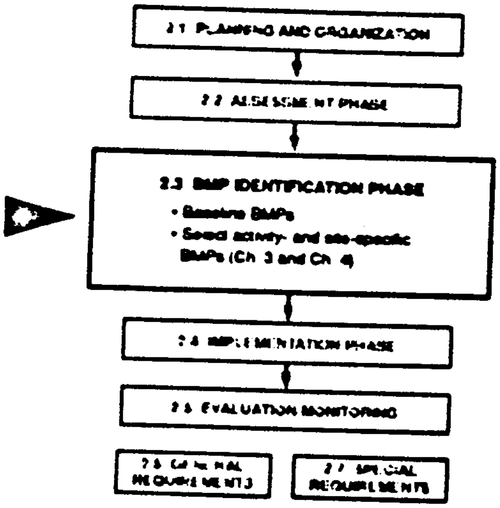
Once you have completed the above steps in your pollutant source assessment, you should have enough information to determine which areas, activities or materials may contribute pollutants to storm water runoff from your site. With this information, you can select the most appropriate BMPs to prevent or control pollutants from these areas.

The following paragraph is an example of how you can analyze the information you have gathered and start to figure out what you can do to correct these problems:

> *In a particular drainage area, you have a vehicle maintenance facility area where oil filters are stored outdoors. You found that no material management practices were currently being used to protect the used filters from contact with storm water. You would then suspect that the storm water draining from that area would most likely contain a significant amount of oil and grease. Therefore, you have concluded that you need to do something to reduce the possibility of oil and grease mixing with storm water.*

EPA's General Permit requires this type of narrative description summarizing any potential source of storm water pollutants, and what types of pollutants have already been or may be found in storm water runoff from the site.

Worksheet #7 (located at the end of Chapter 2) will help you organize the pollutant sources that you identified during the site assessment phase, relate them to management practices that you already have in place, and list potential new BMP options to address remaining pollutant sources.



2.3 BMP IDENTIFICATION PHASE

Once you have identified and assessed potential and existing sources of contamination to storm water at your facility, the next step is to select the proper measures or BMPs that will eliminate or reduce pollutant loadings in storm water discharges from your facility site. Specifically, your plan design will include the following BMPs:

- Good housekeeping
- Preventive maintenance
- Visual inspections
- Spill prevention and response
- Sediment and erosion control
- Management of runoff
- Employee training
- Recordkeeping and reporting
- Other BMPs as appropriate

BMPs are measures used to prevent or mitigate pollution from any type of activity. BMPs are a very broad class of measures and may include processes, procedures, schedules of activities, prohibitions on practices, and other management practices to prevent or reduce water pollution. In essence, they are anything a plant manager, department foreman, environmental specialist, consultant or employee may identify as a method, short of actual treatment, to curb water pollution. They may be inexpensive or costly. BMPs can be just about anything that "does the job" of preventing toxic or hazardous substances from entering the environment.

The purpose of this section is to describe the "baseline" BMPs that you must include in your facility's storm water pollution prevention program and offer some guidelines about how to select more "advanced" BMPs that are tailored to the specific pollutant sources on your particular site. With this information, you should be able to design a storm water management program that best addresses any problems with runoff from your facility's site.

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2.3.1 Baseline Best Management Practices

EPA GENERAL PERMIT REQUIREMENTS
Measures and Controls Part IV.D.3. Each facility covered by this permit shall develop a description of storm water management controls appropriate for the facility and implement such controls. The appropriateness and priorities of controls in a plan shall reflect identified potential sources of pollutants at the facility. The description of storm water management controls shall address the following minimum components, including a schedule for implementing such controls: • Good Housekeeping • Preventive Maintenance • Visual Inspections • Spill Prevention and Response • Sediment and Erosion Control • Management of Runoff • Employee Training (see Section 2.4.2) • Recordkeeping and Reporting (see Section 2.5.2)

"Baseline" BMPs are practices that are inexpensive, relatively simple, and applicable to a wide variety of industries and activities. Most industrial facilities already have these measures in place for product loss prevention, accident and fire prevention, worker health and safety, or to comply with other environmental regulations. The purpose of this section is to highlight how these common practices can be improved and tailored to prevent storm water pollution. EPA's Storm Water Program is emphasizing these generic measures because they can be effective, are cost-effective, and because they emphasize prevention over treatment.

Industrial facilities must implement, at a minimum, the above-listed eight baseline BMPs, where appropriate. How each of these BMPs can prevent storm water pollution is described in detail below.

Worksheet #7a (located at the end of Chapter 2) is designed to help you list the specific activities or practices that you select to include in your plan for each of the baseline BMPs.

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Good Housekeeping

EPA GENERAL PERMIT REQUIREMENTS
Good Housekeeping Part IV.D.3.a. Good housekeeping requires the maintenance of areas which may contribute pollutants to storm water discharges in a clean, orderly manner.

Good housekeeping practices are designed to maintain a clean and orderly work environment. Often the most effective first step towards preventing pollution in storm water from industrial sites simply involves using good common sense to improve the facility's basic housekeeping methods. Poor housekeeping can result in more waste being generated than necessary and an increased potential for storm water contamination. A clean and orderly work area reduces the possibility of accidental spills caused by mishandling of chemicals and equipment and should reduce safety hazards to plant personnel. Well maintained material and chemical storage areas will reduce the possibility of storm water mixing with pollutants.

There are some simple procedures a facility can use to promote good housekeeping, including improved operation and maintenance of industrial machinery and processes, material storage practices, material inventory controls, routine and regular clean-up schedules, maintaining well organized work areas, and educational programs for employees about all of these practices. The following sections describe these good housekeeping procedures and provide a checklist that you can use to evaluate and improve your facility's storm water pollution prevention program.

Operation and Maintenance

These practices ensure that processes and equipment are working well. Improved operation and maintenance practices are easy to implement. Here are a few examples of basic operation and maintenance BMPs that should be incorporated in your good housekeeping program:

- Maintain dry and clean floors and ground surfaces by using brooms, shovels, vacuum cleaners, or cleaning machines
- Regularly pickup and dispose of garbage and waste material
- Make sure equipment is working properly (see Section 2.3.4 on preventive maintenance)
- Routinely inspect for leaks or conditions that could lead to discharges of chemicals or contact of storm water with raw materials, intermediate materials, waste materials, or products (see Visual Inspection BMP below)
- Ensure that spill cleanup procedures are understood by employees (see Spill Prevention and Response BMP below).

Material Storage Practices

Improper storage can result in the release of materials and chemicals that can cause storm water runoff pollution. Proper storage techniques include:

- Providing adequate aisle space to facilitate material transfer and easy access for inspections
- Storing containers, drums, and bags away from direct traffic routes to prevent accidental spills (see Spill Prevention and Response BMP below)
- Stacking containers according to manufacturers' instructions to avoid damaging the containers from improper weight distribution
- Storing containers on pallets or similar devices to prevent corrosion of the containers which can result when containers come in contact with moisture on the ground
- Assigning the responsibility of hazardous material inventory to a limited number of people who are trained to handle hazardous materials.

Material Inventory Procedures

Keeping an up-to-date inventory of all materials (hazardous and non-hazardous) present on your site will help to keep material costs down caused by overstocking, track how materials are stored and handled onsite, and identify which materials and activities pose the most risk to the environment. The following instructions explain the basic steps to completing a material inventory. Worksheets #3 and 3A provide an example of the types of information you should collect while conducting the inventory.

- **Identify all chemical substances present in the workplace.** Walk through the facility and review the purchase orders for the previous year. List all of the chemical substances used in the workplace, and then obtain the Material Safety Data Sheet (MSDS) for each.
- **Label all containers** to show the name and type of substance, stock number, expiration date, health hazards, suggestions for handling, and first aid information. This information can usually be found on the MSDS. Unlabeled chemicals and chemicals with deteriorated labels are often disposed of unnecessarily or improperly.
- **Clearly mark on the inventory hazardous materials that require special handling, storage, use, and disposal considerations.**

Improved material tracking and inventory practices, such as instituting a shelf-life program, can reduce the waste that results from overstocking and the disposal of out-dated materials. Careful tracking of all materials ordered may also result in more efficient materials use.

Decisions on the amount of hazardous materials the facility stores should include an evaluation of your emergency control systems. Ensure that storage areas are designed to contain spills.

Employee Participation

Frequent and proper training of employees in good housekeeping techniques reduces the possibility that the chemicals or equipment will be mishandled. Motivating employees to reduce waste generation is another important pollution prevention technique. Section 2.4.2 provides more information on employee training programs. Here are some suggestions for involving employees in good housekeeping practices:

- Incorporate information sessions on good housekeeping practices into the facility's employee training program
- Discuss good housekeeping at employee meetings
- Publicize pollution prevention concepts through posters
- Post bulletin boards with updated good housekeeping procedures, tips and reminders.

Good Housekeeping Checklist
☐ Is good housekeeping included in the storm water pollution prevention program?
☐ Are outside areas kept in a neat and orderly condition?
☐ Is there evidence of drips or leaks from equipment or machinery onsite?
☐ Is the facility orderly and neat? Is there adequate space in work areas?
☐ Is garbage removed regularly?
☐ Are walkways and passageways easily accessible, safe, and free of protruding objects, materials or equipment?
☐ Is there evidence of dust on the ground from industrial operations or processes?
☐ Are cleanup procedures used for spilled solids?
☐ Is good housekeeping included in the employee program?
☐ Are good housekeeping procedures and reminders posted in appropriate locations around the workplace?
☐ Are there regular housekeeping inspections?

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Preventive Maintenance

EPA GENERAL PERMIT REQUIREMENTS
Preventive Maintenance Part IV.D.3.b. Your preventive maintenance program must include: • Timely inspection and maintenance of storm water management devices (e.g., cleaning oil/water separators, catch basins) • Inspection and testing of facility equipment and systems to uncover conditions that could cause breakdowns or failures resulting in discharges of pollutants to surface waters • Proper maintenance of facility equipment and systems.

Most plants already have preventive maintenance programs that provide some degree of environmental protection. The program you undertake as part of the Storm Water Pollution Prevention Plan should not just duplicate previous efforts, but should expand the current preventive maintenance programs to include storm water considerations, especially the upkeep and maintenance of storm water management devices. The pollution prevention team should evaluate the existing plant preventive maintenance program and recommend any necessary changes.

Preventive maintenance involves the regular inspection and testing of plant equipment and operational systems (see Visual Inspections description below). These inspections should uncover conditions such as cracks or slow leaks which could cause breakdowns or failures that result in discharges of chemicals to storm sewers and surface waters. The program should prevent breakdowns and failures by adjustment, repair or replacement of equipment. An effective preventive maintenance program should therefore include the following elements:

- Identification of equipment, systems, and facility areas that should be inspected
- Schedule for periodic inspections or tests of these equipment and systems
- Appropriate and timely adjustment, repair or replacement of equipment and systems
- Maintenance of complete records on inspections, equipment, and systems.

Identification of Equipment to Inspect

The first step is to identify which systems or equipment may malfunction and cause spills, leaks, or other situations that could lead to storm water runoff contamination. Look back at what sources of potential storm water contamination were identified during the pollutant source assessment phase. The following list identifies some types of equipment to include in your preventive maintenance inspection and testing program:

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Equipment to Inspect
• Pipes • Pumps • Storage tanks and bins • Pressure vessels • Pressure release valves • Process and material handling equipment • Storm water management devices (oil/ water separators, catch basins, or other structural or treatment BMPs).

Schedule Routine Preventive Maintenance Inspections

Once you have identified which equipment and areas to inspect at your facility, set schedules for routine inspections. Include examination for leaks, corrosion, support or foundation failure, or other forms of deterioration or leaks in your inspection. Look for spots or puddles of chemicals and document any detection of smoke, fumes, or other signs of leaks. Periodic testing of plant equipment for structural soundness is a key element of preventive maintenance. This can be done by making sure storage tanks are solid and strong enough to hold materials. Another important consideration is when and how often preventive maintenance inspections should be conducted to ensure that this practice is effective. Smaller facilities with little equipment and few systems may still find it necessary to conduct frequent inspections if the equipment is older and more susceptible to leaks or other discharges. Preventive maintenance inspections may be conducted as part of your regular visual inspections.

Equipment Repair or Replacement

Promptly repair or replace defective equipment found during inspections and testings. Keeping spare parts for equipment that needs frequent repair is another simple practice that can help avoid problems and equipment down-time.

Records on Preventive Maintenance

Include a suitable records system for scheduling tests and documenting inspections in the preventive maintenance program. Record test results and follow up with corrective action. Make sure records are complete and detailed. These records should be kept with other visual inspection records.

EPCRA, Section 313 Facility Preventive Maintenance Inspection Requirements

EPA's General Permit contains additional preventive maintenance inspection requirements for facilities subject to reporting under EPCRA, Section 313 for water priority chemicals [Part IV.D.7.b.(7).]. For these facilities, all areas of the facility must be inspected for the following at appropriate intervals as specified in the plan:

- Leaks or conditions that would lead to discharges of Section 313 water priority chemicals
- Conditions that could lead to direct contact of storm water with raw materials, intermediate materials, waste materials or products
- Examine piping, pumps, storage tanks and bins, pressure vessels, process and material handling equipment, and material bulk storage areas for leaks, wind blowing, corrosion, support or foundation failure, or other deterioration or noncontainment.

These inspections must occur at intervals based on facility design and operational experience, and the timing must be specified in the plan.

When a leak or other threatening condition is found, corrective action must be taken immediately or the facility unit or process must be shut down until the problem is repaired.

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Visual Inspections

EPA GENERAL PERMIT REQUIREMENTS
Visual Inspections **Part IV.D.3.d.** • Identify qualified plant personnel who will inspect plant equipment and areas at appropriate intervals in the plan • Track results of inspections to ensure that appropriate actions are taken • Maintain records of all inspections.

Preventing pollution of storm water runoff from your facility requires good housekeeping in areas where materials are handled, stored, or transferred and preventive maintenance of process equipment and systems. Such practices are described in detail above and should be outlined in your Storm Water Pollution Prevention Plan. Regular visual inspections are your means to ensure that all of the elements of the plan are in place and working properly.

Routine visual inspections are not meant to be a comprehensive evaluation of the entire storm water pollution prevention program—that is the function of the Annual Site Inspection and Site Evaluation described in Section 2.5.1 below. Rather, they are meant to be a routine look-over of the facility to identify conditions which may give rise to contamination of storm water runoff with pollutants from your facility.

Every facility is different, so it is up to the facility owner/operator to determine what areas of your facility could potentially contribute pollutants to storm water runoff, and to devise and implement a visual inspection program based on this information. The visual inspection is simply a way to confirm that the measures chosen are in place and working and should periodically take place during storm events. The frequency of visual inspection should be determined by the types and amounts of materials handled at the facility, existing BMPs at the facility, and any other factors that may be relevant, such as the age of the facility (in general, older facilities should be inspected at more frequent intervals than new facilities). The following lists identify some types of equipment and plant areas to include in your Visual Inspections and preventive maintenance plan:

Areas to Inspect
• Areas around all of equipment listed in Preventive Maintenance box • Areas where spills and leaks have occurred in the past • Material storage areas (tank farms, drum storage) • Outdoor material processing areas • Material handling areas (e.g., loading, unloading, transfer) • Waste generation, storage, treatment and disposal areas.

Implementation of a Visual Inspection Plan

The best plan is a simple one, and this includes the visual inspection plan - there is no reason for it to be highly technical, complicated or labor-intensive. If your facility already has a routine surveillance program in place, consider expanding it to include the visual inspection element of your Storm Water Pollution Prevention Plan. For example, if your facility has a security surveillance program, you might consider training facility security personnel to perform the visual inspection program. If your facility has no routine surveillance or inspection program already in place, then a plan must be developed and people must be assigned the responsibility for carrying the inspections out. It is important to remember that the employees carrying out the visual inspection program should be properly trained, familiar with the storm water pollution prevention program, and knowledgeable about proper recordkeeping and reporting procedures.

Records of Inspections

The most important thing for you to remember here is to document all inspections. Inspection records should note when inspections were done, who conducted the inspection, what areas were inspected, what problems were found, and steps taken to correct any problems, including who has been notified. Many industrial facilities will already have some sort of incident reporting procedure in place — existing incident reporting and security surveillance procedures could easily be incorporated into the Storm Water Pollution Prevention Plan. These records should be kept with the plan. EPA's General Permit requires that records be kept until at least one year after coverage under the permit expires.

Visual Inspection Checklist

Do you see:

- ☐ Corroded drums or drums without plugs or covers
- ☐ Corroded or damaged tanks, tank supports, and tank drain valves
- ☐ Torn bags or bags exposed to rain water
- ☐ Corroded or leaking pipes
- ☐ Leaking or improperly closed valves and valve fittings
- ☐ Leaking pumps and/or hose connections
- ☐ Broken or cracked dikes, walls or other physical barriers designed to prevent storm water from reaching stored materials
- ☐ Windblown dry chemicals
- ☐ Improperly maintained or overloaded dry chemical conveying systems.

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Spill Prevention and Response

EPA GENERAL PERMIT REQUIREMENTS
Spill Prevention and Response Part IV.D.3.c. • Identify areas where spills can occur onsite and their drainage points • Specify material handling procedures, storage requirements, and use of equipment such as diversion valves, where appropriate • Identify procedures used for cleaning up spills and inform personnel about these procedures • Provide the appropriate spill clean-up equipment to personnel.

Spills and leaks together are one of the largest industrial sources of storm water pollutants, and in most cases are avoidable. Establishing standard operating procedures such as safety and spill prevention procedures along with proper employee training can reduce these accidental releases. Avoiding spills and leaks is preferable to cleaning them up after they occur, not only from an environmental standpoint, but also because spills cause increased operating costs and lower productivity.

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Development of spill prevention and response procedures is a very important element of an effective Storm Water Pollution Prevention Plan. A spill prevention and response plan may have already been developed in response to other environmental regulatory requirements. If your facility already has a spill prevention and response plan, it should be evaluated and revised if necessary to address the objectives of the Storm Water Pollution Prevention Plan.

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The next section outlines the steps you should take to identify and characterize potential spills, to eliminate or reduce spill potential, and how to respond when spills occur.

Identify Potential Spill Areas

As part of the Assessment Phase of developing the Storm Water Pollution Prevention Plan, you should have created a list or inventory of materials handled, used, and disposed of. A site map indicating the drainage area of each storm water outfall was also created. Now overlay the drainage area map with the locations of areas and activities with high material spill potential to determine where spills will most likely occur. Spill potential also depends on how materials are handled, the types and volumes of materials handled, and how materials are stored on your site. You must describe these factors in your plan.

The activities and areas where spills are likely to occur on your site are listed and described below:

- Loading and unloading areas
- Storage areas
- Process activities

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- Dust or particulate generating processes
- Waste disposal activities.

Loading and unloading areas have a high spill potential because the nature of the activity involves transfer of materials from one container to another. The spill potential is affected by the integrity of the container, the form of the chemical being transferred, the design of the transfer area (bermed vs. direct connection to the storm water collection system), the proximity of this area to the storage area, and procedures for loading and unloading. Evaluate the spill potential from all loading and unloading equipment, such as barges, railroad cars, tank trucks, and front end loaders, as well as storage and vehicle wash areas.

Storage areas, both indoor and outdoor, are potential spill areas. Outdoor storage areas are exposed to storm water runoff and may provide direct contact between potential pollutants and storm water. Indoor storage areas may contaminate storm water if the drains in the storage area are connected to the storm sewer or if improper clean up procedures in the event of a spill are used. This evaluation should consider the type, age, and condition of storage containers and structures (including tanks, drums, bags, bottles). An evaluation of the spill potential of storage areas should also focus on how employees handle materials.

All process areas are potential sources of storm water contamination if the floor drains in these areas are connected to storm sewers (see Section 2.2.4). If these drains cannot be sealed, the process area should be evaluated for the adequacy of spill control structures such as secondary containment, if necessary. One should also consider normal housekeeping procedures. Some process areas are hosed down periodically and the resulting wash water contains pollutants. Outdoor process activities may contaminate storm water if spills are diverted to the storm sewer.

Also, evaluate spill potential from the following stationary facilities:

- Manufacturing areas
- Warehouses
- Chemical processing and or blending areas
- Temporary and permanent storage sites
- Power generating facilities
- Food processing areas
- Tank farms
- Service stations
- Parking lots
- Access roads.

Also evaluate the possibility of storm water contamination from underground sources, such as tanks and pipes. Leaking underground storage tanks are often a source of storm water contamination.

In addition to identifying these and other potential spill areas, projecting possible spill volume and type of material is critical to developing the correct response procedures for a particular area.

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Specify Material Handling Procedures and Storage Requirements

Through the process of developing various spill scenarios, ideas for eliminating or minimizing the spill or its impact will emerge. These solutions should be prioritized and adopted according to conditions of effectiveness, cost, feasibility, and ease of implementation. Following is a list of some suggested activities or alterations that may be made to reduce the potential that spills will occur or impact storm water quality:

- Develop ways to recycle, reclaim and/or reuse process materials to reduce the volume brought into the facility
- Install leak detection devices, overflow controls, and diversion berms
- Disconnect drains from processing areas that lead to the storm sewer (however, be sure that any such action would not create a health hazard within your facility)
- Adopt effective housekeeping practices
- Adopt a materials flow/plant layout plan (i.e., do not store bags that are easily punctured near high-traffic areas where they may be hit by moving equipment or personnel)
- Perform regular visual inspections to identify signs of wear on tanks, drums, containers, storage shelves, and berms and to identify sloppy housekeeping or other clues that could lead to potential spills
- Perform preventive maintenance on storage tanks, valves, pumps, pipes, and other equipment
- Use filling procedures for tanks and other equipment that minimize spills
- Use material transfer procedures that reduce the chance of leaks or spills
- Substitute less or non-toxic materials for toxic materials
- Ensure appropriate security.

Identify Spill Response Procedures and Equipment

In the event that spill prevention measures fail, a swiftly executed response may prevent contamination of storm water. Spill response plans are required by numerous programs for various reasons. However, this may be the first time that a spill response plan specifically addresses protection of storm water quality.

Past experience has shown that the single most important obstacle to an effective spill response plan is its implementation. Develop the plan with its ease of implementation in mind. The spill response procedures should be clear, concise, step-by-step instructions for responding to the spill events at a particular facility. Organize the plan to facilitate rapid identification of the appropriate set of procedures. For example, you may find that the plan works best for your facility when organized by spill location. Another possible method of organization is by spilled material. The key component to implementation is the ability of employees to use the plan quickly and effectively. The specific approach you take will depend on the specific conditions at your facility such as size, number of employees and the spill potential of the site.

The spill response plan is developed based on the spill potential scenarios identified. It reflects a consideration of the potential magnitude and frequency of spills, of the types of materials spilled, and of the variety of potential spill locations. Specific procedures may be needed to correspond to particular chemicals onsite. At all times during the operation of a facility, personnel with appropriate training and authority should be available to respond to spills.

The spill response plan should describe:

- Identification of spill response "team" responsible for implementing the spill response plan.
- Safety measures.
- Procedures to notify appropriate authorities providing assistance (police, fire, hospital, Publicly Owned Treatment Works (POTW), etc.).
- Spill containment, diversion, isolation, cleanup.
- Spill response equipment including:
  - Safety equipment such as respirators, eye guards, protective clothing, fire extinguisher, and two-way radios.
  - Cleanup equipment such as booms, barriers, sweeps, adsorbents, containers, etc.

Following any spills, evaluate how the prevention plan was successful or unsuccessful in responding and how it can be improved.

EPCRA, Section 313, Facility Spill Prevention and Response Requirements

EPA's General Permit sets forth more specific requirements for facilities subject to reporting under EPCRA, Section 313 for water priority chemicals (Part IV.D.7.b.(7).). When a leak or spill of a Section 313 water priority chemical has occurred, the contaminated soil, material, or debris must be removed promptly and disposed of in accordance with Federal, State, and local requirements and as described in the Storm Water Pollution Prevention Plan.

These facilities are also required to designate a person responsible for spill prevention, response, and reporting procedures (see Section 2.1.1, Pollution Prevention Team).

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Sediment and Erosion Control

EPA GENERAL PERMIT REQUIREMENTS
Sediment and Erosion Control
Part IV.D.3.h.
Identify areas which, due to topography, activities, or other factors, have a high potential for significant soil erosion, and identify structural, vegetative, and/or stabilization measures to be used to limit erosion.

There may be certain areas on your site which, due to construction activities, steep slopes, sandy soils, or other reasons, are prone to soil erosion. Construction activities typically remove grass and other protective ground covers resulting in the exposure of underlying soil to wind and rain. Similarly, steep slopes or sandy soils may not be able to hold plant life so that soils are exposed. Because the soil surface is unprotected, dirt and sand particles are easily picked up by wind and/or washed away by rain. This process is called erosion. Erosion can be controlled or prevented with the use of certain BMPs. A number of these measures are described in Chapter 4.

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Management of Runoff

EPA GENERAL PERMIT REQUIREMENTS
Management of Runoff
Part IV.D.3.i.
The plan shall contain a narrative consideration of the appropriateness of traditional storm water management practices (practices other than those which control the source of pollutants) used to divert, infiltrate, reuse, or otherwise manage storm water runoff in a manner that reduces pollutants in storm water discharges from the site. The plan shall provide that measures determined to be reasonable and appropriate shall be implemented and maintained. The potential of various sources at the facility to contribute pollutants to storm water discharges associated with industrial activity (see Part IV.D.2. (description of potential pollutant sources) of this permit) shall be considered when determining reasonable and appropriate measures. Appropriate measures may include: vegetative swales and practices, reuse of collected storm water (such as for a process or as an irrigation source), inlet controls (such as oil/water separators), snow management activities, infiltration devices, and wet detention/retention devices.

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Many BMPs discussed in this chapter are measures to reduce pollutants at the source before they have an opportunity to contaminate storm water runoff. Traditional storm water management practices also can be used to direct storm water away from areas of exposed materials or potential pollutants. Further, traditional storm water management practices can be used to direct storm water that contains pollutants to natural or other types of treatment locations. For example, using an oil/water separator on storm water that has oil and grease in it will take out some of the oil and grease before the storm water leaves the site. Permits will generally not require specific storm water management practices since these practices must be selected on a case-by-case basis depending on the activities at your site and the amount of space you have available.

Chapter 4 provides descriptions of several traditional storm water management practices. Additional sources of information are listed in Appendix A.

2.3.2 Advanced Best Management Practices

In addition to those BMPs that should be routinely incorporated into your storm water prevention pollution plan, you may need to implement some "advanced" BMPs that are specifically directed to address particular pollutant sources or activities on your site. As discussed in Chapters 3 and 4, these BMPs must be tailored to address specific problems.

In determining which BMPs represent the Best Available Technology Economically Achievable (BAT), the following factors are considered: (1) the age of equipment and facilities involved; (2) the process employed; (3) the engineering aspects of the application of various types of control techniques; (4) process changes; (5) the cost of achieving effluent reduction; and (6) non-water quality environmental impact (including energy requirements).

BMP Cost and Effectiveness

The costs of implementing the BMPs described in this manual vary depending upon many factors and site-specific conditions. In general, the required baseline BMPs are relatively low in cost when compared with more traditional storm water treatment or highly engineered controls. Costs also vary depending upon the size of the facility, the number of employees, the types of chemicals or raw materials stored or used, and the nature of plant operations. However, because many of the baseline practices are widely accepted and considered "common sense" or standard good operating practices, many facilities have them in place.

Because BMP effectiveness is also site-specific, this manual does not attempt to provide specific guidance on this matter.

Reduce, Reuse, Recycle

As described in Chapter 1, EPA encourages industrial facilities to choose practices that prevent the contamination of storm water rather than treat it once it is polluted. Use of the Storm Water Management Hierarchy (see Table 2.1) as a tool to help select BMPs for your program will help you discover how to prevent pollution and avoid its associated costs and liabilities while meeting the environmental goals of EPA's Storm Water Program.

When selecting a BMP for your storm water management program, EPA recommends that you choose practices that eliminate or reduce the amount of pollutants generated on your site. This practice is referred to as "source reduction." When it is impossible, select options that recycle or reuse the storm water in your industrial processes, or those that reduce the need to store and expose more hazardous materials to storm water by recycling or recovering used materials. Treating storm water to remove pollutants before they leave the site is the next best option, although this often just transfers the problem from one place or medium to another. Table 2.1, below, provides examples of BMPs that are representative of the different types of storm water management.

TABLE 2.1 CLASSIFICATION OF STORM WATER BMPs

Storm Water Management Hierarchy	Example BMPs
Source Reduction	• Preventive maintenance • Spill prevention • Chemical substitution • Housekeeping • Training • Materials management practices
Containment/Diversion	• Segregating the activity of concern • Covering the activity • Berming the activity • Diverting flow to grassed area • Dust control
Recycling	• Recycling
Treatment	• Oil/water separator • Vegetated swale • Storm water detention pond

2.3.3 Completing the BMP Identification Phase

When you started designing your pollution prevention plan, you assembled certain crucial pieces of information:

- A list of actual and potential storm water discharge problems
- The location of each outfall on a site map showing the drainage route from your property
- A list of the management plans and practices that are already in place at your facility
- Information contained in this manual on "baseline" BMPs and "advanced" BMPs for resolving storm water problems.

At the completion of the BMP identification phase, you should have accomplished the following:

- Reviewed your current management plans and practices to assess their effectiveness in addressing storm water discharges on your site.
- Scheduled the implementation of "baseline" BMPs and whatever "advanced" BMPs were necessary to effectively eliminate storm water pollution problems at your site.
- Determined what to do about any identified, unpermitted connections of non-storm water discharges to separate storm sewers. Your options were to:
  - Discontinue any connections of non-storm water discharges to a separate storm sewer system
  - Obtain an NPDES permit for the non-storm water discharge.

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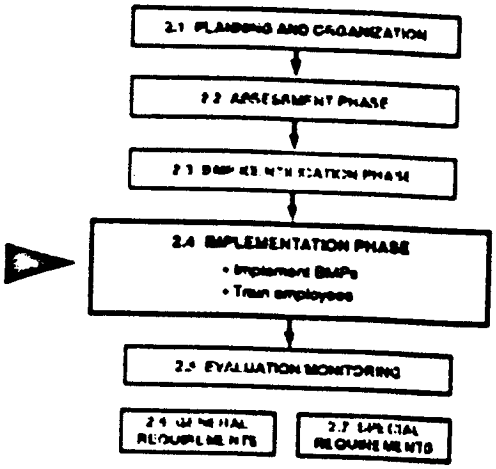
- Identified options for addressing any unresolved storm water discharge problems.
- Gained management approval and acceptance of the plan.



2.4 IMPLEMENTATION PHASE

At this point, you have designed your Storm Water Pollution Prevention Plan and the plan has been approved by facility management. This next section of the manual will guide you through the next major phase in the planning process—implementation. Specifically, you will:

- Implement the selected storm water BMPs
- Train all employees to carry out the goals of the plan.

2.4.1 Implement Appropriate Controls

EPA GENERAL PERMIT REQUIREMENTS
Implementation Part IV.D. Facilities must implement the provisions of the storm water pollution prevention plan as a condition of EPA's general permit. The plan shall include a schedule for implementing identified storm water management controls.

Implementing your plan will involve several steps:

- Develop a schedule for implementation. For example, your schedule might include a deadline for putting improved housekeeping measures into practice. Should implementation involve certain types of modifications to your site (e.g., any construction), you will need to account for the time required to secure any necessary local or State permits.
- Assign specific individuals with responsibility for implementing aspects of the plan and/or monitoring implementation.
- Ensure that management approves of your implementation schedule and strategy and schedule regular times for reporting progress to management.

Worksheet #8 (located at the end of Chapter 2) will help you list the schedule for implementation of your facility's plan.

2.4.2 Employee Training

EPA GENERAL PERMIT REQUIREMENTS
Employee Training Part IV.D.3.e. Employee training programs must inform personnel at all levels of responsibility of the components and goals of the Storm Water Pollution Prevention Plan. Training should address each component of your pollution prevention plan, including how and why tasks are to be implemented. Topics will include: • Spill prevention and response • Good housekeeping • Material management practices. The pollution prevention plan must specify how often training is conducted.

Employee training is essential to effective implementation of the Storm Water Pollution Prevention Plan. The purpose of a training program is to teach personnel at all levels of responsibility the components and goals of the Storm Water Pollution Prevention Plan. When properly trained, personnel are more capable of preventing spills, responding safely and effectively to an accident when one occurs, and recognizing situations that could lead to storm water contamination.

The following sections include ideas about how to create an effective storm water pollution prevention training program for your facility.

Worksheet #9 (located at the end of Chapter 2) is designed to help you organize your employee training program.

Spill Prevention and Response

Spill prevention and response procedures are described in detail in Section 2.3.1. Discuss these procedures or plans in the training program in order to ensure all plant employees, not just those on the spill response teams, are aware of what to do if a spill occurs. Specifically, all employees involved in the industrial activities of your facility should be trained about the following measures:

- Identifying potential spill areas and drainage routes, including information on past spills and causes
- Reporting spills to appropriate individuals, without penalty (e.g., employees should be provided "amnesty" when they report such instances)
- Specifying material handling procedures and storage requirements
- Implementing spill response procedures.

Onsite contractors and temporary personnel should also be informed of the plant operations and design features in order to help prevent accidental discharges or spills from occurring.

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Good Housekeeping

Also, teach facility personnel how to maintain a clean and orderly work environment. Section 2.3.1 above outlines the steps for practicing good housekeeping. Emphasize these points in the good housekeeping portion of your training program:

- Require regular vacuuming and/or sweeping
- Promptly clean up spilled materials to prevent polluted runoff
- Identify places where brooms, vacuums, sorbents, foams, neutralizing agents, and other good housekeeping and spill response equipment are located
- Display signs reminding employees of the importance and procedures of good housekeeping
- Discuss updated procedures and report on the progress of practicing good housekeeping at every meeting
- Provide instruction on securing drums and containers and frequently checking for leaks and spills
- Outline a regular schedule for housekeeping activities to allow you to determine that the job is being done.

Materials Management Practices

- Neatly organize materials for storage
- Identify all toxic and hazardous substances stored, handled, and produced onsite
- Discuss handling procedures for these materials.

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Tools For a Successful Training Program

Here are some suggestions of training tools that you can include in your facility's training program:

- Employee handbooks
- Films and slide presentations
- Drills
- Routine employee meetings
- Bulletin boards
- Suggestion boxes
- Newsletters
- Environmental excellence awards or other employee incentive programs.

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Providing employees with incentives, such as awards for practicing pollution prevention, is a good way to motivate personnel in working to achieve the goals of the Storm Water Pollution Prevention Plan.

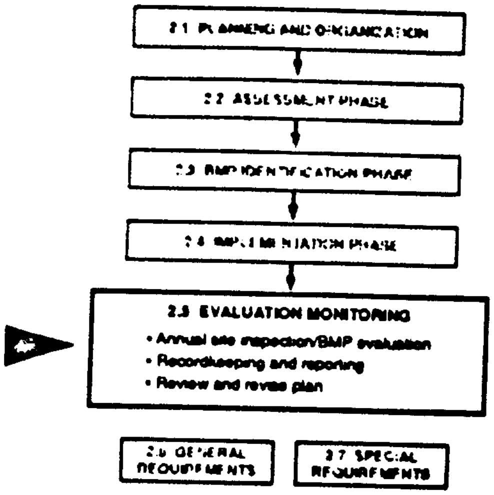
How Often to Conduct Training

You should examine your plan to determine how often you should train the employees at your facility. Frequency should take into account the complexity of your management practices and the nature of your staff, including staff turnover and changes in job assignments. Facilities are required to specify a schedule for periodic training activities in their plan. In any case, you should regularly evaluate the effectiveness of your training efforts. In many cases, this will simply involve speaking with your employees to verify that information has been communicated effectively.

EPCRA, Section 313 Facility Requirements

EPA's General Permit contains additional training requirements for employees and contractor personnel that work in areas where EPCRA, Section 313 water priority chemicals are used or stored [Part IV.D.7.b.(9).]. These individuals must be trained in the following areas at least once per year:

- Preventive measures, including spill prevention and response and preventive maintenance
- Pollution control laws and regulations
- The facility's Storm Water Pollution Prevention Plan
- Features and operations of the facility which are designed to minimize discharges of Section 313 water priority chemicals, particularly spill prevention procedures.



2.5 EVALUATION PHASE

Now that your Storm Water Pollution Prevention Plan has been put to action, you must keep it up-to-date by regularly evaluating the information you collected in the Assessment Phase and the controls you selected in the BMP Identification Phase. Specifically, you will:

- Conduct site evaluations
- Keep records of all inspections and reports
- Revise the plan as needed.

2.5.1 Annual Site Compliance Evaluation

EPA GENERAL PERMIT REQUIREMENTS

Comprehensive Site Compliance Evaluation

Part IV.D.4.

Qualified personnel must conduct site compliance evaluations at appropriate intervals specified in the plan at least once a year (at least once in three years for inactive mining sites). As part of your compliance evaluations, you are required to:

- Inspect storm water drainage areas for evidence of pollutants entering the drainage system
- Evaluate the effectiveness of measures to reduce pollutant loadings and whether additional measures are needed
- Observe structural measures, sediment controls, and other storm water BMPs to ensure proper operation
- Inspect any equipment needed to implement the plan, such as spill response equipment
- Revise the plan as needed within two weeks of inspection (potential pollutant source description and description of measures and controls)
- Implement any necessary changes in a timely manner, but at least within 12 weeks of the inspection
- Prepare a report summarizing inspection results and follow up actions, the date of inspection and personnel who conducted the inspection; identify any incidents of noncompliance or certify that the facility is in compliance with the plan.
- All incidents of noncompliance must be documented in the inspection report. Where there are no incidents of noncompliance, the inspection report must contain a certification that the facility is in compliance with the plan.
- Sign the report in accordance with Section 2.6.2 and keep it with the plan.

Annual site compliance evaluations are comprehensive inspections performed by individuals specifically designated in the Storm Water Pollution Prevention Plan as having responsibility for conducting such inspections. These employees should be familiar with all facility industrial operations and Storm Water Pollution Prevention Plan goals and requirements. Furthermore, inspectors should be able to make necessary management decisions or have direct access to management.

This annual evaluation provides a basis for evaluating the overall effectiveness of your Storm Water Pollution Prevention Plan. In particular, the annual site compliance evaluation will allow you to verify that the description of potential pollutant sources contained in the plan is accurate, that the plan drainage map is accurate or has been updated to reflect current conditions, and that controls identified in the plan to reduce pollutants in storm water discharges are accurately identified, in place and working. The annual site compliance evaluation will also identify where new controls are needed so that you may implement them and incorporate them into the plan.

The scope of the annual site compliance evaluation will depend on various factors, including the scope of the Storm Water Pollution Prevention Plan and the size and nature of the activities occurring at the facility. The process for conducting the evaluation should follow these steps:

- Review the Storm Water Pollution Prevention Plan and draw up a list of those items which are part of material handling, storage, and transfer areas covered by the plan
- List all equipment and containment in these areas covered in the plan
- Review facility operations for the past year to determine if any more areas should be included in the original plan, or if any existing areas were modified so as to require plan modification; change plan as appropriate
- Conduct inspection to determine (1) if all storm water pollution prevention measures are accurately identified in the plan, and (2) are in place and working properly
- Document findings
- Modify Storm Water Pollution Prevention Plan as appropriate.

As each facility and Storm Water Pollution Prevention Plan is unique, so the exact inspection format will vary from facility to facility. All documentation regarding conditions necessitating modification to the Storm Water Pollution Prevention Plan should be kept on file as part of the plan until one year after coverage under the permit expires.

2.5.2 Recordkeeping and Internal Reporting

EPA GENERAL PERMIT REQUIREMENTS
Keeping Records Part IV.D.3.f. Incidents such as spills or other discharges, along with other information describing the quality and quantity of storm water discharges must be included in the records. Inspections and maintenance activities shall be documented and recorded in the plan. Records must be maintained for one year after the permit expires.

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Keeping records of and reporting events that occur onsite is an effective way of tracking the progress of pollution prevention efforts and waste minimization. Analyzing records of past spills, for example, can provide useful information for developing improved BMPs to prevent future spills of the same kind. Recordkeeping and internal reporting represent good operating practices because they can increase the efficiency of the facility and effectiveness of BMPs.

Recordkeeping and Reporting Procedures for Spills, Leaks, and Other Discharges

A recordkeeping system set up for documenting spills, leaks, and other discharges, including discharges of hazardous substances in reportable quantities (for a discussion of reportable quantities, see Section 2.2.3 and Appendix H), could help your facility minimize incident recurrence, correctly respond with appropriate cleanup activities, and comply with legal requirements. The system for recordkeeping and reporting could also include any other information that would enhance the effectiveness of the Storm Water Pollution Prevention Plan. You should make a point of keeping track of reported incidents and following up on results of inspections and reported spills, leaks, or other discharges.

Records should include the following, as appropriate:

- The date and time of the incident, weather conditions, duration, cause, environmental problems, response procedures, parties notified, recommended revisions of the BMP program, operating procedures, and/or equipment needed to prevent recurrence.
- Formal written reports. These are helpful in reviewing and evaluating the discharges and making revisions to improve the BMP program. Document all reports you call in to the National Response Center in the event of a reportable quantity discharge. For more information on reporting spills or other discharges, refer to Section 2.2.3 and 40 CFR 117.3 and 40 CFR 302.4.
- A list of the procedures for notifying the appropriate plant personnel and the names and telephone numbers of responsible employees. This enables more rapid reporting of and response to spills and other incidents.

Recordkeeping and Reporting Procedures for Inspections and Maintenance Activities

Maintaining records for all inspections is an important element of any Storm Water Pollution Prevention Plan. Documenting all inspections, whether routine or detailed, is a good preventive maintenance technique, because analysis of inspection records allows for early detection of any potential problems. Recordkeeping also helps to devise improvements in the BMP program after inspection records have been analyzed. Recordkeeping and reporting for maintenance activities should also be a part of the plan as another preventive maintenance measure. Keeping a log of all maintenance activities, such as the cleaning of oil and grit separators or catch basins, will enable the facility to evaluate the effectiveness of the BMP program, equipment, and operation.

There are various simple techniques used to accurately document and report inspection results including the following:

- Field notebooks
- Timed and dated photographs

- Video tapes
- Drawings and maps.

Keeping Records Updated

It is important to keep all records updated on:

- The correct name and address of facility
- The correct name and location of receiving waters
- The number and location of discharge points
- Principal products and production rates (where appropriate).

Records Retention

Records of spills, leaks, or other discharges, inspections, and maintenance activities must be retained for at least one year after coverage under the permit expires.

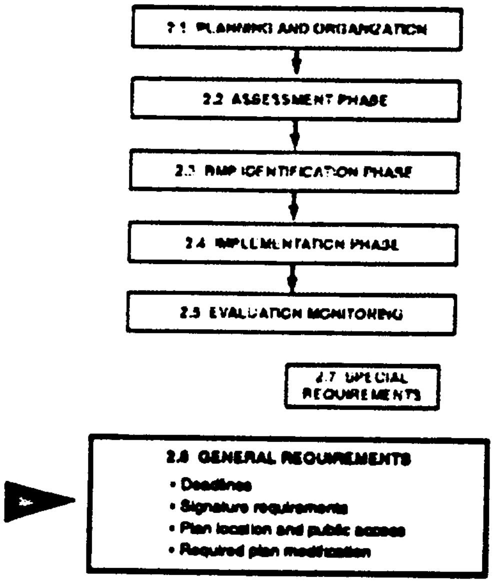
2.5.3 Plan Revisions

EPA GENERAL PERMIT REQUIREMENTS
Keeping Plans Current
Part IV.C.
You must amend your plan whenever there is a change in design, construction, operation, or maintenance, which may impact the potential for pollutants to be discharged or if the Storm Water Pollution Prevention Plan proves to be ineffective in controlling the discharge of pollutants. Facilities are not required to submit a notice to the Director each time the pollution prevention plan is modified unless the Director specifically requests changes to be made to the plan.

For your Storm Water Pollution Prevention Plan to be effective, you should ensure that your plan complies with any permit conditions that apply to your facility and that you have accurately represented facility features and operations. Should either of these conditions not be met by the plan, you must make the necessary changes. Either the managers of facilities or the permitting authority may recommend changes to the plan (see Section 2.6.4 for requirements).

Storm Water Pollution Prevention Plans are developed based on site-specific features. When there are changes in design, construction, operation, or maintenance, and that change will have a significant effect on the potential for discharging pollutants in storm water at a facility, your Storm Water Pollution Prevention Plan should be modified to reflect the changes and new conditions. For example, if your facility begins to use a new chemical in its production operations, proper handling procedures for this chemical should be incorporated into the facility plan.

You may also decide to change the plan because it has proven to be ineffective in controlling storm water contamination based on the results of routine visual inspections (see Section 2.3.1) or more comprehensive site evaluations (see Section 2.5.1).



2.6 GENERAL REQUIREMENTS

This Section provides guidance on some of the administrative requirements related to organizing and developing your Storm Water Pollution Prevention Plan. This information should be reviewed prior to beginning to develop your facility's Storm Water Pollution Prevention Plan. These requirements include:

- Deadlines for plan development and implementation
- Who must sign the plan
- Where to keep the plan
- How to make changes to the plan that are required by the Director.

2.6.1 Schedule for Plan Development and Implementation

EPA GENERAL PERMIT REQUIREMENTS Schedule for Plan Development and Implementation Part IV.A.		
Type of Facility	**Deadline for Plan Completion**	**Deadline for Plan Compliance**
Facilities with industrial activities existing on or before October 1, 1992	April 1, 1993	October 1, 1993
Facilities commencing industrial activities after October 1, 1992, but on or before December 31, 1992	60 days after commencement of discharge	60 days after commencement of discharge
Facilities commencing industrial activities on or after January 1, 1993	48 hours prior to commencement of discharge (upon submittal of NOI)	48 hours prior to commencement of discharge (upon submittal of NOI)
Oil and gas exploration, production, processing or treatment operations discharging a reportable quantity release in storm water after October 1, 1992	60 days after release	60 days after release
Industrial facilities that are owned or operated by a municipality that are rejected or denied from the group application process	365 days after date of rejection or denial	545 days after date of rejection or denial
Note: The Director may grant a written extension for plan preparation and compliance for new dischargers (after October 1, 1992) upon showing of good cause.		

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The deadlines to complete and comply with or implement your facility's Storm Water Pollution Prevention Plan may depend on the type of permit under which your facility is covered. Be sure to read your permit carefully so that you know what the deadlines are. Many NPDES-delegated States may issue general permits for storm water that contain deadlines similar to the deadlines in EPA's General Permits.

2.6.2 Required Signatures

EPA GENERAL PERMIT REQUIREMENTS

Signature Requirements

Part VII.G.1.

Where your facility is subject to storm water permit requirements, all reports, certifications, or information either submitted to the permitting authority or to the operator of a large or medium municipal separate storm sewer system, or required to be maintained by the permittee onsite should be signed as follows:

- For a corporation, the plan must be signed by a "responsible corporate officer." A responsible corporate officer may be <u>any one of the following</u>:
  - A president, secretary, treasurer, or vice-president of the corporation in charge of a principal business function, or any other person who performs similar policy or decision-making functions for the corporation
  - The manager of one or more manufacturing, production, or operating facilities employing more than 250 persons or having gross annual sales or expenditures exceeding $25,000,000 (in second quarter 1980 dollars) if authority to sign documents has been assigned or delegated to the manager in accordance with corporate procedure.
- For a partnership or sole proprietorship, the plan must be signed by a general partner or the proprietor, respectively.
- For a municipality, State, Federal, or other public agency, the plan must be signed by either:
  - The principal executive officer or ranking official, which includes the chief executive officer of the agency, or
  - The senior officer having responsibility for the overall operations of a principal geographic unit of the agency.

Designating Signatory Authority

Part VII.G.2.

Any of the above persons may designate a duly authorized representative to sign for them. The representative should either have overall responsibility for the operation of the facility or environmental matters for the company. If an authorized representative is appointed, the authorization must be put in writing by the responsible signatory and submitted to the Director. Any change in an authorized individual or an authorized position must be made in writing and submitted to the permitting authority.

EPA GENERAL PERMIT REQUIREMENTS
Certification Part VII.G.2.d. Any person signing documents under this permit shall make the following certification: "I certify under penalty of law that this document and all attachments were prepared under my direction or supervision in accordance with a system designed to assure that qualified personnel properly gathered and evaluated the information submitted. Based on my inquiry of the person or persons who manage the system, or those persons directly responsible for gathering the information, the information submitted is, to the best of my knowledge and belief, true, accurate, and complete. I am aware that there are significant penalties for submitting false information, including the possibility of fine and imprisonment for knowing violations."

To ensure that your facility's Storm Water Pollution Prevention Plan is completely developed and adequately implemented, your NPDES permit will generally require that an authorized facility representative sign and certify the plan. The authorized facility representative should be someone at or near the top of your facility's management chain, such as the president, vice president, or a production manager who has been delegated the authority to sign and certify this type of document. In signing the plan, the corporate officer is attesting that the information is true. This signature provides a basis for an enforcement action to be taken against the person signing the plan and related reports. The permittee should be aware that Section 309 of the Clean Water Act provides for significant penalties where information is false or the permittee violates, either knowingly or negligently, its permit requirements. In some cases, your general permit may require certification of the plan by a professional engineer. Specific signatory requirements will be listed in your NPDES permit.

EPCRA, Section 313 Facility Plan Certification Requirements

EPA's General Permit contains additional certification requirements for facilities subject to reporting under EPCRA, Section 313 for water priority chemicals (Part IV.D.7.b.(10).). The plan must be reviewed and certified by a Registered Professional Engineer and recertified every three years or as soon as practicable after significant modifications are made to the facility. This certification that the plan was prepared in accordance with good engineering practices does not relieve the facility owner or operator of responsibility to prepare and implement the plan, however.

2.6.3 Plan Location and Public Access

EPA GENERAL PERMIT REQUIREMENTS
Where and How Long to Keep the Plan Parts IV.B. and VI.E. Plans are required to be maintained onsite of the facility unless the Director, or authorized representative, or the operator of a large or medium municipal separate storm sewer system, requests that the plan be submitted. Plans and all required records must be kept until at least one year after coverage under the permit expires.

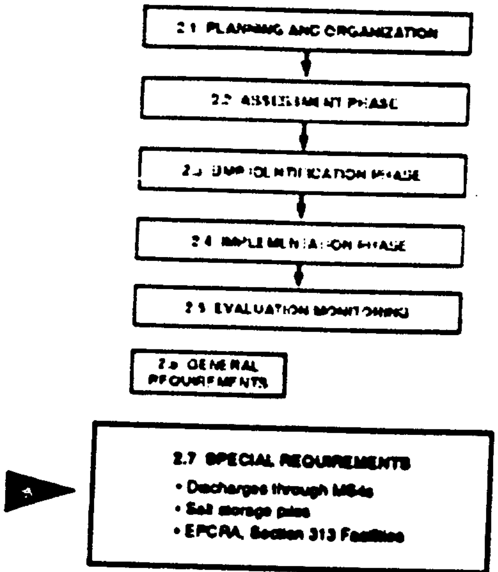
Although all plans are to be maintained onsite, some NPDES storm water permits may require that facilities submit copies of their Storm Water Pollution Prevention Plans to the Director for review. Examine your permit carefully to determine what submittal requirements apply to your facility. Even if your permit does not require you automatically to submit your plan to your permitting authority, you must provide copies of the plan to your permitting authority or to your municipal operator upon request. Plans and associated records are available to the public by request through the permitting authority.

2.6.4 Director-Required Plan Modifications

EPA GENERAL PERMIT REQUIREMENTS
Required Changes **Part IV.B.3.** Any changes required by the permitting authority shall be made within 30 days, unless otherwise provided by the notification, and the facility must submit a certification signed in accordance with Section 2.6.2 to the Director that the requested changes have been made.

Upon reviewing your plan, the permitting authority may find that it does not meet one or more of the minimum standards established by the pollution prevention plan requirements. In this case, the permitting authority will notify you of changes needed to improve the plan.

For example, where a facility has not addressed spill response procedures for a toxic chemical to the extent that the permitting authority believes is necessary, the facility will be required to revise the procedures. The permitting authority retains the authority to make this type of request at any time during the effective period of the plan. In the notification, the permitting authority will establish a deadline for the incorporation of the required changes, unless the permit specifies a deadline. Permittees may or may not have to certify that the requested changes have been implemented depending on their specific permit conditions. You should examine your permit for such details.



2.7 SPECIAL REQUIREMENTS

In addition to the minimum "baseline" BMPs discussed in previous sections, facilities may be subject to additional "special" requirements. Not all facilities will have to include these special requirements in their Storm Water Pollution Prevention Plan. Be sure to check your permit closely for these conditions. In particular, EPA's General Permit includes special requirements for:

- Facilities that discharge storm water through municipal separate storm sewer systems
- Facilities subject to EPCRA, Section 313 reporting requirements
- Facilities with salt storage piles.

2.7.1 Special Requirements for Discharges Through Municipal Separate Storm Sewer Systems

EPA GENERAL PERMIT REQUIREMENTS
Discharges Through Large or Medium Municipal Separate Storm Sewer Systems (MS4s)
Part IV.D.5.
Permittees must comply with conditions in municipal storm water management programs developed under the NPDES permit issued for that system to which the industrial facility discharges, provided that the facility was directly notified of the applicable requirements by the municipal operator. The facility must be in compliance with these conditions by the deadlines specified in the pollution prevention plan listed in Section 2.6.1.

The November 16, 1990, storm water discharge permit application regulations require large and medium municipal separate storm sewer systems (systems serving a population of 100,000 or more) to develop storm water management programs in order to control pollutants discharged through the municipal systems. These management programs will address discharges of industrial storm water through the systems to the extent that they are harmful to the water quality of receiving streams. Municipalities should be aware of the facilities with storm water discharges associated with industrial activity that discharge into their separate storm sewer system because the November 16, 1990, final rule required these facilities to notify the municipal operator. In addition, facilities covered by general permits will typically be required to submit a copy of their NOI to the municipal operator. EPA emphasizes that it is the facility's responsibility to inform the municipality of all storm water discharges associated with industrial activity to the separate storm sewer system. Facilities with such discharges that have not yet contacted the appropriate municipal authority should do so immediately.

Although facility-specific Storm Water Pollution Prevention Plans for industries are designed to prevent pollutants from entering storm water discharges, the municipal operator may find it necessary to impose specific requirements on a particular industrial facility or class of industrial facilities in some situations. One way to ensure that facilities comply with these requirements is to include a provision in the facility's NPDES storm water discharge permit that directly requires compliance. This mechanism provides a basis for enforcement action to be directed, where necessary, against the owner or operator of the facility with a storm water discharge associated with industrial activity.

2.7.2 Special Requirements for EPCRA, Section 313 Reporting Facilities

Section 313 of EPCRA requires operators of manufacturing facilities that handle toxic chemicals in amounts exceeding threshold levels (listed at 40 CFR 372.25) to report to the government on an annual basis. Because these types of facilities handle large amounts of toxic chemicals, EPA concluded that they have an increased potential to degrade the water quality of receiving streams. To address this risk, EPA established specific control requirements in its general permit. In particular, these requirements apply to Section 313 facilities that report for "water priority chemicals" that include any of over 200 chemicals that have been identified by EPA as especially toxic to water ecosystems. For reference, Appendix I contains a list of Section 313 water priority chemicals.

Many of the requirements outlined below are specifically designed to address the water quality concerns that toxic chemicals present. Incorporation of these requirements into site-specific Storm Water Pollution Prevention Plans will prevent spills and leaks of water priority chemicals and eliminate or reduce other opportunities for exposure of toxic chemicals to storm water, thus protecting receiving streams from toxic discharges.

Specific Requirements

The following specific control requirements must be practiced in areas where Section 313 water priority chemicals are stored, handled, processed, or transferred:

- **Provide containment, drainage control, and/or diversionary structures:**
  - Prevent or minimize runon by installing curbing, culverting, gutters, sewers, or other controls, and/or
  - Prevent or minimize exposure by covering storage piles.
- **Prevent discharges from all areas:**
  - Use manually activated valves with drainage controls in all areas, and/or
  - Equip the plant with a drainage system to return spilled material to the facility.
- **Prevent discharges from liquid storage areas:**
  - Store liquid materials in compatible storage containers
  - Provide secondary containment designed to hold the volume of the largest storage tank plus precipitation.

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- **Prevent discharges from loading/unloading areas:**
  - Use drip pans and/or
  - Implement a strong spill contingency and integrity testing plan.
- **Prevent discharges from handling/processing/transferring areas:**
  - Use covers, guards, overhangs, door skirts
  - Conduct visual inspections or leak tests for overhead piping.
- **Introduce facility security programs to prevent spills:**
  - Use fencing, lighting, traffic control, and/or secure equipment and buildings.

Additional requirements are baseline BMPs that have been enhanced to address specific storm water concerns associated with the handling of toxic chemicals. These additional requirements are highlighted in previous sections on the pages indicated below:

Pollution Prevention Team	p. 2-5
Preventive Maintenance	p. 2-27
Spill Prevention Response	p. 2-34
Employee Training	p. 2-42
Professional Engineer Certification	p. 2-49

2.7.3 Special Requirements for Salt Storage Piles

EPA GENERAL PERMIT REQUIREMENTS
Salt Storage Piles
Part IV.D.8.
Where storm water from a salt storage pile is discharged to waters of the United States, the pile must be covered or enclosed to prevent exposure to precipitation, except when salt is being added to or taken from the pile. Discharges shall comply with this provision as expeditiously as practicable, but in no event later than October 1, 1995.

Facilities may use salt for de-icing purposes or part of their industrial processes. Since exposed salt piles will easily contaminate storm water runoff, an obvious BMP for these piles is to cover them with a tarp or other covering or enclose them in a shed or building. This requirement may not be applicable to all Storm Water Pollution Prevention Plans, however. Where runoff from the salt pile is not discharged to waters of the United States, then this requirement would not apply since the pollutants will not reach a waterbody. Since it may not be feasible to maintain cover over a salt pile when adding to it or taking salt from it, permits will generally incorporate some flexibility, as does EPA's General Permit.

STORM WATER POLLUTION PREVENTION PLAN WORKSHEETS

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POLLUTION PREVENTION TEAM (Section 2.1.1) MEMBER ROSTER	Worksheet #1 Completed by: ________ Title: ________ Date: ________

Leader: ________ Title: ________

Office Phone: ________

Responsibilities: ________

Members:

(1) ________ Title: ________

Office Phone: ________

Responsibilities: ________

(2) ________ Title: ________

Office Phone: ________

Responsibilities: ________

(3) ________ Title: ________

Office Phone: ________

Responsibilities: ________

(4) ________ Title: ________

Office Phone: ________

Responsibilities: ________

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DEVELOPING A SITE MAP (Section 2.2.1)	Worksheet #2 Completed by: ______ Title: ______ Date: ______

Instructions: Draw a map of your site including a footprint of all buildings, structures, paved areas, and parking lots. The information below describes additional elements required by EPA's General Permit (see example maps in Figures 2.3 and 2.4).

EPA's General Permit requires that you indicate the following features on your site map:

- All outfalls and storm water discharges
- Drainage areas of each storm water outfall
- Structural storm water pollution control measures, such as:
  - Flow diversion structures
  - Retention/detention ponds
  - Vegetative swales
  - Sediment traps
- Name of receiving waters (or if through a Municipal Separate Storm Sewer System)
- Locations of exposed significant materials (see Section 2.2.2)
- Locations of past spills and leaks (see Section 2.2.3)
- Locations of high-risk, waste-generating areas and activities common on industrial sites such as:
  - Fueling stations
  - Vehicle/equipment washing and maintenance areas
  - Area for unloading/loading materials
  - Above-ground tanks for liquid storage
  - Industrial waste management areas (landfills, waste piles, treatment plants, disposal areas)
  - Outside storage areas for raw materials, by-products, and finished products
  - Outside manufacturing areas
  - Other areas of concern (specify:______________)

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MATERIAL INVENTORY
(Section 2.2.2)

Worksheet #3
Completed by: ______________________
Title: ______________________
Date: ______________________

Instructions: List all materials used, stored, or produced onsite. Assess and evaluate these materials for their potential to contribute pollutants to storm water runoff. Also complete Worksheet 3A if the material has been exposed during the last three years.

Material	Purpose/Location	Quantity (units)			Quantity Exposed in Last 3 Years	Likelihood of contact with storm water. If yes, describe reason.	Past Significant Spill or Leak	
		Used	Produced	Stored			Yes	No

DESCRIPTION OF EXPOSED SIGNIFICANT MATERIAL
(Section 2.2.2)

Worksheet #3A
Completed by: ______________________
Title: ______________________
Date: ______________________

Instructions: Based on your material inventory, describe the significant materials that were exposed to storm water during the past three years and/or are currently exposed. For the definition of "significant materials" see Appendix B of the manual.

Description of Exposed Significant Material	Period of Exposure	Quantity Exposed (units)	Location (as indicated on the site map)	Method of Storage or Disposal (e.g., pile, drum, tank)	Description of Material Management Practice (e.g., pile covered, drum sealed)

LIST OF SIGNIFICANT SPILLS AND LEAKS
(Section 2.2.3)

Worksheet #4
Completed by: ______________________
Title: ______________________
Date: ______________________

Directions: Record below all significant spills and significant leaks of toxic or hazardous pollutants that have occurred at the facility in the three years prior to the effective date of the permit.

Definitions: Significant spills include, but are not limited to, releases of oil or hazardous substances in excess of reportable quantities.

1st Year Prior

Date (month/day/year)	Spill	Leak	Location (as indicated on site map)	Description: Type of Material	Description: Quantity	Description: Source, If Known	Description: Reason	Response Procedure: Amount of Material Recovered	Response Procedure: Material No Longer Exposed to Storm Water (True/False)	Preventive Measures Taken

2nd Year Prior

Date (month/day/year)	Spill	Leak	Location (as indicated on site map)	Description: Type of Material	Description: Quantity	Description: Source, If Known	Description: Reason	Response Procedure: Amount of Material Recovered	Response Procedure: Material No Longer Exposed to Storm Water (True/False)	Preventive Measures Taken

3rd Year Prior

Date (month/day/year)	Spill	Leak	Location (as indicated on site map)	Description: Type of Material	Description: Quantity	Description: Source, If Known	Description: Reason	Response Procedure: Amount of Material Recovered	Response Procedure: Material No Longer Exposed to Storm Water (True/False)	Preventive Measures Taken

NON-STORM WATER DISCHARGE ASSESSMENT AND CERTIFICATION (Section 2.2.4)	Worksheet #5 Completed by: ____________ Title: ____________ Date: ____________

Date of Test or Evaluation	Outfall Directly Observed During the Test (identify as indicated on the site map)	Method Used to Test or Evaluate Discharge	Describe Results from Test for the Presence of Non-Storm Water Discharge	Identify Potential Significant Sources	Name of Person Who Conducted the Test or Evaluation

CERTIFICATION

I, ______________________ (responsible corporate official), certify under penalty of law that this document and all attachments were prepared under my direction or supervision in accordance with a system designed to assure that qualified personnel properly gather and evaluate the information submitted. Based on my inquiry of the person or persons who manage the system or those persons directly responsible for gathering the information, the information submitted is, to the best of my knowledge and belief, true, accurate, and complete. I am aware that there are significant penalties for submitting false information, including the possibility of fine and imprisonment for knowing violations.

A. Name & Official Title (type or print)	B. Area Code and Telephone No.
C. Signature	D. Date Signed

NON-STORM WATER DISCHARGE ASSESSMENT AND FAILURE TO CERTIFY NOTIFICATION
(Section 2.2.4)

Worksheet #6
Completed by: ______________
Title: ______________
Date: ______________

Directions: If you cannot feasibly test or evaluate an outfall due to one of the following reasons, fill in the table below with the appropriate information and sign this form to certify the accuracy of the included information.

List all outfalls not tested or evaluated, describe any potential sources of non-storm water pollution from listed outfalls, and state the reason(s) why certification is not possible. Use the key from your site map to identify each outfall.

Important Notice: A copy of this notification must be signed and submitted to the Director within 180 days of the effective date of this permit.

Identify Outfall Not Tested/Evaluated	Description of Why Certification Is Infeasible	Description of Potential Sources of Non-Storm Water Pollution

CERTIFICATION

I certify under penalty of law that this document and all attachments were prepared under my direction or supervision in accordance with a system designed to assure that qualified personnel properly gather and evaluate the information submitted. Based on my inquiry of the person or persons who manage the system or those persons directly responsible for gathering the information, the information submitted is, to the best of my knowledge and belief, true, accurate, and complete. I am aware that there are significant penalties for submitting false information, including the possibility of fine and imprisonment for knowing violations, and that such notification has been made to the Director within 180 days of ________ (date permit was issued), the effective date of this permit.

A. Name & Official Title (type or print)

B. Area Code and Telephone No.

C. Signature

D. Date Signed

POLLUTANT SOURCE IDENTIFICATION (Section 2.2.6)	Worksheet #7 Completed by: ______ Title: ______ Date: ______

Instructions: List all identified storm water pollutant sources and describe existing management practices that address those sources. In the third column, list BMP options that can be incorporated into the plan to address remaining sources of pollutants.

Storm Water Pollutant Sources	Existing Management Practices	Description of New BMP Options
1.		
2.		
3.		
4.		
5.		
6.		
7.		
8.		
9.		
10.		

BMP IDENTIFICATION (Section 2.3.1)	Worksheet #7a Completed by: ________ Title: ________ Date: ________

Instructions: Describe the Best Management Practices that you have selected to include in your plan. For each of the baseline BMPs, describe actions that will be incorporated into facility operations. Also describe any additional BMPs [activity-specific (Chapter 3) and site-specific BMPs (Chapter 4)] that you have selected. Attach additional sheets if necessary.

BMPs	Brief Description of Activities
Good Housekeeping	
Preventive Maintenance	
Inspections	
Spill Prevention Response	
Sediment and Erosion Control	
Management of Runoff	
Additional BMPs (Activity-specific and Site-specific)	

IMPLEMENTATION
(Section 2.4.1)

Worksheet #8
Completed by: ____________________
Title: ____________________
Date: ____________________

Instructions: Develop a schedule for implementing each BMP. Provide a brief description of each BMP, the steps necessary to implement the BMP (i.e., any construction or design), the schedule for completing those steps (list dates) and the person(s) responsible for implementation.

BMPs	Description of Action(s) Required for Implementation	Scheduled Completion Date(s) for Req'd. Action	Person Responsible for Action	Notes
Good Housekeeping	1.			
	2.			
	3.			
Preventive Maintenance	1.			
	2.			
	3.			
Inspections	1.			
	2.			
	3.			
Spill Prevention and Response	1.			
	2.			
	3.			
Sediment and Erosion Control	1.			
	2.			
	3.			
Management of Runoff	1.			
	2.			
	3.			
Additional BMPs (Actively-specific and site-specific)	1.			
	2.			
	3.			

EMPLOYEE TRAINING (Section 2.4.2)	Worksheet #9 Completed by: ____________ Title: ____________ Date: ____________

Instructions: Describe the employee training program for your facility below. The program should, at a minimum, address spill prevention and response, good housekeeping, and material management practices. Provide a schedule for the training program and list the employees who attend training sessions.

Training Topics	Brief Description of Training Program/Materials (e.g., film, newsletter course)	Schedule for Training (list dates)	Attendees
Spill Prevention and Response			
Good Housekeeping			
Material Management Practices			
Other Topics			

CHAPTER 3

ACTIVITY-SPECIFIC SOURCE CONTROL BMPs

This chapter describes specific BMPs for common industrial activities that may contaminate storm water. Chapter 2 led you through the steps of identifying activities at your facility that can contaminate storm water. At this point, you should be ready to choose the BMPs that best fill your facility's need. You should read this chapter if any of the activities listed below take place at your facility. BMPs for each of these activities are provided in the sections listed below:

Activity	Section
Fueling	3.1
Maintaining Vehicles and Equipment	3.2
Painting Vehicles and Equipment	3.3
Washing Vehicles and Equipment	3.4
Loading and Unloading Materials	3.5
Liquid Storage in Above-Ground Tanks	3.6
Industrial Waste Management and Outside Manufacturing	3.7
Outside Storage of Raw Materials, By-Products, or Finished Products	3.8
Salt Storage	3.9

Each section is presented in a question and answer format. By answering these questions, you will be able to quickly identify source controls or recycling BMPs that are suitable for your facility. The BMPs suggested are relatively easy to use, are inexpensive, and often are effective in removing the source of storm water contaminants. This is not a complete list of BMPs for every industrial activity; rather, it is meant to help you think about ways you can reduce storm water contamination on your site. You may want to contact one of the State or Federal pollution prevention assistance offices listed in Appendix D for suggestions or help in choosing or using these and other BMP options.

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3.1 BMPs FOR FUELING STATIONS

When storm water mixes with fuel spilled or leaked onto the ground, it becomes polluted with chemicals that are harmful to humans and to fish and wildlife. The following questions will help you identify activities that can contaminate storm water and suggest BMPs to reduce or eliminate storm water contamination from fueling stations. Read this section if your facility has outdoor fueling operations or if fueling occurs in areas where leaks or spills could contaminate storm water. Also refer to the BMPs listed in Section 4.2 on Exposure Minimization.

FUEL STATION ACTIVITIES THAT CAN CONTAMINATE STORM WATER:

- Spills and leaks that happen during fuel or oil delivery
- Spills caused by "topping off" fuel tanks
- Allowing rainfall on the fuel area or storm water to run onto the fuel area
- Hosing or washing down the fuel area
- Leaking storage tanks

Q. Have you installed spill and overfill prevention equipment?

Fuel overflows during storage tank filling are a major source of spills. Overflows can be prevented. Watch the transfer constantly to prevent overfilling and spilling. Overfill prevention equipment automatically shuts off flow, restricts flow, or sounds an alarm when the tank is almost full. Federal regulations require overfill prevention equipment on all Underground Storage Tanks (USTs) installed after December 1988. For USTs installed before December 1988, overfill prevention equipment is required by 1998. State or local regulations may be stricter, so contact your State and/or local government for details. Consider installing overflow prevention equipment sooner than the required deadline as part of your pollution prevention plan.

Q. Are vehicle fuel tanks often "topped off"?

Gas pumps automatically shut off when the vehicle fuel tank is almost full to prevent spills. Trying to completely fill the tanks or topping off the tank often results in overfilling the tank and spilling fuel. Discourage topping off by training employees and posting signs.

Q. Have you taken steps to protect fueling areas from rain?

Fueling areas can be designed to minimize spills, leaks, and incidental losses of fuel, such as vapor loss, from coming into contact with rain water:

- Build a roof over the fuel area.
- Pave the fuel area with concrete instead of asphalt. Asphalt soaks up fuel or can be slowly dissolved by fuel, engine fluids, and other organic liquids. Over time, the asphalt itself can become a source of storm water contamination.

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Q. Is runon to the fueling area minimized?

Runon is storm water generated from other areas that flows or "runs on" to your property or site. Runon flowing across fueling areas can wash contaminants into storm drains. Runon can be minimized by:

- Grading, berming, or curbing the area around the fuel site to direct runon away from the fuel area
- Locating roof downspouts so storm water is directed away from fueling areas
- Using valley gutters to route storm water around fueling area.

Q. Are oil/water separators or oil and grease traps installed in storm drains in the fueling area?

Oil/water separators and oil and grease traps are devices that reduce the amount of oil entering storm drains. These devices should be installed and routinely inspected, cleaned, and maintained.

Q. Is the fueling area cleaned by hosing or washing?

Cleaning the fueling area with running water should be avoided because the wash water will pick up fuel, oil, and grease and make it storm water. Consider using a damp cloth on the pumps and a damp mop on the pavement rather than a hose. Check with your local sewer authority about any treatment required before discharging the mop water or wash water to the sanitary sewer.

Q. Do you control petroleum spills?

Spills should be controlled immediately. Small spills can be contained using sorbent material such as kitty litter, straw, or sawdust. Do not wash petroleum spills into the storm drain or sanitary sewer. For more information on spill control measures, see sections on Containment Diking and Curbing in Chapter 4.

Q. Are employees aware of ways to reduce contamination of storm water at fueling stations?

Storm water contamination from fueling operations often occurs from small actions such as topping off fuel tanks, dripping engine fluids, and hosing down fuel areas. Inform employees about ways to eliminate or reduce storm water contamination.

EMPLOYEE INVOLVEMENT IS THE KEY:

Getting employees interested in reducing waste generation is the key to a successful storm water pollution prevention plan. Discuss pollution prevention with your employees. They are most familiar with the operations that generate wastes and may have helpful waste reduction suggestions. Consider setting up an employee reward program to promote pollution prevention.

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Q. Where does the water drain from your fueling area?

In many cases, wash water and storm water in fueling areas drain directly to the storm sewer without adequate treatment. Some types of oil/water separators installed at these locations can provide treatment to discharges from oil contaminated pavements, but this equipment is only effective when properly maintained (i.e., cleaned frequently). Some States require that these discharges be tied in to a sanitary sewer system or process wastewater treatment system. If discharges from fueling or other high risk areas at your facility drain to a sanitary sewer system, you should inform your local POTW.

SUMMARY OF FUELING STATION BMPs
• Consider installing spill and overflow protection.
• Discourage topping off of fuel tanks.
• Reduce exposure of the fuel area to storm water.
• Use dry cleanup methods for the fuel area.
• Use proper petroleum spill control.
• Encourage employee participation.

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3.2 BMPs FOR VEHICLE AND EQUIPMENT MAINTENANCE

Many vehicle and equipment maintenance operations use materials or create wastes that are harmful to humans and the environment. Storm water runoff from areas where these activities occur can become polluted by a variety of contaminants such as solvents and degreasing products, waste automotive fluids, oils and greases, acids, and caustic wastes. These and other harmful substances in storm water can enter water bodies through storm drains or through small streams where they can harm fish and wildlife.

The following questions will help you find sources of storm water contamination from vehicle and equipment maintenance operations on your site and to help you choose BMPs that can reduce or eliminate these sources.

Q. Are parts cleaned at your facility?

Parts are often cleaned using solvents such as trichloroethylene, 1,1,1-trichloroethane or methylene chloride. Many of these cleaners are harmful and must be disposed of as a hazardous waste. Cleaning without using liquid cleaners whenever possible reduces waste. Scrape parts with a wire brush, or use a bake oven if one is available. Prevent spills and drips of solvents and cleansers to the shop floor. Do all liquid cleaning at a centralized station so the solvents and residues stay in one area. If you dip parts in liquid, remove them slowly to avoid spills. Locate drip pans, drain boards, and drying racks to direct drips back into a sink or fluid holding tank for reuse.

ACTIVITIES THAT CAN CONTAMINATE STORM WATER:
Engine repair and service: • Parts cleaning • Shop cleanup • Spilled fuel, oil, or other materials • Replacement of fluids (oil, oil filters, hydraulic fluids, transmission fluid, and radiator fluids)
Outdoor vehicle and equipment storage and parking: • Dripping engine and automotive fluids from parked vehicles and equipment
Disposal of materials or process wastes: • Greasy rags • Oil filters • Air filters • Batteries • Spent coolant, degreasers, etc.

Q. Have you looked into using nontoxic or less toxic cleaners or solvents?

If possible, eliminate or reduce the number or amount of hazardous materials and waste by substituting nonhazardous or less hazardous materials. For example:

- Use noncaustic detergents instead of caustic cleaning agents for parts cleaning (ask your supplier about alternative cleaning agents).
- Use detergent-based or water-based cleaning systems in place of organic solvent degreasers. Wash water may require treatment before it can be discharged to the sanitary sewer. Contact your local sewer authority for more information.
- Replace chlorinated organic solvents (1,1,1-trichloroethane, methylene chloride, etc.) with nonchlorinated solvents. Nonchlorinated solvents like kerosene or mineral spirits are less

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toxic and less expensive to dispose of but are by no means harmless themselves. Check the list of active ingredients to see whether it contains chlorinated solvents.

- Choose cleaning agents that can be recycled.

Contact your supplier or trade journal for more waste minimization ideas.

Q. Are work areas and spills washed or hosed down with water?

Clean up leaks, drips, and other spills without large amounts of water. Use rags for small spills, a damp mop for general cleanup, and dry absorbent material for larger spills. Consider the following BMPs:

- Avoid hosing down your work areas.
- Collect leaking or dripping fluids in drip pans or containers. If different liquids are kept separate, the fluids are easier to recycle.
- Keep a drip pan under the vehicle while you unclip hoses, unscrew filters, or remove other parts. Use a drip pan under any vehicle that might leak while you work on it to keep splatters or drips off the shop floor.
- Promptly transfer used fluids to the proper waste or recycling drums. Don't leave full drip pans or other open containers lying around
- Locate waste and recycling drums in properly controlled areas of the yard, preferably areas with a concrete slab and secondary containment.

Q. Are spills or materials washed or poured down the drain?

Do not pour liquid waste to floor drains, sinks, outdoor storm drain inlets, or other storm drains or sewer connections. Used or leftover cleaning solutions, solvents, and automotive fluids and oil are often toxic and should not be put into the sanitary sewer. Be sure to dispose of these materials prope or find opportunities for reuse and recycling. If you are unsure of how to dispose of chemical wastes, contact your State hazardous waste management agency or the RCRA hotline at 1-800- 424-9346. Post signs at sinks to remind employees, and paint stencils at outdoor drains to tell customers and others not to pour wastes down drains.

Q. Are oil filters completely drained before recycling or disposal?

Oil filters disposed of in trash cans or dumpsters can leak oil and contaminate storm water. Place the oil filter in a funnel over the waste oil recycling or disposal collection tank to drain excess oil before disposal. Oil filters can be crushed and recycled. Ask your oil supplier or recycler about recycling oil filters.

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Q. Are incoming vehicles and equipment checked for leaking oil and fluids?

If possible, park vehicles indoors or under a roof so storm water does not contact the area. If you park vehicles outdoors while they await repair, watch them closely for leaks.

Put pans under leaks to collect fluids for proper recycling or disposal. Keeping leaks off the ground reduces the potential for storm water contamination and reduces cleanup time and costs. If the vehicle or equipment is to be stored outdoors, oil and other fluids should be drained first.

Designate a special area to drain and replace motor oil, coolant, and other fluids, where there are no connections to the storm drain or the sanitary sewer and drips and spills can be easily cleaned up.

Q. Are wrecked vehicles or damaged equipment stored onsite?

Be especially careful with *wrecked vehicles*, whether you keep them indoors or out, as well as with vehicles kept onsite for scrap or salvage. Wrecked or damaged vehicles often drip oil and other fluids for several days.

- As the vehicles arrive, place drip pans under them immediately, even if you believe that all fluids have leaked out before the car reaches your shop.
- Build a shed or temporary roof over areas where you park cars awaiting repairs or salvage, especially if you handle wrecked vehicles. Build a roof over vehicles you keep for parts.
- Drain all fluids, including air conditioner coolant, from wrecked vehicles and "parts" cars. Also drain engines, transmissions, and other used parts.
- Store cracked batteries in a nonleaking secondary container. Do this with all cracked batteries, even if you think all the acid has drained out. If you drop a battery, treat it as if it is cracked. Put it into the containment area until you are sure it is not leaking.

BATTERY ACID SPILLS:
Handle spilled acid from broken batteries with care. If you use baking soda to neutralize spilled acid during cleanup, remember that the residue is still dangerous to handle and must be disposed of as a hazardous waste because it may contain lead and other contaminants.

Q. Do you recycle any of these materials?

- Degreasers
- Used oil or oil filters
- Antifreeze
- Cleaning solutions
- Automotive batteries
- Hydraulic fluid.

All of these materials can be either recycled at your facility or sent offsite for recycling. Some recycling options, ranked by level of effort required, follow.

Least Effort:
• Arrange for collection and transportation of car batteries, used oil and other fluids, cleaning solutions, and degreasers to a commercial recycling facility. This requires that you separate wastes and store them until they are picked up by the recycling company. • "Dirty" solvent can be reused. Presoak dirty parts in used solvent before cleaning the parts in fresh solvent.
Moderate Effort:
• Used oil, antifreeze, and cleaning solutions can be recycled onsite using a filtration system that removes impurities and allows the fluid to be reused. Filtration systems are commercially available.
Most Effort:
• Install an onsite solvent recovery unit. If your facility creates large volumes of used solvents, you may consider purchasing or leasing an onsite still to recover the solvent for reuse. Contact your State hazardous waste management agency for more information about onsite recycling of used solvents.

Q. Can you reduce the number of different solvents used?

Reducing the number of solvents makes recycling easier and reduces hazardous waste management costs. Often, one solvent can perform a job as well as two different solvents.

Q. Are wastes separated?

Separating wastes allows for easier recycling and may reduce treatment costs. Keep hazardous and non-hazardous wastes separate, do not mix used oil and solvents, and keep chlorinated solvents (like 1,1,1-trichloroethane) separate from nonchlorinated solvents (like kerosene and mineral spirits). Proper labeling of all wastes and materials will help accomplish this goal (see Signs and Labels BMP).

EMPLOYEE INVOLVEMENT IS THE KEY:

Getting employees interested in reducing waste generation is the key to a successful storm water pollution prevention plan. Discuss pollution prevention with your employees. They are most familiar with the operations that generate wastes and may have helpful waste reduction suggestions. Consider setting up an employee reward program to promote pollution prevention.

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Q. Do you use recycled products?

Many products made of recycled (i.e., refined or purified) materials are available. Engine oil, transmission fluid, antifreeze, and hydraulic fluid are available in recycled form. Buying recycled products supports the market for recycled materials.

SUMMARY OF VEHICLE MAINTENANCE AND REPAIR BMPs
• Check for leaking oil and fluids. • Use nontoxic or low-toxicity materials. • Drain oil filters before disposal or recycling. • Don't pour liquid waste down drains. • Recycle engine fluids and batteries. • Segregate and label wastes. • Buy recycled products.

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3.3 BMPs FOR PAINTING OPERATIONS

Many painting operations use materials or create wastes that are harmful to humans and the environment. Storm water runoff from areas where these activities occur can become polluted by a variety of contaminants such as solvents and dusts from sanding and grinding that contain toxic metals like cadmium and mercury. These and other potentially harmful substances in storm water can enter water bodies directly through storm drains where they can harm fish and wildlife.

The following questions will help you identify potential sources of storm water contamination from painting operations on your site and BMPs that can reduce or eliminate these sources. Reading this section can help you eliminate, reduce, or recycle pollutants that may otherwise contaminate storm water.

Q. Is care taken to prevent paint wastes from contaminating storm water runoff?

Use tarps and vacuums to collect solid wastes produced by sanding or painting. Tarps, drip pans, or other spill collection devices should be used to collect spills of paints, solvents, or other liquid materials. These wastes should be disposed of properly to keep them from contaminating storm water.

PAINTING ACTIVITIES THAT CAN CONTAMINATE STORM WATER:
• Painting and paint removal
• Sanding or paint stripping
• Spilled paint or paint thinner

Q. Are wastes from sanding contained?

Prevent paint chips from coming into contact with storm water. Paint chips may contain hazardous metallic pigments or biocides. You can reduce contamination of storm water with paint dust and chips from sanding by the following practices:

- Avoid sanding in windy weather when possible.
- Enclose outdoor sanding areas with tarps or plastic sheeting. Be sure to provide adequate ventilation and personal safety equipment. After sanding is complete, collect the waste and dispose of it properly.
- Keep workshops clean of debris and grit so that the wind will not carry any waste into areas where it can contaminate storm water.
- Move the activity indoors if you can do so safely.

Q. Are parts inspected before painting?

Inspect the part or vehicle to be painted to ensure that it is dry, clean, and rust free. Paint sticks to dry, clean surfaces, which in turn means a better, longer-lasting paint job.

Q. Are you using painting equipment that creates little waste?

As little as 30 percent of the paint may reach the target from conventional airless spray guns; the rest is lost as overspray. Paint solids from overspray are deposited on the ground where they can contaminate storm water. Other spray equipment that delivers more paint to the target and less overspray should be used:

- Electrostatic spray equipment
- Air-atomized spray guns
- High-volume/low-pressure spray guns
- Gravity-feed guns.

Q. Are employees trained to use spray equipment correctly?

Operator training can reduce overspray and minimize the amount of paint solids that can contaminate storm water. Correct spraying techniques also reduce the amount of paint needed per job. If possible, avoid spraying on windy days. When spraying outdoors, use a drop cloth or ground cloth to collect and dispose of overspray.

Q. Do you recycle paint, paint thinner, or solvents?

These materials can either be recycled at the facility or sent offsite for recycling. Some recycling options ranked by the level of effort required follow.

Least Effort:
• Dirty solvent can be reused for cleaning dirty spray equipment and parts before equipment is cleaned in fresh solvent. • Give small amounts of left-over paint to the customer for touchup.
Moderate Effort:
• Arrange for collection and transportation of paints, paint thinner, or spent solvents to a commercial recycling facility.
Most Effort:
• Install an onsite solvent recovery unit. If your facility creates large volumes of used solvents, paint, or paint thinner, you may consider buying or leasing an onsite still to recover used solvent for reuse. Contact your State hazardous waste management agency for more information about onsite recycling of used solvents.

Q. Are wastes separated?

Separating wastes makes recycling easier and may reduce treatment costs. Keep hazardous and nonhazardous wastes separate, and keep chlorinated solvents (like 1,1,1-trichloroethane) separate from nonchlorinated solvents (like petroleum distillate and mineral spirits). Check the materials data sheet for ingredients, or talk with your waste hauler or recycling company to learn which waste types can be stored together and which should be separated.

Q. Can you reduce the number of solvents you use?

Reducing the number of solvents makes recycling easier and reduces hazardous waste management costs. Often, one solvent can do a job as well as two different solvents.

Q. Do you use recycled products?

Many products made of recycled (i.e., refined or purified) materials are available. Buying recycled paints, paint thinner, or solvent products helps build the market for recycled materials.

SUMMARY OF PAINTING OPERATION BMPs
• Inspect parts prior to painting.
• Contain sanding wastes.
• Prevent paint waste from contacting storm water.
• Proper interim storage of waste paint, solvents, etc.
• Evaluate efficiency of equipment.
• Recycle paint, paint thinner, and solvents.
• Segregate wastes.
• Buy recycled products.

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3.4 BMPs FOR VEHICLE AND EQUIPMENT WASHING

Washing vehicles and equipment outdoors or in areas where wash water flows onto the ground can pollute storm water. Wash water can contain high concentrations of oil and grease, phosphates, and high suspended solid loads (these and other potentially harmful substances can pollute storm water when deposited on the ground where they can be picked up by rainfall runoff). Vehicle wash water is considered to be a process wastewater and needs to be covered by an NPDES permit. Contact your permitting authority for information about how vehicle wash water is being regulated in your area.

The following questions are designed to help you find sources of storm water contamination from vehicle and equipment washing and to select BMPs to reduce those sources. Reading this section can help you eliminate, reduce, or recycle pollutants that otherwise may contaminate storm water. Also refer to Vehicle Washing BMP in Section 4.4.

Q. Have you considered using phosphate-free biodegradable detergents?

Phosphates, which are plant nutrients, can cause excessive growth of nuisance plants in water when they enter lakes or streams in wash water. Some States ban the use of detergents containing high amounts of phosphates. Contact your supplier about phosphate-free biodegradable detergents that are available on the market.

VEHICLE AND EQUIPMENT WASHING ACTIVITIES THAT CAN CONTAMINATE STORM WATER:

- Outside equipment or vehicle cleaning (washing or steam cleaning)
- Wash water discharged directly to the ground or storm water drain

Q. Are vehicles, equipment, or parts washed over the open ground?

Used wash water contains high concentrations of solvents, oil and grease, detergents, and metals. Try not to wash parts or equipment outside. Washing over impervious surfaces like concrete, blacktop, or hardpacked dirt allows wash water to enter storm drains directly or deposits contaminants on the ground, where they are washed into storm drains when it rains. Washing over pervious ground such as sandy soils potentially can pollute ground water. Therefore, small parts and equipment washing should be done over a parts washing container where the wash water can be collected and recycled or disposed of properly.

EMPLOYEE INVOLVEMENT IS THE KEY:

Getting employees interested in reducing waste is the key to a successful storm water pollution prevention plan. Discuss pollution prevention with your employees. They are most familiar with the operations that generate wastes and may have helpful waste reduction suggestions. Consider setting up an employee award program to promote pollution prevention.

If you are washing large equipment or vehicles, and have to wash outside, designate a specific area for washing. This area should be bermed to collect the wastewater and graded to direct the wash water to a treatment facility. Consider filtering and recycling vehicle wash water. If recycling is not practical, the wastewater can be discharged to the sanitary sewer. Contact your local sewer authority to find out whether treatment is required before wash water is discharged to the sewer (pretreatment).

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SUMMARY OF VEHICLE AND EQUIPMENT WASHING BMPs
• Consider use of phosphate-free detergents.
• Use designated cleaning areas.
• Consider recycling wash water.

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3.5 BMPs FOR LOADING AND UNLOADING MATERIALS

Loading/unloading operations usually take place outside on docks or terminals. Materials spilled, leaked, or lost during loading/unloading may collect in the soil or on other surfaces and be carried away by rainfall runoff or when the area is cleaned. Rainfall may wash off pollutants from machinery used to unload or load materials. The following questions are designed to help you find sources of storm water contamination from loading and unloading materials and choose BMPs to reduce or eliminate those sources. Reading this section can start you on the road to eliminating, reducing, or recycling pollutants that otherwise may contaminate storm water. Also refer to the BMP on Loading and Unloading by Air Pressure or Vacuum in Section 4.2.

Q. Are tank trucks and material delivery vehicles located where spills or leaks can be contained?

Loading/unloading equipment and vehicles should be located so that leaks can be contained in existing containment and flow diversion systems.

Q. Is loading/unloading equipment checked regularly for leaks?

Check vehicles and equipment regularly for leaks, and fix any leaks promptly. Common areas for leaks are valves, pumps, flanges, and connections. Look for dust or fumes. These are signs that material is being lost during unloading/loading operations.

LOADING AND UNLOADING ACTIVITIES THAT CAN CONTAMINATE STORM WATER:

- Pumping of liquids or gases from barge, truck or rail car to a storage facility or vice versa
- Pneumatic transfer of dry chemicals to or from the loading and unloading vehicles
- Transfer by mechanical conveyor systems
- Transfer of bags, boxes, drums, or other containers by forklift, trucks, or other material handling equipment

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Q. Are loading/unloading docks or areas covered to prevent exposure to rainfall?

Covering loading and unloading areas, such as building overhangs at loading docks, can reduce exposure of materials, vehicles, and equipment to rain.

Q. Are loading/unloading areas designed to prevent storm water runon?

Runon is storm water created from other areas that flows or "runs on" to your property or site. Runon flowing across loading/unloading areas can wash contaminants into storm drains. Runon can be minimized by:

- Grading, berming, or curbing the area around the loading area to direct runon away from the area
- Positioning roof down spouts so storm water is directed away from loading sites and equipment and preferably to a grassy or vegetated area where the storm water can soak into the ground.

SUMMARY OF LOADING/UNLOADING OPERATIONS BMPs
• Contain leaks during transfer. • Check equipment regularly for leaks. • Limit exposure of material to rainfall. • Prevent storm water runon.

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3.6 BMPs FOR LIQUID STORAGE IN ABOVE-GROUND TANKS

Accidental releases of chemicals from above-ground liquid storage tanks can contaminate storm water with many different pollutants. Materials spilled, leaked, or lost from storage tanks may accumulate in soils or on other surfaces and be carried away by rainfall runoff. The following questions can help you find sources of storm water contamination from above-ground storage tanks and select BMPs to reduce or eliminate those sources. Also refer of the BMPs listed in Section 4.2 on exposure minimization and Section 4.3 on exposure mitigation for more information.

Q. Do storage tanks contain liquid hazardous materials, hazardous wastes, or oil?

Storage of oil and hazardous materials must meet specific standards set by Federal and State laws. These standards include SPCC plans, secondary containment, installation, integrity and leak detection monitoring, and emergency preparedness plans. Federal regulations set specific standards for preventing runon and collecting runoff from hazardous waste storage, disposal, or treatment areas. These standards apply to container storage areas and other areas used to store, treat, or dispose of hazardous waste. If the collected storm water is a hazardous waste, it must be managed as a hazardous waste in accordance with all applicable State and Federal environmental regulations. States may also have standards about controlling runon and runoff from hazardous waste treatment, storage, and disposal areas. To find out more about storage requirements, call the toll-free EPA RCRA hotline at 1-800-424-9346 or contact your State hazardous waste management agency.

THE MOST COMMON CAUSES OF UNINTENTIONAL RELEASES FROM TANKS:

- External corrosion and structural failure
- Installation problems
- Spills and overfills due to operator error
- Failure of piping systems (pipes, pumps, flanges, couplings, hoses, and valves)
- Leaks or spills during pumping of liquids or gases from barges, trucks, or rail cars to a storage facility or vice versa

Q. Are operators trained in correct operating procedures and safety activities?

Well-trained employees can reduce human errors that lead to accidental releases or spills.

Q. Do you have safeguards against accidental releases?

Engineered safeguards can help prevent operator errors that may cause the accidental release of pollutants. Safeguards include:

- Overflow protection devices on tank systems to warn the operator or to automatically shut down transfer pumps when the tank reaches full capacity
- Protective guards around tanks and piping to prevent vehicle or forklift damage
- Clearly tagging or labeling of valves to reduce human error.

Q. Are the tank systems inspected and is tank integrity tested regularly?

Visually inspect the tank system to identify problem areas before they lead to a release. Correct any problems or potential problems as soon as possible. An audit of a newly installed tank system by a registered and specially trained professional engineer can identify and correct potential problems such as loose fittings, poor welding, and improper or poorly fitted gaskets. After installation, have operators visually inspect the tank system on a routine basis. Areas to inspect include tank foundations, connections, coatings, tank walls, and the piping system. Look for corrosion, leaks, straining of tank support structures from leaks, cracks, scratches in protective coatings, or other physical damage that may weaken the tank system. Integrity testing should be done periodically by a qualified professional.

Q. Are tanks bermed or surrounded by a secondary containment system?

A secondary containment system around both permanent and temporary tanks allows leaks to be more easily detected and contains spills or leaks. Methods include berms, dikes, liners, vaults, and double-walled tanks. See Chapter 4 for additional information on containment and spill control.

SUMMARY OF BMPs FOR LIQUID STORAGE IN ABOVE-GROUND TANKS

- Comply with applicable State and Federal laws.
- Properly train employees.
- Install safeguards against accidental releases.
- Routinely inspect tanks and equipment.
- Consider installing secondary containment.

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3.7 BMPs FOR INDUSTRIAL WASTE MANAGEMENT AREAS AND OUTSIDE MANUFACTURING

Storm water runoff from areas where industrial waste is stored, treated, or disposed of can be polluted. Outside manufacturing activities can also contaminate storm water runoff. Activities such as rock grinding or crushing, painting or coating, grinding or sanding, degreasing or parts cleaning, or operations that use hazardous materials are particularly dangerous. Wastes spilled, leaked, or lost from waste management areas or outside manufacturing activities may build-up in soils or on other surfaces and be carried away by rainfall runoff. There is also a potential for liquid wastes from lagoons or surface impoundments to overflow to surface waters or soak the soil where they can be picked up by storm water runoff. Possible storm water contaminants include toxic compounds, oil and grease, paints or solvents, heavy metals, and high levels of suspended solids.

The best way to reduce the potential for storm water contamination from both waste management areas and outside manufacturing activities is to reduce the amount of waste that is created and, consequently, the amount that must be stored or treated. The following questions are designed to help you find BMPs that can eliminate or reduce the amount or toxicity of industrial wastes as well as minimize contamination of storm water from existing waste management areas. Waste reduction BMPs are appropriate for a wide range of industries and are designed to provide ideas on ways to reduce wastes. Turn to Appendix D for a list of State and Federal pollution prevention resources that can provide more information and assistance in choosing industrial waste reduction BMPs.

Q. Have you looked for ways to reduce waste at your facility?

The first step to reducing wastes is to assess activities at your facility. The assessment is designed to find situations at your facility where you can eliminate or reduce waste generation, emissions, and environmental damage. The assessment involves steps very similar to those used to develop your Storm Water Pollution Prevention Plan, such as collecting process-specific information; setting pollution prevention targets; and developing, screening, and selecting waste reduction options for further study. Starting a waste reduction program at your facility has many potential benefits. Some of these benefits are direct (e.g., cost savings from reduced raw material use), while others are indirect (e.g., avoided waste disposal fees).

EPA has developed a series of industry-specific pollution prevention waste minimization guidance manuals. The manuals contain steps for assessing your facility's opportunity for reducing waste and describe source reduction and recycling choices. The manuals currently available are listed in Appendix D.

INDUSTRIAL WASTE MANAGEMENT ACTIVITIES OR AREAS THAT CAN CONTAMINATE STORM WATER:

- Landfills
- Waste piles
- Wastewater and solid waste treatment and disposal:
  - Waste pumping
  - Additions of treatment chemicals
  - Mixing
  - Aeration
  - Clarification
  - Solids dewatering
- Land application

Q. Have you considered waste reduction BMPs?

There are many different types of BMPs that can help eliminate or reduce the amount of industrial waste generated at your facility. Some of these BMPs are listed below and referenced in Appendix D.

- Production planning and sequencing
- Process or equipment modification
- Raw material substitution or elimination
- Loss prevention and housekeeping
- Waste segregation and separation
- Closed-loop recycling
- Training and supervision
- Reuse and recycling.

OUTSIDE MANUFACTURING ACTIVITIES OR SITUATIONS THAT CAN CONTAMINATE STORM WATER:
• Processes or equipment that generate dusts, vapors, or emissions
• Outside storage of hazardous materials or raw materials
• Dripping or leaking fluids from equipment or processes
• Liquid wastes discharged directly onto the ground or into the storm sewer

Q. Are industrial waste management and outside manufacturing areas checked often for spills and leaks?

By checking waste management areas for leaking containers or spills, you can prevent wastes from contaminating storm water. Look for containers that are rusty, corroded, or damaged. Transfer wastes from these damaged containers into safe containers. Close the lids on dumpsters to prevent rain from washing wastes out of holes or cracks in the bottom of the dumpster. In outside manufacturing areas, look for leaking equipment (e.g., valves, lines, seals, or pumps) and fix leaks promptly. Inspect rooftop and other outdoor equipment (e.g., HVAC devices, air pollution control devices, transformers, piping, etc.) for leaks or dust concentrations.

Q. Are industrial waste management areas or manufacturing activities covered, enclosed, or bermed?

The best way to avoid contaminating storm water from existing waste management and manufacturing areas is to prevent storm water runon or rain from entering or contacting these areas. This can be done by:

- Preventing direct contact with rain
- Moving the activity indoors after ensuring that all safety concerns such as fire hazard and ventilation are addressed
- Covering the area with a permanent roof

- Covering waste piles with a temporary covering material such as a reinforced tarpaulin, polyethylene, polyurethane, polypropylene, or Hypalon
- Minimizing storm water runon by enclosing the area or building a berm around the area.

Q. Are vehicles used to transport wastes to the land disposal or treatment site equipped with anti-spill equipment?

Transport vehicles equipped with spill prevention equipment can prevent spills of wastes during transport. Examples include:

- Vehicles equipped with baffles for liquid wastes
- Trucks with sealed gates and spill guards for solid wastes
- Trucks with tarps.

Q. Do you use loading systems that minimize spills and fugitive losses such as dust or mists?

Wastes lost during loading or unloading can contaminate storm water. Vacuum transfer systems minimize waste loss.

Q. Are sediments or wastes prevented from being tracked offsite?

Wastes and sediments tracked offsite can end up on streets where they are picked up by storm water runoff. This can be avoided by using vehicles with specially designed tires, washing vehicles in a designated area before they leave the site, and controlling the wash water.

Q. Is storm water runoff minimized from the land disposal site?

You can take certain precautions to minimize the runoff of polluted storm water from land application sites. Some precautions are detailed below.

DO YOU OWN OR OPERATE A HAZARDOUS WASTE TREATMENT, STORAGE, AND DISPOSAL FACILITY?

Federal and State laws establish strict standards for managing solid and hazardous wastes. If you are not sure whether you own or operate a hazardous waste treatment, storage, or disposal facility, call the toll-free EPA RCRA hotline at 1-800-424-9346 or contact your State hazardous waste management agency. Federal regulations contain specific standards about preventing runon and collecting runoff from hazardous waste storage, disposal, or treatment areas. These standards apply to land treatment units, landfills, waste piles, container storage areas, and other areas used to store, treat, or dispose of hazardous waste. If the collected storm water is a hazardous waste, it must be managed in accordance with all applicable State and Federal environmental regulations. States may also have standards about controlling runon and runoff from hazardous waste treatment, storage, and disposal areas.

- Choose the land application site carefully. Characteristics that help prevent runoff include slopes under 6 percent, permeable soils, a low water table, locations away from wetlands or marshes, and closed drainage systems.

- Avoid applying waste to the site when it is raining or when the ground is frozen or saturated with water. Grow vegetation on areas dedicated to land disposal to stabilize the soils and reduce the volume of surface water runoff from the site.
- Maintain adequate barriers between the land application site and receiving waters.
- Erosion control techniques might include mulching and matting, filter fences, straw bales, diversion terracing, or sediment basins. For a detailed description of erosion control techniques, see Chapter 4.
- Perform routine maintenance to ensure that erosion control or site stabilization measures are working.

SUMMARY OF INDUSTRIAL WASTE MANAGEMENT AND OUTSIDE MANUFACTURING BMPs
• Conduct a waste reduction assessment.
• Institute industrial waste source reduction and recycling BMPs.
• Prevent runoff and runon from contacting the waste management area.
• Minimize runoff from land application sites.

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3.8 BMPs FOR OUTSIDE STORAGE OF RAW MATERIALS, BY-PRODUCTS, OR FINISHED PRODUCTS

Raw materials, by-products, finished products, containers, and material storage areas exposed to rain and/or runoff can pollute storm water. Storm water can become contaminated by a wide range of contaminants (e.g., metals, oil, and grease) when solid materials wash off or dissolve into water, or by spills or leaks. The following questions are designed to help you identify potential sources of storm water contamination and select BMPs that can reduce or eliminate those sources. Reading this section can help you eliminate or reduce pollutants that otherwise may contaminate storm water.

Q. Are materials protected from rainfall, runon, and runoff?

The best way to avoid contaminating storm water from outside material storage areas is to prevent storm water runon or rain from coming in contact with the materials. This can be done by:

- Storing the material indoors
- Covering the area with a roof
- Covering the material with a temporary covering made of polyethylene, polyurethane, polypropylene, or Hypalon.
- Minimizing storm water runon by enclosing the area or building a berm around the area.

ARE ANY OF THESE MATERIALS STORED OUTSIDE OR IN AREAS WHERE THEY CAN CONTAMINATE STORM WATER?
• Fuels
• Raw materials
• By-products
• Intermediates
• Final products
• Process residuals

SUMMARY OF BMPs FOR OUTSIDE STORAGE OF RAW MATERIALS, BY-PRODUCTS, OR FINISHED PRODUCTS
• Cover or enclose materials.

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3.9 BMPs FOR SALT STORAGE FACILITIES

Salt left exposed to rain or snow can be lost. Salt spilled or blown onto the ground during loading and unloading will dissolve in storm water runoff. Storm water contaminated with salt can be harmful to vegetation and aquatic life. Salty storm water runoff soaking into the ground may contaminate ground water and make it unsuitable as a drinking water supply. The following BMPs will help reduce storm water contamination from salt storage and transfer activities. See Chapter 4 for more detailed information on covering storage areas.

SALT STORAGE ACTIVITIES THAT CAN CONTAMINATE STORM WATER:
• Salt stored outside in piles or bags that are exposed to rain or snow • Salt loading and unloading areas located outside or in areas where spilled salt can contaminate storm water.

Q. Are salt piles protected from rain?

The best way to prevent salt from contaminating storm water is to eliminate or limit the exposure of salt to rain. Preventing contact with rain also protects against salt loss and prevents salt from absorbing moisture and becoming caked or lumpy and making it difficult to handle and use.

- Store salt under a roof. This is the best way to stop direct contact with rain.

If salt must be stored outside:

- Build the storage pile on asphalt to reduce the potential for ground water contamination
- Cover the pile with a temporary covering material such as polyethylene, polyurethane, polypropylene, or Hypalon.

Q. Is storm water runon prevented from contacting storage piles and loading and unloading areas?

Storm water runon can be minimized by enclosing the area or building berms around storage, loading, and unloading areas.

SUMMARY OF SALT STORAGE FACILITIES BMPs
• Put it under a roof. • Use temporary covers. • Enclose or berm transfer areas.

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CHAPTER 4

SITE-SPECIFIC INDUSTRIAL STORM WATER BMPs

This chapter describes some of the possible Best Management Practices (BMPs) that you might include in your Storm Water Pollution Prevention Plan so that pollutants from your site do not mix with storm water.

Table 4.1 provides an easy index of the BMP descriptions that follow. The BMPs are grouped by section into six categories: Flow Diversion Practices; Exposure Minimization Practices; Mitigative Practices; Other Preventive Practices; Sediment and Erosion Prevention Practices; and Infiltration Practices.

The following information is provided for each BMP: (1) description of the BMP; (2) when and where the BMP can be used; (3) factors that should be considered when using the BMP; and (4) advantages and disadvantages of the BMP. More detailed fact sheets for a limited number of the Sediment and Erosion Prevention Practices are included as Appendix E. When designing these structural controls, EPA recommends that you refer to any State or local storm water management design standards.

TABLE 4.1 INDEX OF SITE-SPECIFIC INDUSTRIAL STORM WATER BMPs

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TABLE 4.1 INDEX OF SITE-SPECIFIC INDUSTRIAL STORM WATER BMPs (Continued)

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4.1 FLOW DIVERSION PRACTICES

Structures that divert stream flow (such as gutters, drains, sewers, dikes, and graded pavement) are used as BMPs in two ways. First, flow diversion structures, called storm water conveyances, may be used to channel storm water away from industrial areas so that pollutants do not mix with the storm water. Second, they also may be used to carry pollutants directly to a treatment facility. This section briefly describes flow diversion as a BMP for industrial storm water.

Storm Water Conveyances (Channels/Gutters/Drains/Sewers)

What Are They

Storm water conveyances such as channels, gutters, drains, and sewers, collect storm water runoff and direct its flow. A group of connecting conveyances is sometimes installed at an industrial facility to create a storm water collection system. Storm water conveyances can be used for two different purposes. The first purpose is to keep uncontaminated storm water from coming in contact with areas of an industrial site where it may become contaminated with pollutants. This can be accomplished by collecting the storm water in a conveyance and by changing the direction of flow away from those areas. The second purpose is to collect and carry the storm water that has already come into contact with industrial areas and become contaminated to a treatment facility.

Storm water conveyances can be constructed or lined with many different materials, including concrete, clay tiles, asphalt, plastics, metals, riprap, compacted soils, and vegetation. The type of material used depends on the use of the conveyance. These conveyances can be temporary or permanent.

When and Where to Use Them

Storm water conveyances work well at most industrial sites. Storm water can be directed away from industrial areas by collecting it in channels or drains before it reaches the areas. In addition, conveyances can be used to collect storm water downhill from industrial areas and keep it separate from runoff that has not been in contact with those areas. When potentially contaminated storm water is collected in a conveyance like this, it can be directed to a treatment facility on the site if necessary. (If a pollutant is spilled, it should not be allowed to enter a storm water conveyance or drain system.)

What to Consider

In planning for storm water conveyances, consider the amount and speed of the typical storm water runoff. Also, consider the patterns in which the storm water drains so that the channels may be located to collect the most flow and can be built to handle the amount of water they will receive. When deciding on the type of material for the conveyance, consider the resistance of the material, its durability, and compatibility with any pollutants it may carry.

Conveyance systems are most easily installed when a facility is first being constructed. Use of existing grades will decrease costs. Grades should be positive to allow for the continued movement of the runoff through the conveyance system; however, grades should not create an increase in velocity that causes an increase in erosion (this will also depend upon what materials the conveyance is lined with and the types of outlet controls that are provided).

Ideally, storm water conveyances should be inspected to remove debris within 24 hours of rainfall, or daily during periods of prolonged rainfall, since heavy storms may clog or damage them. It is important to repair damages to these structures as soon as possible.

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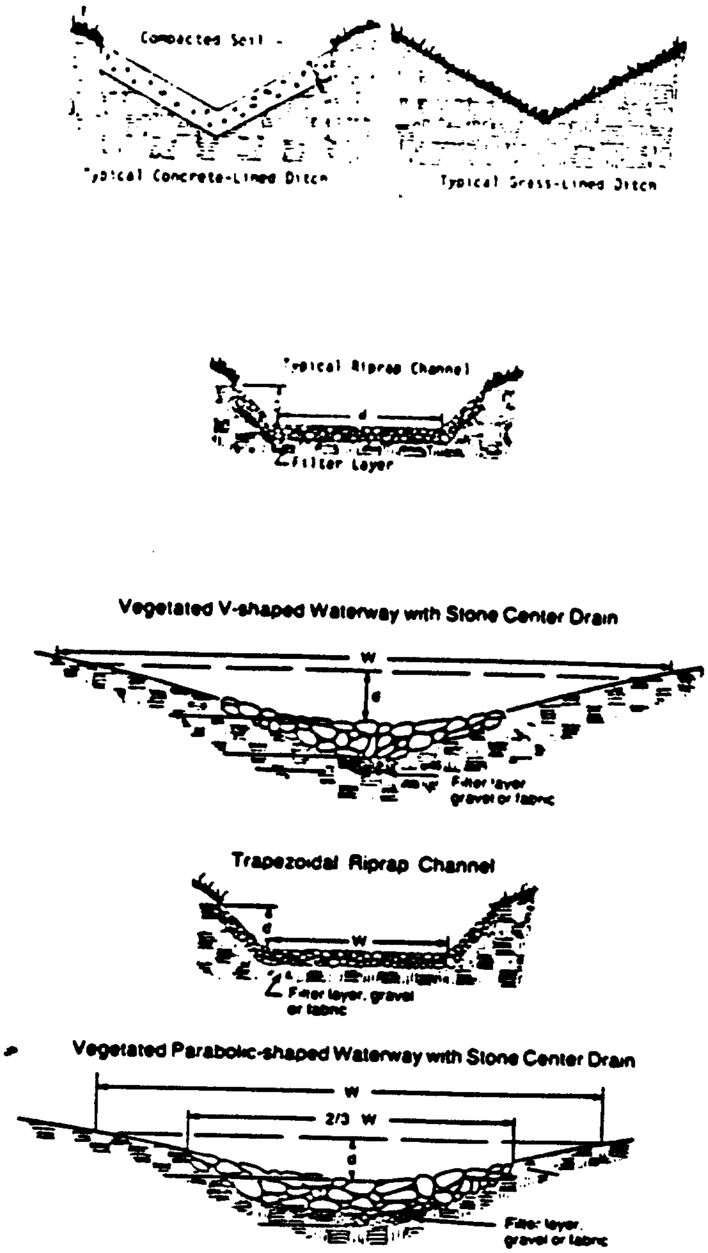

FIGURE 4.1 TYPICAL STORM WATER CONVEYANCE CROSS SECTIONS
(Modified from Commonwealth of Virginia, 1980)

Advantages of Storm Water Conveyances (Channels/Gutters/Drains/Sewers)
• Direct storm water flows around industrial areas • Prevent temporary flooding of industrial site • Require low maintenance • Provide erosion resistant conveyance of storm water runoff • Provide long-term control of storm water flows
Disadvantages of Storm Water Conveyances (Channels/Gutters/Drains/Sewers)
• Once flows are concentrated in storm water conveyances, they must be routed through stabilized structures all the way to their discharge to the receiving water or treatment plant to minimize erosion • May increase flow rates • May be impractical if there are space limitations • May not be economical, especially for small facilities or after a site has already been constructed

Diversion Dikes

What Are They

Diversion dikes or berms are structures used to block runoff from passing beyond a certain point. Temporary dikes are usually made with compacted soil. More permanent ridges are constructed out of concrete, asphalt, or similar materials.

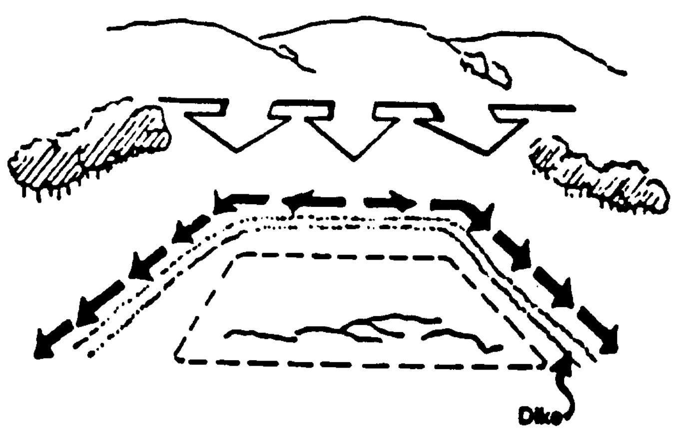

FIGURE 4.2 DIVERSION DIKES
(Modified from North Carolina, 1988)

When and Where to Use Them

Diversion dikes are used to prevent the flow of storm water runoff onto industrial areas. Limiting the volume of flow across industrial areas reduces the volume of storm water that may carry pollutants from the area, requiring treatment for pollutant removal. This BMP is suitable for industrial sites where significant volumes of storm water runoff tend to flow onto active industrial areas. Typically, dikes are built on slopes just uphill from an industrial area together with some sort of a conveyance such as a swale. The storm water conveyance is necessary to direct the water away from the dike so that the water will not pool and seep through the dike.

What to Consider

In planning for the installation of dikes, consider the slope of the drainage area, the height of the dike, the size of rainfall event it will need to divert, and the type of conveyance that will be used with the dike. Steeper slopes result in higher volumes of runoff and higher velocities; therefore, the dike must be constructed to handle this situation. Remember that dikes are limited in their ability to manage large volumes of runoff.

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Ideally, dikes are installed before industrial activity begins. However, dikes can be easily constructed at any time. Temporary dikes (usually made of dirt) generally only last for 18 months or less, but they can be made into permanent structures by stabilizing them with vegetation. Vegetation is crucial for preventing the erosion of the dike.

Dikes should be inspected regularly for damage. This is especially important after storm events since a heavy rain may wash parts of a temporary dike away. Any necessary repairs should be made immediately to make sure the structure continues to do its job.

Advantages of Diversion Dikes
• Effectively limit storm water flows over industrial site areas
• Can be installed at any time
• Are economical temporary structures, when built from soil onsite
• Can be converted from temporary to permanent at any time
Disadvantages of Diversion Dikes
• Are not suitable for large drainage areas unless there is a gentle slope
• May require maintenance after heavy rains

Graded Areas and Pavement

What Is It

Land surfaces can be graded or graded and paved so that storm water runoff is directed away from industrial activity areas. The slope of the grade allows the runoff to flow, but limits the runoff from washing over areas that may be contaminated with pollutants. Like conveyances and dikes, graded areas can prevent runoff from contacting industrial areas and becoming contaminated with pollutants from these areas. Grading can be a permanent or temporary control measure.

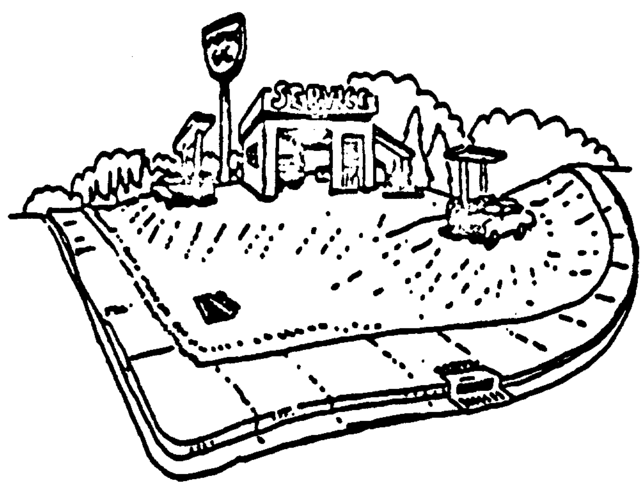

FIGURE 4.3 EXAMPLE OF GRADED PAVEMENT
(Modified from Santa Clara Valley, 1990)

When and Where to Use It

Grading land surfaces is appropriate for any industrial site that has outdoor activities that may contaminate storm water runoff, such as parking lots or outdoor storage areas. Figure 4.3 illustrates the use of graded pavement in preventing runoff from washing over a service station site. Grading is often used with other practices, such as coverings, buffer zones, and other practices to reduce the runoff velocity and provide infiltration of the uncontaminated runoff, or to direct pollutant runoff to storm water treatment facilities.

What to Consider

When designing graded areas and pavement, both control and containment of runoff flows should be considered. The grading should control the uncontaminated flow by diverting it around areas that may have pollutants. The grading should also contain the contaminated flows or divert them to treatment facilities.

When regrading and paving an industrial area, the use of concrete paving instead of asphalt should be considered. This is especially important in potential spill sites or hazardous material storage areas. Asphalt absorbs organic pollutants and can be slowly dissolved by some fluids, thus becoming a possible source of contaminants itself. This control measure should be used with a cover, such as a roof, in areas where contaminants are of concern (see Covering BMP) so that rain or snow does not fall on the area and wash the contaminants down slope.

Inspect paving regularly for cracks that may allow contaminants to seep into the ground. Also, check to make sure that the drains receiving the storm water flow from the paved area remain unclogged with sediment or other debris so that low areas do not flood and wash over the areas where the contaminants may be.

Advantages of Graded Areas and Pavement
• Is effective in limiting storm water contact with contaminants • Is relatively inexpensive and easily implemented
Disadvantages of Graded Areas and Pavement
• May be uneconomical to regrade and resurface large areas • May not be effective during heavy precipitation

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4.2 EXPOSURE MINIMIZATION PRACTICES

By eliminating or minimizing the possibility of storm water coming into contact with pollutants, facilities can eliminate or minimize the contamination of storm water discharges associated with their industrial activity. As a result, fewer materials will be carried away by storm water runoff, the costs of collecting and treating contaminated storm water will be decreased, and safety and environmental liabilities that result from spills and leaks will be reduced.

Completely eliminating the exposure of materials to storm water is not always possible, however. For many industrial facilities, enclosure of facility grounds is not technologically or economically possible. Therefore, this section describes several simple and inexpensive structural and nonstructural BMPs that a facility can use to minimize the exposure of materials to storm water.

Containing spills is one of the primary methods of minimizing exposure of contaminants to storm water runoff. Spill containment is used for enclosing any drips, overflows, leaks, or other liquid material releases, as well as for isolating and keeping pollutant spills away from storm water runoff.

There are numerous spill containment methods, ranging from large structural barriers to simple, small drip pans. The benefits of each of these practices vary based on cost, need for maintenance, and size of the spill they are designed to control. This section describes several containment methods, including:

- Containment Diking
- Curbing
- Drip Pans
- Catch Basins
- Sumps.

Other practices commonly used to minimize exposure of contaminants are also discussed, including the following:

- Covering
- Vehicle Positioning
- Loading and Unloading by Air Pressure or Vacuum.

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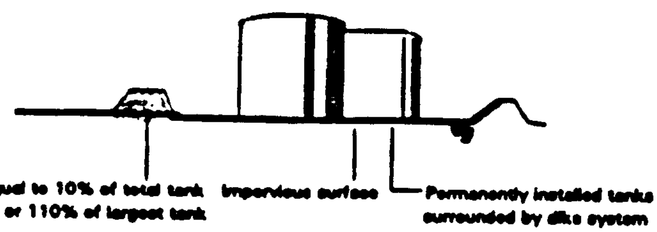
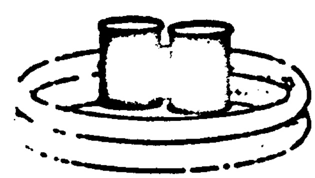
Containment Diking

What Is It

Containment dikes are temporary or permanent earth or concrete berms or retaining walls that are designed to hold spills. Diking, one of the most common types of containment, is an effective method of pollution prevention for above-ground liquid storage tanks and rail car or tank truck loading and unloading areas. Diking can provide one of the best protective measures against the contamination of storm water because it surrounds the area of concern and holds the spill, keeping spill materials separated from the storm water outside of the diked area.



Containment Diking for Large Storage Areas



Containment Diking for Small Storage Areas

FIGURE 4.4 CONTAINMENT DIKING
(Modified from MWCOG, 1992)

When and Where to Use It

Diking can be used at any industrial facility but is most commonly used for controlling large spills or releases from liquid storage areas and liquid transfer areas.

What to Consider

Containment dikes should be large enough to hold an amount equal to the largest single storage tank at the particular facility plus the volume of rainfall. For rail car and tank truck loading and unloading operations, the diked area should be capable of holding an amount equal to any single tank truck compartment. Materials used to construct the dike should be strong enough to safely hold spilled materials. The materials used usually depend on what is available onsite and the substance to be contained, and may consist of earth (i.e., soil or clay), concrete, synthetic materials (liners), metal, or other impervious materials. In general, strong acids and bases may react with metal containers, concrete, and some plastics, so where spills may consist of these substances, other alternatives should be considered. Some of the more reactive organic chemicals may also need to be contained with special liners. If there are any questions about storing chemicals in certain dikes because of their construction materials, refer to the Material Safety Data Sheets (MSDSs).

Containment dikes may need to be designed with impervious materials to prevent leaking or contamination of storm water, surface, and ground water supplies.

Similarly, uncontrolled overflows from diked areas containing spilled materials or contaminated storm water should be prevented to protect nearby surface waters or ground waters. Therefore, dikes should have either pumping systems (see Sumps BMP) or vacuum trucks available to remove the spilled materials. When evaluating the performance of the containment system, you should pay special attention to the overflow system, since it is often the source of uncontrolled leaks. If overflow systems do not exist, accumulated storm water should be released periodically. Contaminated storm water should be treated prior to release. Mechanical parts, such as pumps or even manual systems (e.g., slide gates, stopcock valves), may require regular cleaning and maintenance.

When considering containment diking as a BMP, you should consult local authorities about any regulations governing construction of such structures to comply with local and State requirements. Facilities located in a flood plain should contact their local flood control authority to ensure that construction of the dikes is permitted.

Inspections of containment dikes should be conducted during or after significant storms or spills to check for washouts or overflows. In addition, regular checks of containment dikes (i.e., testing to ensure that dikes are capable of holding spills) is recommended. Soil dikes may need to be inspected on a more frequent basis.

Changes in vegetation, inability of the structure to retain storm water dike erosion, or soggy areas indicate problems with the dike's structure. Damaged areas should be patched and stabilized immediately, where necessary. Earthen dikes may require special maintenance of vegetation, such as mowing and irrigation.

Advantages of Containment Diking
• Contains spills, leaks, and other releases and prevent them from flowing into runoff conveyances, nearby streams, or underground water supplies • Permits materials collected in dikes to be recycled • Is a common industry practice for storage tanks and already required for certain chemicals
Disadvantages of Containment Diking
• May be too expensive for some smaller facilities • Requires maintenance • Could collect contaminated storm water, possibly resulting in infiltration of storm water to ground water

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Curbing

What Is It

Like containment diking, curbing is a barrier that surrounds an area of concern. Curbing functions in a similar way to prevent spills, leaks, etc. from being released to the environment by routing runoff to treatment or control areas. The terms curbing and diking are sometimes used interchangeably.

Because curbing is usually small-scale, it cannot contain large spills like diking can, however, curbing is common at many facilities in small areas where handling and transferring liquid materials occur.

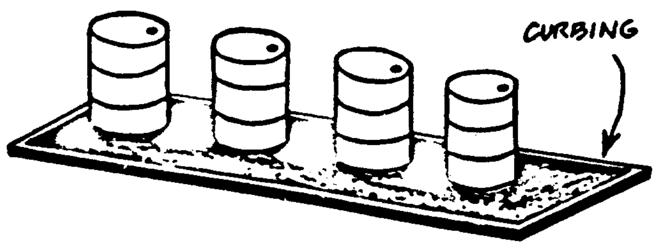

FIGURE 4.5 CURBING AROUND DRUM STORAGE AREA

When and Where to Use It

Curbing can be used at all industrial facilities. It is particularly useful in areas where liquid materials are transferred and as a storm water runoff control.

As with diking, common materials for curbing include earth, concrete, synthetic materials, metal, or other impenetrable materials. Asphalt is also a common material used in curbing.

What to Consider

For maximum efficiency of curbing, spilled materials should be removed immediately, to allow space for future spills. Curbs should have pumping systems, rather than drainage systems, for collecting spilled materials. Manual or mechanical methods, such as those provided by sump systems (see Sump BMP), can be used to remove the material. Curbing systems should be maintained through curb repair (patching and replacement).

When using curbing for runoff control, facilities should protect the berm by limiting traffic and installing reinforced berms in areas of concern.

Spills of materials that are stored within a curbed area can be tracked outside of that area when personnel and equipment leave the area. This tracking can be minimized by grading within the curbing to direct the spilled materials to a down-slope side of the curbing. This will keep the materials away from personnel and equipment that pass through the area. It will also allow the materials to accumulate in one area making cleanup much easier.

Inspections should also be conducted before forecasted rainfall events and immediately after storm events. If spilled or leaked materials are observed, cleanup should start immediately. This will prevent overflows and/or contamination of storm water runoff. In addition, prompt cleanup of materials will prevent dilution by rainwater, which can adversely affect recycling opportunities. Inspection of curbed areas should be conducted regularly, to clear clogging debris. Because curbing is sized to contain small spill volumes, maintenance should also be conducted frequently to prevent overflow of any spilled materials.

Advantages of Curbing
• Is an excellent method to control runon • Is inexpensive • Is easily installed • Materials spilled within curbed areas can be recycled • Exists as a common industry practice
Disadvantages of Curbing
• Is not effective for holding large spills • May require more maintenance than diking

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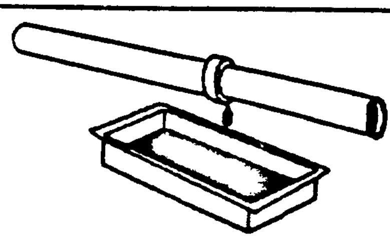
Drip Pans

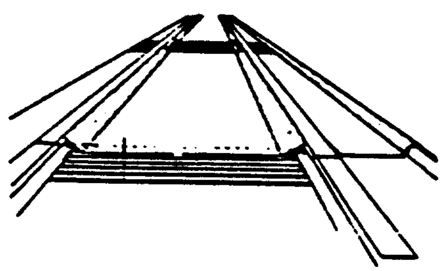
What Are They

Drip pans are small depressions or pans used to contain very small volumes of leaks, drips, and spills that occur at a facility. Drip pans can be depressions in concrete, asphalt, or other impenetrable materials or they can be made of metals, plastic, or any material that does not react with the dripped chemicals. Drip pans can be temporary or permanent.

Drip pans are used to catch drips from valves, pipes, etc. so that the materials or chemicals can be cleaned up easily or recycled before they can contaminate storm water. Although leaks and drips should be repaired and eliminated as part of a preventive maintenance program, drip pans can provide a temporary solution where repair or replacement must be delayed. In addition, drip pans can be an added safeguard when they are positioned beneath areas where leaks and drips may occur.



Use Drip Pans for Leaking Equipment



Use Drip Pans in Loading and Unloading Areas

FIGURE 4.6 USES FOR DRIP PANS
(Modified from Washington State, 1992)

When and Where to Use Them

Drip pans can be used at any industry where valves and piping are present and the potential for small volume leakage and dripping exist.

What to Consider

When using drip pans, consider the location of the drip pan, weather conditions, the type of material to be used for the drip pan, and how it will be cleaned.

The location of the drip pan is important. Because drip pans must be inspected and cleaned frequently, they must be easy to reach and remove. In addition, take special care to avoid placing drip pans in precarious positions such as next to walkways, on uneven pavement/ground, or sitting on pipelines. Drip pans in these locations are easily overturned and may present a safety hazard, as well as an environmental hazard.

Weather conditions are also important factors. Heavy winds and rainfall move or damage drip pans because of their small size and their light weight (if not built-in). To prevent this, secure the pans by installing or anchoring them. Drip pans may be placed on platforms or behind wind blocks or tied down.

For drip pans to be effective, employees must pay attention to the pans and empty them when they are nearly full. Because of their small holding capacities, drip pans will easily overflow if not emptied. Also, recycling efforts can be affected if storm water accumulates in drip pans and dilutes the spilled material. It is important to have clearly specified and easily followed practices of reuse/recycle and/or disposal, especially the disposal of hazardous materials. Many facilities dump the drip pan contents into a nearby larger volume storage container and periodically recycle the contents of the storage container.

In addition, frequent inspection of the drip pans is necessary due to the possibility of leaks in the pan itself or in piping or valves that may occur randomly or irregular slow drips that may increase in volume. Conduct inspections before forecasted rainfall events to remove accumulated materials and immediately after storm events to empty storm water accumulations.

Advantages of Drip Pans
• Are inexpensive • Are easily installed and simple to operate • Allow for reuse/recycle of collected material • Empty or discarded containers may be reused as drip pans
Disadvantages of Drip Pans
• Contain small volumes only • Must be inspected and cleaned frequently • Must be secured during poor weather conditions • Contents may be disposed of improperly unless facility personnel are trained in proper disposal methods

Collection Basins

What Are They

Collection basins, or storage basins, are permanent structures where large spills or contaminated storm water are contained and stored before cleanup or treatment. Collection basins are designed to receive spills, leaks, etc. that may occur and prevent these materials from being released to the environment. Unlike containment dikes, collection basins can receive and contain materials from many locations across a facility.

Collection basins are commonly confused with treatment units such as ponds, lagoons, and other containment structures. Collection basins differ from these structures because they are designed to temporarily store storm water rather than treat it.

When and Where to Use Them

Collection basins are appropriate for all industrial sites where space allows. Collection basins are particularly useful for areas that have a high spill potential.

What to Consider

The design and installation considerations for collection basins include sizing the basin either to hold a certain amount of spill or a certain size storm, or both. In designing the collection system, the type of material for the conveyances, compatibility of various materials to be carried through the system, and requirements for compliance with State and local regulations should be considered. Ideally, the system should function to route the materials quickly and easily to the collection basin.

When spills occur, the collection system must route the spill or storm water immediately to the collection basin. After a spill is contained, the collection system and basin may require cleaning. Remove the collection basin contents immediately to prevent an unintentional release and recycle the spilled material as much as possible. Inspect the structure on a regular basis and after storm events or spills. Depending upon the types of pollutants that may be in the storm water, or are collected as spills, design of the basin may require a liner to prevent infiltration into the ground water. Make sure that the installation of this BMP does not violate State ground water regulations.

If it is possible that the collection basin may handle combustible or flammable spilled materials, explosion-proof pumping equipment and controls or other appropriate precautions should be taken to prevent explosions or fires. Consult OSHA and local safety codes and standards for specific requirements and guidance.

Advantages of Collection Basins
• Can store contaminated storm water until directed to a treatment facility • Can collect spills for recycling where materials are separated
Disadvantages of Collection Basins
• May need a conveyance system for increased effectiveness • May collect materials that are not compatible • May reduce the potential for recycling materials by collecting storm water, which dilutes the materials • May create ground water problems if pollutants infiltrate into ground

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Sumps

What Are They

Sumps are holes or low areas that are structured so that liquid spills or leaks will flow down toward a particular part of a containment area. Frequently, pumps are placed in a depressed area and are turned on automatically to transfer liquids away from the sump when the level of liquids gets too high. Sumps can be temporary or permanent.

When and Where to Use Them

Sumps can be used at all facilities. Sumps are used with other spill containment and treatment measures and can be located almost anywhere onsite. Sumps are frequently located in low lying areas within material handling or storage areas.

What to Consider

When designing and installing a sump system, consider the pump location, function, and system alarms. Design and install the sump in the lowest lying area of a containment structure, allowing for materials to gather in the area of the sump. Construct the sump of impenetrable materials and provide a smooth surface so that liquids are funneled toward the pump. It may be appropriate to house the pumps in a shed or other structure for protection and stabilization.

There are numerous factors that should be considered when purchasing a pump. Base the size of the pump on the maximum expected volume to be collected in the containment structure. In some cases, more than one pump may be appropriate. Typically, pumps that can be submerged under the spill are the most appropriate for areas where large spills may occur and that may submerge the sump area. The viscosity (thickness) of the material and the distance that the material must be pumped are also important considerations. Install pumps according to the manufacturer's recommendations.

An alarm system can be installed for pumps that are used to remove collected materials. An alarm system can indicate that a pump should be operated by hand or that an automatically operated pump has failed to function. Ultimately, facility personnel should have some mechanism to take action to prevent spills from by-passing and overflowing containment structures.

The pumps and the alarm system used in the sump generally require regular inspections for service and maintenance of parts based on manufacturers' recommendations.

If it is possible that the sump may handle combustible or flammable spilled materials, explosion-proof pumping equipment and controls or other appropriate precautions should be taken to prevent explosions or fires. Consult OSHA and local safety codes and standards for specific requirements and guidance.

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Advantages of Sumps
• Provide a simple and quick collection method for recycling, reusing, or treating materials in a containment structure • Are commonly used at industrial facilities
Disadvantages of Sumps
• Pumps may clog easily if not designed correctly • May require maintenance/servicing agreements with pump dealers • Costs for purchasing and/or replacing pumps may be high

Covering

What Is It

Covering is the partial or total physical enclosure of materials, equipment, process operations, or activities. Covering certain areas or activities prevents storm water from coming into contact with potential pollutants and reduces material loss from wind blowing. Tarpaulins, plastic sheeting, roofs, buildings, and other enclosures are examples of covering that are effective in preventing storm water contamination. Covering can be temporary or permanent.

When and Where to Use It

Covering is appropriate for outdoor material storage piles (e.g., stockpiles of dry materials, gravel, sand, compost, sawdust, wood chips, de-icing salt, and building materials) and areas where liquids and solids in containers are stored or transferred. Although it may be too expensive to cover or enclose all industrial activities, cover high-risk areas (identified during the storm water pollutant source identification). For example, cover chemical preparation areas, vehicle maintenance areas, areas where chemically treated products are stored, and areas where salts are stored.

If covering or enclosing the entire activity is not possible, the high-risk part of the activity can often be separated from other processes and covered. Another option that reduces the cost of building a complete enclosure is to build a roof over the activity. A roof may also eliminate the need for ventilation and lighting systems (Washington State, 1992).

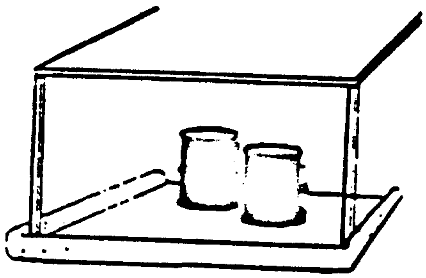
What to Consider

Evaluate the strength and longevity of the covering, as well as its compatibility with the material or activity being enclosed. When designing an enclosure, consider access to materials, their handling, and transfer. Materials that pose environmental and safety dangers because they are radioactive, biological, flammable, explosive, or reactive require special ventilation and temperature considerations.

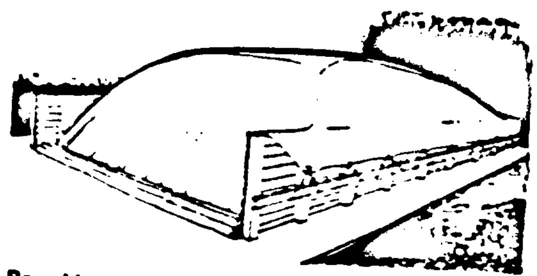
Covering alone may not protect exposed materials from storm water contact. Place the material on an elevated, impermeable surface or build curbing around the outside of the materials to prevent problems from runon of uncontaminated storm water from adjacent areas.

Frequently inspect covering, such as tarpaulins, for rips, holes, and general wear. Anchor the covering with stakes, tie-down ropes, large rocks, tires, or other easily available heavy objects.

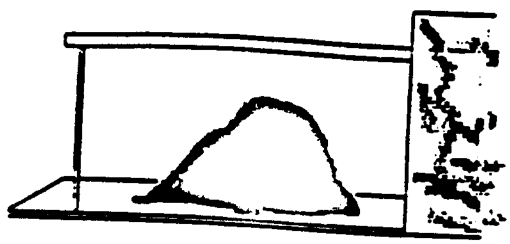
Practicing proper materials management within an enclosure or underneath a covered area is essential. For example, floor drainage within an enclosure should be properly designed and connected to the wastewater sewer where appropriate and allowed. If connection to an offsite wastewater sewer is considered, the local Publicly Owned Treatment Works (POTW) should be consulted to find out if there are any pretreatment requirements or restrictions that must be followed.



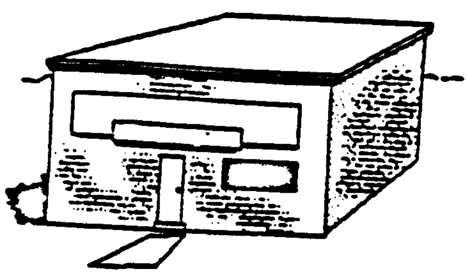
Small Chemical Storage Area with Curbing and Cover



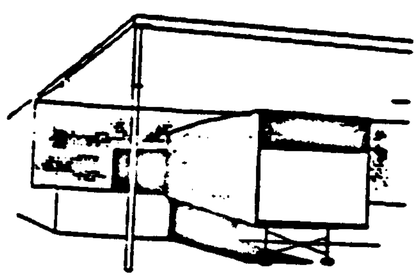
Raw Material Storage Covered with Tarpaulin



Covered Area for Raw Materials



Enclosed Area for Storage of Raw Materials or Chemicals



Covered Area for Loading and Unloading

FIGURE 4.7 EXAMPLE COVERING FOR INDUSTRIAL ACTIVITIES
(Modified from Washington State, 1992; Salt Institute, 1987)

Advantages of Covering
• Is simple and effective • Is commonly inexpensive
Disadvantages of Covering
• Requires frequent inspection • May pose health or safety problems if enclosure is built over certain activities

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Vehicle Positioning

What Is It

Vehicle positioning is the practice of locating trucks or rail cars while transferring materials to prevent spills of materials onto the ground surface, which may then contaminate storm water runoff. Vehicle positioning is a simple and effective method of material spill prevention and yet it is commonly overlooked.

When and Where to Use It

Vehicle positioning can be used at all types of industrial facilities. This practice is appropriate for any area where materials are transferred from or to vehicles, such as loading and unloading areas, storage areas, and material transfer areas. Use vehicle positioning in conjunction with other practices such as covering, sumps, drip pans, or loading and unloading by air pressure or vacuum where chemical spills are of concern.

What to Consider

The purpose of vehicle positioning is to locate vehicles in a stable and appropriate position to prevent problems, such as spills resulting from broken material storage containers, spills caused by vehicle movement during materials transfer activities, and spills caused by improperly located vehicles. Vehicles should also be positioned near containment or flow diversion systems to collect unexpected spills from leaks in transfer lines or connections. The following activities are included in this practice:

- Constructing walls that help in positioning the vehicles
- Positioning vehicle either over a drain or on a sloped surface that drains to a containment structure
- Outlining required vehicle positions on the pavement
- Using wheel guards or wheel blocks
- Posting signs requiring the use of emergency brakes
- Requiring vehicles to shut off engines during materials transfer activities.

Advantages of Vehicle Positioning
• Is inexpensive
• Is easy and effective
Disadvantages of Vehicle Positioning
• May require redesign of loading and unloading areas

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Loading and Unloading by Air Pressure or Vacuum

What Is It

Air pressure and vacuum systems are commonly used for transporting and loading and unloading materials. These systems are simple to use and effective in transferring dry chemicals or solids from one area to another, but are less effective as the particles of material become more dense.

In an air pressure system, a safety-relief valve and a dust collector are used to separate the dry materials from the air and then release the air accumulated during transfer operations. In a vacuum system, a dust collection device and an air lock, such as a rotary gate or trap door feeder, are typically used.

The use of mechanical equipment that involves enclosed lines, such as those provided by air pressure (also referred to as pneumatic) and vacuum loading systems, are effective methods for minimizing releases of pollutants into the environment. Because of the enclosed nature of the system, pollutants are not exposed to wind or precipitation and therefore have less potential to contaminate storm water discharges.

When and Where to Use It

Air pressure and vacuum systems can be used at all types of industrial facilities. This equipment is located in material handling areas to use for storing, loading and unloading, transporting, or conveying materials.

What to Consider

Unlike many of the other BMPs discussed in this manual, air pressure and vacuum systems may be expensive because of the costs of purchasing the system and retrofitting the system to existing materials handling procedures. In many cases, these systems can be shipped to a facility and be installed onsite without contractor help. Manufacturer's recommendations should be followed closely to ensure proper installation. In other cases, systems may have to be designed specifically for a site. Proper design and installation are very important for air pressure and vacuum systems to be as effective as possible. The equipment may be weatherproof or, if not, consider enclosing or covering the equipment.

Conduct routine inspections of air pressure and vacuum systems. Regular maintenance is required of these systems, especially the dust collectors. Conduct maintenance activities based on manufacturers' recommendations. Inspect air pressure systems more frequently due to the greater potential for leaks to the environment.

Advantages of Loading and Unloading by Air Pressure or Vacuum
• Is quick and simple • May be economical if materials can be recovered • Will minimize exposure of pollutants to storm water
Disadvantages of Loading and Unloading by Air Pressure or Vacuum
• May be costly to install and maintain • May not be appropriate for some denser materials • May require site-specific design • Dust collectors may need a permit under the Clean Air Act to install

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4.3 MITIGATIVE PRACTICES

Mitigation involves cleaning up or recovering a substance after it has been released or spilled to reduce the potential impact of a spill before it reaches the environment. Therefore, pollution mitigation is a second line of defense where pollution prevention practices have failed or are impractical. Because spills cannot always be avoided at industrial sites, it is necessary to plan for these events and to design proper response procedures. This section discusses mitigative BMPs to avoid contamination of storm water. Most of the mitigative practices discussed are simple and should be incorporated in your facility's good housekeeping and spill response plans. The mitigation practices discussed include manual cleanup methods, such as sweeping and shoveling, mechanical cleanup by excavation or vacuuming, and cleanup with sorbents and gels.

Facilities are cautioned that spills of certain toxic and hazardous substances and their cleanup may be covered under regulations, including those imposed under the Superfund Amendments and Reauthorization Act (SARA), the Comprehensive Environmental Responsibility, Compensation, and Liability Act (CERCLA), and the Resource Conservation and Recovery Act (RCRA).

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Sweeping

What Is It

Sweeping with brooms, squeegees, or other mechanical devices is used to remove small quantities of dry chemicals and dry solids from areas that are exposed to precipitation or storm water runoff. These areas may include dust or contaminant covered bags, drums containing remaining materials on their lids, areas housing enclosed or covered materials, and spills of dry chemicals and dry solids in locations on the industrial site. Cleaning by sweeping with brooms is a low cost practice that can be performed by all employees and requires no special equipment or training.

When and Where to Use It

Sweeping can be used at many material handling areas and process areas in all types of industrial facilities. Timing is an important consideration for all mitigative practices. To be effective as a storm water control, cleanup must take place before rainfall or contact with storm water runoff or before an outside area is hosed down.

Do not limit your cleanup activities to those outside activities that are exposed to rainfall. In many cases, tracking of materials to the outside from areas that are enclosed or covered (e.g., on shoes) may also occur.

What to Consider

Store brooms appropriately and do not expose them to precipitation. In addition, rules of compatibility also apply. Do not use the same broom to clean up two chemicals that are incompatible. Determine the compatibility between the brooms themselves and the chemical of concern before using this practice. In some instances, chemicals should be vacuumed instead of swept. Be sure that swept material is disposed of properly.

Advantages of Sweeping
• Is inexpensive • Requires no special training • Provides recycling opportunities
Disadvantages of Sweeping
• Is a labor-intensive practice • Is limited to small releases of dry materials

Shoveling

What Is It

Shoveling is another manual cleanup method that is simple and low in cost. Generally, shoveling can be used to remove larger quantities of dry chemicals and dry solids, as well as to remove wetter solids and sludge. Shoveling is also useful in removing accumulated materials from sites not accessible by mechanical cleanup methods.

When and Where to Use It

Shoveling can be used at any facility. Shoveling provides an added advantage over sweeping because cleanup methods are not limited to dry materials. In many cases, accumulated solids and sludges that are in ditches, sumps, or other facility locations can be effectively and quickly removed by shoveling.

Shovels can also be used to clean up contaminated snows. Timing is an important consideration in any mitigative practice. Materials that could contaminate storm water runoff should be removed before any storm event.

What to Consider

As with brooms, clean and store shovels properly. Also, consider planning for the transport and disposal or reuse of the shoveled materials.

Advantages of Shoveling
• Is inexpensive • Provides recycling opportunities • Can remediate larger releases and is effective for dry and wet materials
Disadvantages of Shoveling
• Is labor-intensive • Is not an appropriate practice for large spills

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Excavation Practices

What Are They

Excavation (i.e., removal of contaminated material) of released materials is typically conducted by mechanical equipment, such as plows and backhoes. Generally, plowing and backhoeing can be done using a specifically designed vehicle, tractor, or truck.

Excavation removes the materials of concern and any deposition of contaminants, thereby reducing the potential for storm water contamination. Mechanical cleanup methods are typically less precise than manual cleanup methods, resulting in reduced opportunities for recycle and reuse.

When and Where to Use Them

Excavation practices are most useful for large releases of dry materials and for areas contaminated by liquid material releases. In excavation, you want to be sure that all of the contaminated material is removed.

Timing is an important consideration for all mitigative practices. To be effective as a storm water control, cleanup must take place before a rainfall event.

What to Consider

Conduct inspections and operations and maintenance in accordance with a manufacturer's recommendations, which may include the following:

- A specified frequency for inspection, maintenance, and servicing of the equipment
- Parts replacement, rotation, and lubrication specifications
- Procedures for evaluating all parts.

As with any equipment used during cleanup, other considerations apply, including the following:

- Plows, backhoes, etc. should be stored appropriately with no exposure to precipitation
- Excavated materials should be properly handled or disposed of.

Advantages of Excavation Practices
• Are a cost effective method for cleaning up dry materials release • Are common and simple
Disadvantages of Excavation Practices
• Are less precise, resulting in less recycling and reuse opportunities

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Vacuum and Pump Systems

What Are They

Vacuum and pump systems are effective for cleaning up spilled or exposed materials.

The benefits of vacuum and pump cleanup systems include simplicity and speed. With such systems, only the spilled materials need be collected. Also, these systems are often portable and can be used at many locations to clean up releases to the environment. Portable systems can usually be rented.

When and Where to Use Them

Vacuum and pump systems can be used at any industrial facility. Both wet and dry materials can be collected with these systems. Vacuum systems can be used in material handling areas and process areas.

What to Consider

Consider the area of use and the most appropriate size for the system. Since these systems can be portable, size is important, especially if materials will be stored in the unit. In this case, the portable system must have enough suction or positive air pressure to transport materials over long distances. Include plans for proper disposal or reuse of the collected materials.

Advantages of Vacuum and Pump Systems
• Remove materials by air pressure or vacuum quickly and simply
• Collect materials accurately
• Offer good recycling opportunities
Disadvantages of Vacuum and Pump Systems
• May require high initial capital cost
• Require equipment maintenance

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Sorbents

What Are They

Sorbents are materials that are capable of cleaning up spills through the chemical processes of adsorption and absorption. Sorbents adsorb (an attraction to the outer surface of a material) or absorb (taken in by the material like a sponge) only when they come in contact with the sorbent materials. The sorbents must be mixed with a spill or the liquid must be passed through the sorbent. Sorbent materials come in many different forms from particles to foams. Often the particles are held together in structures called booms, pads, or socks. Sorbents include, but are not limited to, the following:

- **Common Materials (clays, sawdust, straw, and flyash)**—Generally come in small particles that can be thrown onto a spill that is on a surface. The materials absorb the spill by taking up the liquid.
- **Polymers (polyurethane and polyolefin)**—Come in the form of spheres, beads, or foam tablets. These materials absorb a chemical spill by taking up the liquid into their open-pore structure.
- **Activated Carbon**—Comes in a powdered or granular form and can be mixed with liquids to remove pollutants. This sorbent works by adsorbing the organics to its surface and can be recycled and then reused by a process called regeneration.
- **"Universal Sorbent Material"**—Is a silicate glass foam consisting of rounded particles that can absorb the material.

When and Where to Use Them

Sorbents are useful BMPs for facilities with liquid materials onsite. Timing is important for these practices. To be effective as a storm water BMP, cleanup must take place before a rainfall. Sorbents are often used in conjunction with curbing to provide cleanup of small spills within a containment area.

"Universal Sorbent Materials" are suitable for use on many compounds including acids, alkalis, alcohols, aldehydes, arsenate, ketones, petroleum products, and chlorinated solvents.

Activated carbon is useful for adsorbing many organic compounds. Organics that are diluted in water can be passed through a column that is filled with the activated carbon material to remove the organics, or the activated carbon can be mixed into the water and can then be filtered out.

Polyurethane is good with chemical liquids such as benzene, chlorinated solvents, epicholorhydrin, and phenol. Polyolefin is used to remove organic solvents, such as phenol and various chlorinated solvents. The beads and spheres are usually mixed into a spill by use of a blower and then are skimmed from the top surface by use of an oil boom.

More common materials such as clay, sawdust, straw, and fly-ash can be used for a liquid spill on a surface that is relatively impenetrable, and are usually spread over the spill area with shovels.

Booms, pads, and socks are also useful in areas where there are small liquid spills or drips or where small amounts of solids may mix with small amounts of storm water runoff. They can function

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both to absorb the pollutants from the storm water and restrict the movement of a spill. Socks are often used together with curbing to clean up small spills.

What to Consider

Because sorbents work by a chemical or physical reaction, some sorbents are better than others for certain types of spills. Therefore, the use of sorbents requires that personnel know the properties of the spilled material(s) to know which sorbent is appropriate. To be effective, sorbents must adsorb the material spilled but must not react with the spilled material to form hazardous or toxic substances. Follow the manufacturers' recommendations.

For sorbents to be effective, they must be applied immediately in the release area. The use of sorbent material is generally very simple: the sorbent is added to the area of release, mixed well, and allowed to adsorb or absorb. Many sorbents are not reusable once they have been used. Proper disposal is required.

Advantages of Sorbents
• Work in water environments (booms and socks) • Offer recycling opportunities (some types of sorbents)
Disadvantages of Sorbents
• Require a knowledge of the chemical makeup of a spill (to choose the best sorbent) • Offer no recycling opportunities (some types of sorbents) • May be expensive practice for large spills • May create disposal problems and increase disposal costs by creating a solid waste and potentially a hazardous waste.

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Gelling Agents

What Are They

Gelling agents are materials that interact with liquids either physically or chemically (i.e., thickening or polymerization). Some of the typical gelling agents are polyelectrolytes, polyacrylamide, butylstyrene copolymers, polyacrylonitrile, polyethylene oxide, and a gelling agent referred to as the universal gelling agent which is a combination of these synthetics.

Gelling interacts with a material by concentrating and congealing it to become semisolid. The semisolid gel later forms a solid material, which can then be cleaned up by manual or mechanical methods. The BMP of using a gelling agent is one of the few ways to effectively control a liquid spill before it reaches a receiving water or infiltrates into the soil and then ground water.

When and Where to Use Them

Gelling agents are useful for facilities with significant amounts of liquid materials stored onsite. Gels cannot be used to clean up spills on surface water unless authorized by the U.S. Coast Guard or EPA Regional Response Team.

What to Consider

Gels can be used to stop the liquid's flow on land, prevent its seeping into the soil, and reduce the surface spreading of a spill. Because of these properties, gels can reduce the need for extensive cleanup methods and reduce the possibility of storm water contamination from an uncontrolled industrial spill. As with sorbents, the use of gels simply involves the addition of the gel to the area of the spill, mixing well, and allowing the mass to congeal. To use gels correctly, however, personnel need to know the properties of the spilled materials so that they can choose the correct gel.

Timing is particularly important for gelling agent use. To prevent the movement of materials, gelling agents must be applied immediately after the spill. The use of gelling agents results in a large bulk of congealed mass that usually cannot be separated. Ultimately, this mass will need to be cleaned up by manual or mechanical methods and disposed of properly.

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Advantages of Gelling Agents
• Stop the movement of spilled or released liquid materials • Require no permanent structure
Disadvantages of Gelling Agents
• May require knowledge of the spilled materials to select correct gelling agents • Usually offer no recycling opportunities • May be difficult to clean up • May create disposal problems and increase disposal costs by creating a solid waste and potentially a hazardous waste

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4.4 OTHER PREVENTIVE PRACTICES

A number of preventive measures can be taken at industrial sites to limit or prevent the exposure of storm water runoff to contaminants. This section describes a few of the most easily implemented measures:

- Preventive Monitoring Practices
- Dust Control (Land Disturbance and Demolition Areas)
- Dust Control (Industrial)
- Signs and Labels
- Security
- Area Control Procedures
- Vehicle Washing.

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Preventive Monitoring Practices

What Are They

Preventive monitoring practices include the routine observation of a process or piece of equipment to ensure its safe performance. It may also include the chemical analysis of storm water before discharge to the environment.

When and Where to Use Them

Automatic Monitoring System—In areas where overflows, spills, and catastrophic leaks are possible, an automatic monitoring system is recommended. Some Federal, State, and local laws require such systems to be present if threats exist to the health and safety of personnel and the environment. For material management areas, monitoring may include liquid level detectors, pressure and temperature gauges, and pressure-relief devices. In material transfer, process, and material handling areas, automatic monitoring systems can include pressure drop shutoff devices, flow meters, thermal probes, valve position indicators, and operation lights. Loading and unloading operations might use these devices for measuring the volume of tanks before loading, for weighing vehicles or containers, and for determining rates of flow during loading and unloading.

Automatic Chemical Monitoring—Measures the quality of plant runoff to determine whether discharge is appropriate or whether diversion to a treatment system is warranted. Such systems might monitor pH, turbidity, or conductivity. These parameters might be monitored in diked areas, sewers, drainage ditches, or holding ponds. Systems can also be designed to signal automatic diversion of contaminated storm water runoff to a holding pond (e.g., a valve or a gate could be triggered by a certain pollutant in the storm water runoff).

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Manned Operations—In material transfer areas and process areas, personnel can be stationed to watch over the operations so that any spills or mismanagement of materials can be corrected immediately. This is particularly useful at loading and unloading areas where vehicles or equipment must be maneuvered into the proper position to unload (see Vehicle Positioning BMP).

Nondestructive Testing—Some situations require that a storage tank or a pipeline system be tested without being physically moved or disassembled. The structural integrity of tanks, valves, pipes, joints, welds, and other equipment can be tested using nondestructive methods. Acoustic emission tests use high frequency sound waves to draw a picture of the structure to reveal cracks, malformations, or other structural damage. Another type of testing is hydrostatic pressure testing. During pressure testing, the tank or pipe is subjected to pressures several times the normal pressure. A loss in pressure during the testing may indicate a leak or some other structural damage. Tanks and containers should be pressure tested as required by Federal, State, or local regulations.

What to Consider

Automated monitoring systems should be placed in an area where plant personnel can easily observe the measurements. Alarms can be used in conjunction with the measurement display to warn personnel. Manned operations should have communication systems available for getting help in case spills or leaks occur. Especially sensitive or spill-prone areas may require back-up instrumentation in case the primary instruments malfunction.

Mechanical and electronic equipment should be operated and maintained according to the manufacturers' recommendations. Equipment should be inspected regularly to ensure proper and accurate operation.

The pollution prevention team, in consultation with a certified safety inspector, should evaluate system monitoring requirements to decide which systems are appropriate based on hazard potential.

Advantages of Preventive Monitoring Practices
• Pressure and vacuum testing can locate potential leaks or damage to vessels early. The primary benefit of such testing is in ensuring the safety of personnel, but it also has secondary benefits including prevention of storm water contamination.
• Automatic system monitors allow for early warnings if a leak, overflow, or catastrophic incident is imminent.
• Manning operations, especially during loading and unloading activities, is effective and generally inexpensive.
• The primary benefit of nondestructive testing is in ensuring the safety of personnel, but it also has secondary benefits including early detection of the potential for contaminating storm water runoff.
Disadvantages of Preventive Monitoring Practices
• Plant personnel often do not have the expertise to maintain automatic equipment.
• Automatic equipment can fail without warning.
• Automated process control and monitoring equipment may be expensive to purchase and operate

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Dust Control (Land Disturbance and Demolition Areas)

What Is It

Dust controls for land disturbance and demolition areas are any controls that reduce the potential for particles being carried through air or water. Types of dust control are:

- **Irrigation**—Irrigation is a temporary measure involving a light application of water to moisten the soil surface. The process should be repeated as necessary.
- **Minimization of Denuded Areas**—Minimizing soil exposure reduces the amount of soil available for transport and erosion. Soil exposure can be lessened by temporary or permanent soil stabilization controls, such as seeding, mulching, topsoiling, crushed stone or coarse gravel spreading, or tree planting. Maintaining existing vegetation on a site will also help control dust.
- **Wind Breaks**—Wind breaks are temporary or permanent barriers that reduce airborne particles by slowing wind velocities (slower winds do not suspend particles). Leaving existing trees and large shrubs in place will create effective wind breaks. More temporary types of wind breaks are solid board fences, snow fences, tarp curtains, bales of hay, crate walls, and sediment walls.
- **Tillage**—Deep plowing will roughen the soil surface to bring up to the surface cohesive clods of soil, which in turn rest on top of dusts, protecting them from wind and water erosion. This practice is commonly practiced in arid regions where establishing vegetation may take time.
- **Chemical Soil Treatments (palliatives)**—These are temporary controls that are applied to soil surfaces in the form of spray-on adhesives, such as anionic asphalt emulsion, latex emulsion, resin-water emulsions, or calcium chloride. The palliative is the chemical used. These should be used with caution as they may create pollution if not used correctly.

When and Where to Use It

Dust controls can be used on any site where dust may be generated and where the dust may cause onsite and offsite damage. Dust controls are especially critical in arid areas, where reduced rainfall levels expose soil particles for transport by air and runoff. This control should be used in conjunction with other sedimentation controls such as sediment traps.

What to Consider

To control dust during land disturbance and at demolition areas, exposure of soil should be limited as much as possible. When possible, work that causes soil disturbance or involves demolition should be done in phases and should be accompanied by temporary stabilization measures. These precautions will minimize the amount of soil that is disturbed at any one time and, therefore, control dust.

Oil should not be used to control dust because of its high potential for polluting storm water discharges.

Irrigation will be most effective if site drainage systems are checked to ensure that the right amount of water is used. Too much water can cause runoff problems.

Chemical treatment is only effective on mineral soils, as opposed to muck soils, because the chemicals bond better to mineral soils. Therefore, it should be used only in arid regions. Vehicular traffic should be routed around chemically treated areas to avoid tracking of the chemicals. Certain chemicals may be inappropriate for some types of soils or application areas. For example, spraying chemicals on the soil of an industrial site adjacent to a school may be dangerous. Local governments usually have information about restrictions on the types of palliatives that may be used. Special consideration must be given to preserving ground water quality whenever chemicals are applied to the land.

Since most of these techniques are temporary controls sites should be inspected often and materials should be reapplied when needed. The frequency for these inspections depends on site-specific conditions, weather conditions, and the type of technique used.

Advantages of Dust Control (Land Disturbance and Demolition Areas)
• Can help prevent wind-and-water based erosion of disturbed areas and will reduce respiratory problems in employees • Some types can be implemented quickly at low cost and effort (except wind breaks) • Helps preserve the aesthetics of the site and screens certain activities from view (wind breaks) • Vegetative wind breaks are permanent and an excellent alternative to chemical use
Disadvantages of Dust Control (Land Disturbance and Demolition Areas)
• Some types are temporary and must be reapplied or replenished regularly • Some types are expensive (irrigation and chemical treatment) and may be ineffective under certain conditions • May result in health and/or environmental hazards, e.g., if overapplication of the chemicals leaves large amounts exposed to wind and rain erosion or ground water contamination • May create excess runoff that the site was not designed to control (irrigation) • May cause increased offsite tracking of mud (irrigation) • Is not as effective as chemical treatment or mulching and seeding; requires land space that may not be available at all locations (wind breaks)

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Dust Control (Industrial)

What Is It

Dust controls for material handling areas are controls that prevent pollutants from entering storm water discharges by reducing the surface and air transport of dust caused by industrial activities. Consider the following types of controls:

- Water spraying
- Negative pressure systems (vacuum systems)
- Collector systems (bag and cyclone)
- Filter systems
- Street sweeping.

The purpose of industrial dust control is to collect or contain dusts to prevent storm water runoff from carrying the dusts to the sewer collection system or to surface waters.

When and Where to Use It

Dust control is useful in any process area, loading and unloading area, material handling areas, and transfer areas where dust is generated. Street sweeping is limited to areas that are paved.

What to Consider

Mechanical dust collection systems are designed according to the size of dust particles and the amount of air to be processed. Manufacturers' recommendations should be followed for installation (as well as the design of the equipment).

If water sprayers are used, dust-contaminated waters should be collected and taken for treatment. Areas will probably need to be resprayed to keep dust from spreading.

Two kinds of street sweepers are common: brush and vacuum. Vacuum sweepers are more efficient and work best when the area is dry.

Mechanical equipment should be operated according to the manufacturers' recommendations and should be inspected regularly.

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Advantages of Dust Control (Industrial)
• May cause a decrease of respiratory problems in employees around the site
• May cause less material to be lost and may therefore save money
• Provides efficient collection of larger dust particles (street sweepers)
Disadvantages of Dust Control (Industrial)
• Is generally more expensive than manual systems
• May be impossible to maintain by plant personnel (the more elaborate equipment)
• Is labor and equipment intensive and may not be effective for all pollutants (street sweepers)

Signs and Labels

What Are They

Signs and labels identify problem areas or hazardous materials at a facility. Warning signs, often found at industrial facilities, are a good way to suggest caution in certain areas. Signs and labels can also provide instructions on the use of materials and equipment. Labelling is a good way to organize large amounts of materials, pipes, and equipment, particularly on large sites.

Labels tell material type and container contents. Accurate labeling can help facilities to quickly identify the type of material released so facility personnel can respond correctly.

Two effective labeling methods include color coding and Department of Transportation (DOT) labeling. Color coding is easily recognized by facility personnel and simply involves painting/coating or applying an adhesive label to the container. Color codes must be consistent throughout the facility to be effective, and signs explaining the color codes should be posted in all areas.

DOT requires that labels be prominently displayed on transported hazardous and toxic materials. Labeling required by DOT could be expanded to piping and containers, making it easy to recognize materials that are corrosive, radioactive, reactive, flammable, explosive, or poisonous.

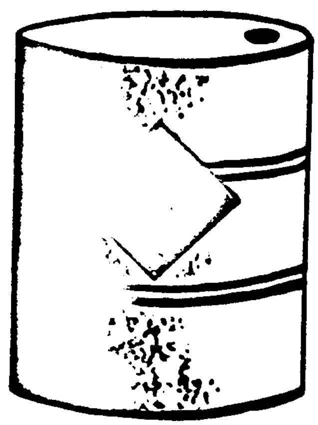

FIGURE 4.8 SIGN ON DRUM INDICATING FLAMMABILITY

When and Where to Use Them

Signs and labels can be used at all types of facilities. Areas where they are particularly useful are material transfer areas, equipment areas, loading and unloading areas, or anywhere information might prevent contaminants from being released to storm water.

What to Consider

Signs and labels should be visible and easy to read. Useful signs and labels might provide the following information:

- Names of facility and regulatory personnel, including emergency phone numbers, to contact in case of an accidental discharge, spill, or other emergency
- Proper uses of equipment that could cause release of storm water contaminants
- Types of chemicals used in high-risk areas
- The direction of drainage lines/ditches and their destination (treatment or discharge)
- Information on a specific material
- Refer to OSHA standards for sizes and numbers of signs required for hazardous material labeling.

Hazardous chemicals might be labeled as follows:

- Danger
- Combustible
- Warning
- Caution
- Flammable
- Poisonous
- Caustic
- Corrosive
- Volatile
- Explosive

Periodic checks can ensure that signs are still in place and labels are properly attached. Signs and labels should be replaced and repaired as often as necessary.

Advantages of Signs and Labels
• Are inexpensive and easily used
Disadvantages of Signs and Labels
• Must be updated and maintained so they are legible

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Security

What Is It

Setting up a security system as part of your Plan could help prevent an accidental or intentional release of materials to storm water runoff as a result of vandalism, theft, sabotage, or other improper uses of facility property. If your facility already has a security system, consider improving it by training security personnel about the specifics of the Storm Water Pollution Prevention Plan. Routine patrol, lighting, and access control are discussed below as possible measures to include in your facility's security system.

When and Where to Use It

Routine patrol, lighting, and access control are measures that can be used at any facility.

What to Consider

Security information could be included in the existing training required by the Plan to instruct personnel about where and how to patrol areas within the facility. Instruction might also include what to look for in problem areas and how to respond to problems. During routine patrol, security personnel can actively search the facility site for indications of spills, leaks, or other discharges; respond to any disturbance resulting from intruders or inappropriate facility operations; and generally work as a safeguard to prevent unexpected events. Routine patrols could be an effective part of the Storm Water Pollution Prevention Plan, especially for large facilities with established security measures. To make this practice effective, security personnel can help develop the Storm Water Pollution Prevention Plan, possibly with one person acting as a member of the pollution prevention committee.

Sufficient lighting throughout the facility during daytime and night hours will make it easier to get to equipment during checks and will make it easy to detect spills and leaks that might otherwise be hidden. Routine patrols are also easier with proper lighting.

Controlling access to the industrial site is an important part of plant security and of activity and traffic control. Signs, fencing, guard houses, dog patrols, and visitor clearance requirements are often used to control site access.

- Signs are the simplest, most inexpensive method of access control, but they are limited in their actual control since they provide no physical barriers and require that people obey them voluntarily.
- Fencing provides a physical barrier to the facility site and an added means of security.
- Guard houses used with visitor rules can help to ensure that only authorized personnel enter the facility site and can limit vehicular traffic as well.
- Traffic signs are also useful at facility sites. Restricting vehicles to paved roads and providing direction and warning signs can help prevent accidents. Where restricting vehicles to certain pathways is not possible, it is important to ensure that all above-ground valves and pipelines are well marked.

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Advantages of Security
• Provides a preventive safeguard to operational malfunctions or other facility disturbances (routine patrols) • Allows easier detection of vandals or thieves (lighting) • Allows easier detection of spills, leaks, or other releases (lighting) • Prevents spills by providing good visibility (lighting) • Prevents unauthorized access to facility (access control)
Disadvantages of Security
• May not be feasible for smaller facilities • May be costly (e.g., installation of lighting systems) • May increase energy costs as a result of additional lighting • May not be feasible to have extensive access controls at smaller facilities

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Area Control Procedures

What Are They

The activities conducted at an industrial site often result in the materials being deposited on clothes and footwear and the being carried throughout the facility site. As a result, these materials may find their way into the storm water runoff.

Area control procedures involve practicing good housekeeping measures such as maintaining indoor or covered material storage and industrial processing areas. If the area is kept clean, the risk of accumulating materials on footwear and clothing is reduced. In turn, the chance of left over pollutants making contact with storm water and polluting surface water is minimized.

When and Where to Use Them

Area control measures can be used at any facility where materials may be tracked into areas where they can come in contact with storm water runoff. Areas can include material handling areas, storage areas, or process areas.

What to Consider

Materials storage areas and industrial processing areas should be checked regularly to ensure that good housekeeping measures are being implemented. Cover-garments, foot mats, and other devices used to collect residual material near the area should be cleaned regularly.

Other effective practices include the following:

- Brushing off clothing before leaving the area
- Stomping feet to remove material before leaving the area
- Using floor mats at area exits
- Using coveralls, smocks, and other overgarments in areas where exposure to material is of greatest concern (employees should remove the overgarments before leaving the area)
- Posting signs to remind employees about these practices.

Advantages of Area Control Procedures
• Are easy to implement • Result in a cleaner facility and improved work environment
Disadvantage of Area Control Procedures
• May be seen as tedious by employees and therefore may not be followed

Vehicle Washing

What Is It

Materials that accumulate on vehicles and then scatter across industrial sites represent an important source of storm water contamination. Vehicle washing removes materials such as site-specific dust and spilled materials that have accumulated on the vehicle. If not removed, residual material will be spread by gravity, wind, snow, or rainfall as the vehicles move across the facility site and off the site.

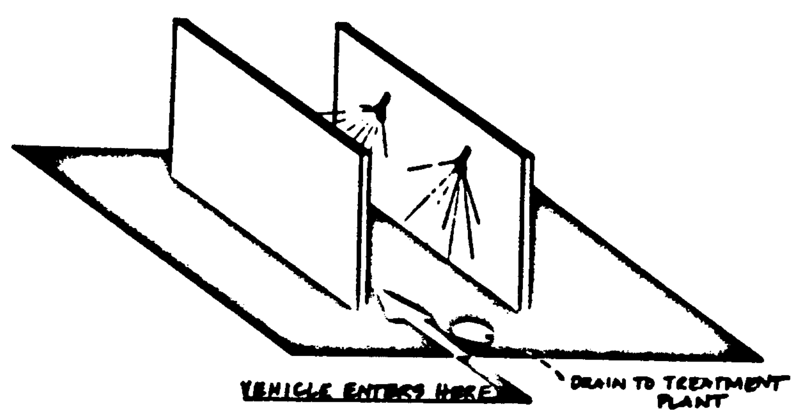

FIGURE 4.9 TRUCK WASHING AREA

When and Where to Use It

This practice is appropriate for any facility where vehicles come into contact with raw materials on a site. If possible, the vehicle washing area should be built near the location where the most vehicle activity occurs. Wastewater from vehicle washing should be directed away from process materials to prevent contact. Those areas include material transfer areas, loading and unloading areas, or areas located just before the site exit.

What to Consider

When considering the method of vehicle washing, the facility should consider using a high-pressure water spray with no detergent additives. In general, water will adequately remove contaminants from the vehicle. If detergents are used, they may cause other environmental impacts. Phosphate- or organic-containing compounds should be avoided.

If this practice is considered, truck wash waters will result in a non-storm water discharge, thus requiring an application for an NPDES permit to cover the discharge.

Blowers or vacuums should be considered where the materials are dry and easily removed by air.

Advantages of Vehicle Washing
• Prevents dispersion of materials across the facility site • Is necessary only where methods for transferring contained materials and minimizing exposure have not been successfully adopted and implemented
Disadvantages of Vehicle Washing
• May be costly to construct a truck washing facility

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4.5 SEDIMENT AND EROSION PREVENTION PRACTICES

Any site where soils are exposed to water, wind or ice can have soil erosion and sedimentation problems. Erosion is a natural process in which soil and rock material is loosened and removed. Sedimentation occurs when soil particles are suspended in surface runoff or wind and are deposited in streams and other water bodies.

Human activities can accelerate erosion by removing vegetation, compacting or disturbing the soil, changing natural drainage patterns, and by covering the ground with impermeable surfaces (pavement, concrete, buildings). When the land surface is developed or "hardened" in this manner, storm water and snowmelt can not seep into or "infiltrate" the ground. This results in larger amounts of water moving more quickly across a site which can carry more sediment and other pollutants to streams and rivers.

EPA's General Permit requires that all industries identify in their Storm Water Pollution Prevention Plans areas that may have a high potential for soil erosion. This includes areas with such heavy activity that plants cannot grow, soil stockpiles, stream banks, steep slopes, construction areas, demolition areas, and any area where the soil is disturbed, denuded (stripped of plants), and subject to wind and water erosion. EPA further requires that you take steps to limit this erosion.

There are seven ways to limit and control sediment and erosion on your site:

- Leave as much vegetation (plants) onsite as possible.
- Minimize the time that soil is exposed.
- Prevent runoff from flowing across disturbed areas (divert the flow to vegetated areas).
- Stabilizing the disturbed soils as soon as possible.
- Slow down the runoff flowing across the site.
- Provide drainage ways for the increased runoff (use grassy swales rather than concrete drains).
- Remove sediment from storm water runoff before it leaves the site.

Using these measures to control erosion and sedimentation is an important part of storm water management. Selecting the best set of sediment and erosion prevention measures for your industry depends upon the nature of the activities on your site (i.e., how much construction or land disturbance there is) and other site-specific conditions (soil type, topography, climate, and season). Section 4.5.1 discusses some temporary and permanent ways to stabilize your site. Section 4.5.2 describes more structural ways to control sediment and erosion.

In some arid regions, growing vegetation to prevent erosion may be difficult. The local Soil Conservation Service Office or County Extension Office can provide information on any special measures necessary to promote the establishment of vegetation.

4.5.1 Vegetative Practices

Preserving existing vegetation or revegetating disturbed soil as soon as possible after construction is the most effective way to control erosion. A vegetation cover reduces erosion potential in four ways: (1) by shielding the soil surface from direct erosive impact of raindrops; (2) by improving the soil's water storage porosity and capacity so more water can infiltrate into the ground; (3) by slowing the runoff and allowing the sediment to drop out or deposit; and (4) by physically holding the soil in place with plant roots.

Vegetative cover can be grass, trees, shrubs, bark, mulch, or straw. Grasses are the most common type of cover used for revegetation because they grow quickly, providing erosion protection within days. Other soil stabilization practices such as straw or mulch may be used during non-growing seasons to prevent erosion. Newly planted shrubs and trees establish root systems more slowly, so keeping existing ones is a more effective practice.

Vegetative and other site stabilization practices can be either temporary or permanent controls. Temporary controls provide a cover for exposed or disturbed areas for short periods of time or until permanent erosion controls are put in place. Permanent vegetative practices are used when activities that disturb the soil are completed or when erosion is occurring on a site that is otherwise stabilized. The remainder of this section describes the common vegetative practices listed below:

- **Preservation of Natural Vegetation**
- **Buffer Zones**
- **Stream Bank Stabilization**
- **Mulching, Matting, and Netting**
- **Temporary Seeding**
- **Permanent Seeding and Planting**
- **Sodding**
- **Chemical Stabilization.**

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Preservation of Natural Vegetation

What Is It

The preservation of natural vegetation (existing trees, vines, brushes, and grasses) provides natural buffer zones. By preserving stabilized areas, it minimizes erosion potential, protects water quality, and provides aesthetic benefits. This practice is used as a permanent control measure.

When and Where to Use It

This technique is applicable to all types of sites. Areas where preserving vegetation can be particularly beneficial are floodplains, wetlands, stream banks, steep slopes, and other areas where erosion controls would be difficult to establish, install, or maintain.

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What to Consider

Preservation of vegetation on a site should be planned before any site disturbance begins. Preservation requires good site management to minimize the impact of construction activities on existing vegetation. Clearly mark the trees to be preserved and protect them from ground disturbances around the base of the tree. Proper maintenance is important to ensure healthy vegetation that can control erosion. Different species, soil types, and climatic conditions will require different maintenance activities such as mowing, fertilizing, liming, irrigation, pruning, and weed and pest control. Some State/local regulations require natural vegetation to be preserved in sensitive areas; consult the appropriate State/local agencies for more information on their regulations. Maintenance should be performed regularly, especially during construction.

Advantages of Preservation of Natural Vegetation
• Can handle higher quantities of storm water runoff than newly seeded areas • Does not require time to establish (i.e., effective immediately) • Increases the filtering capacity because the vegetation and root structure are usually denser in preserved natural vegetation than in newly seeded or base areas • Enhances aesthetics • Provides areas for infiltration, reducing the quantity and velocity of storm water runoff • Allows areas where wildlife can remain undisturbed • Provides noise buffers and screens for onsite operations • Usually requires less maintenance (e.g., irrigation, fertilizer) than planting new vegetation
Disadvantages of Preservation of Natural Vegetation
• Requires planning to preserve and maintain the existing vegetation • May not be cost effective with high land costs • May constrict area available for construction activities

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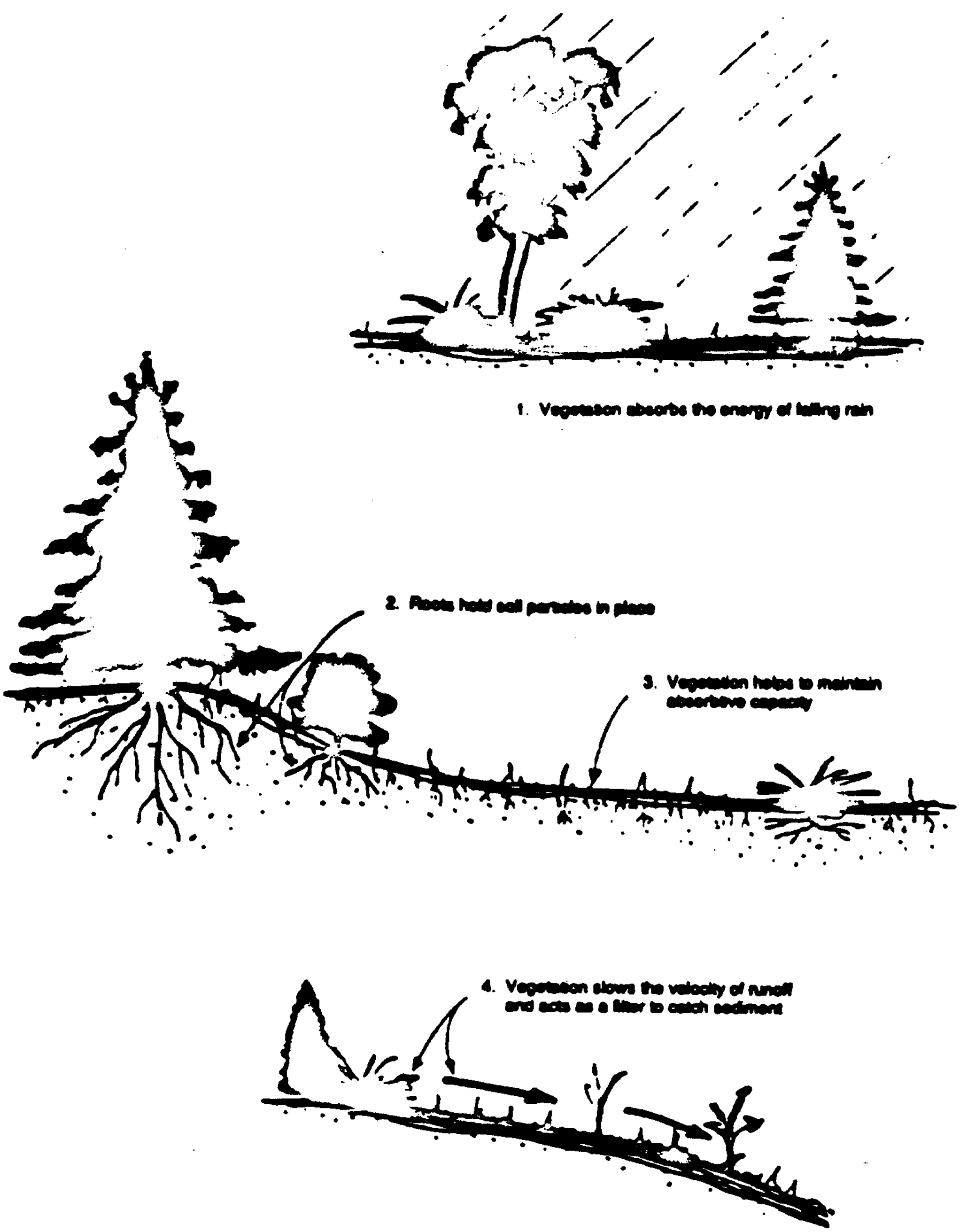

FIGURE 4.10 BENEFITS OF PRESERVING NATURAL VEGETATION
(Modified from Washington State, 1992)

Buffer Zones

What Are They

Buffer zones are vegetated strips of land used for temporary or permanent water quality benefits. Buffer zones are used to decrease the velocity of storm water runoff, which in turn helps to prevent soil erosion. Buffer zones are different from vegetated filter strips (see section on Vegetated Filter Strips) because buffer zone effectiveness is not measured by its ability to improve infiltration (allow water to go into the ground). The buffer zone can be an area of vegetation that is left undisturbed during construction, or it can be newly planted.

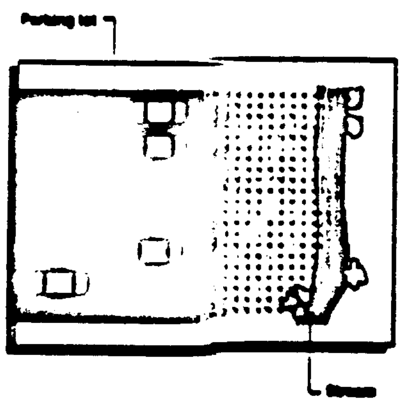

FIGURE 4.11 EXAMPLE BUFFER ZONE
(Modified from Washington State, 1992)

When and Where to Use Them

Buffer zones technique can be used at any site that can support vegetation. Buffer zones are particularly effective on floodplains, next to wetlands, along stream banks, and on steep, unstable slopes.

What to Consider

If buffer zones are preserved, existing vegetation, good planning, and site management are needed to protect against disturbances such as grade changes, excavation, damage from equipment, and other activities. Establishing new buffer strips requires the establishment of a good dense turf, trees, and shrubs (see Permanent Seeding and Planting). Careful maintenance is important to ensure healthy vegetation. The need for routine maintenance such as mowing, fertilizing, liming, irrigating, pruning, and weed and pest control will depend on the species of plants and trees involved, soil types, and climatic conditions. Maintaining planted areas may require debris removal and protection against unintended uses or traffic. Many State/local storm water program or zoning agencies have regulations which define required or allowable buffer zones especially near sensitive areas such as wetlands. Contact the appropriate State/local agencies for their requirements.

Advantages of Buffer Zones
• Provide aesthetic as well as water quality benefits • Provide areas for infiltration, which reduces amount and speed of storm water runoff • Provide areas for wildlife habitat • Provide areas for recreation • Provide buffers and screens for onsite noise if trees or large bushes are used • Low maintenance requirements • Low cost when using existing vegetation
Disadvantages of Buffer Zones
• May not be cost effective to use if the cost of land is high • Are not feasible if land is not available • Require plant growth before they are effective

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Stream Bank Stabilization

What Is It

Stream bank stabilization is used to prevent stream bank erosion from high velocities and quantities of storm water runoff. Typical methods include the following:

- Riprap–Large angular stones placed along the stream bank or lake
- Gabion–Rock-filled wire cages that are used to create a new stream bank
- Reinforced Concrete–Concrete bulkheads and retaining walls that replace natural stream banks and create a nonerosive surface
- Log Cribbing–Retaining walls built of logs to anchor the soils against erosive forces. Usually built on the outside of stream bends
- Grid Pavers–Precast or poured-in-place concrete units that are placed along stream banks to stabilize the stream bank and create open spaces where vegetation can be established
- Asphalt–Asphalt paving that is placed along the natural stream bank to create a nonerosive surface.

When and Where to Use It

Stream bank stabilization is used where vegetative stabilization practices are not practical and where the stream banks are subject to heavy erosion from increased flows or disturbance during construction. Stabilization should occur before any land development in the watershed area. Stabilization can also be retrofitted when erosion of a stream bank occurs.

What to Consider

Stream bank stabilization structures should be planned and designed by a professional engineer licensed in the State where the site is located. Applicable Federal, State, and local requirements should be followed, including Clean Water Act Section 404 regulations. An important design feature of stream bank stabilization methods is the foundation of the structure; the potential for the stream to erode the sides and bottom of the channel should be considered to make sure the stabilization measure will be supported properly. Structures can be designed to protect and improve natural wildlife habitats; for example, log structures and grid pavers can be designed to keep vegetation. Only pressure-treated wood should be used in log structures. Permanent structures should be designed to handle expected flood conditions. A well-designed layer of stone can be used in many ways and in many locations to control erosion and sedimentation. Riprap protects soil from erosion and is often used on steep slopes built with fill materials that are subject to harsh weather or seepage. Riprap can also be used for flow channel liners, inlet and outlet protection at culverts, stream bank protection, and protection of shore lines subject to wave action. It is used where water is turbulent and fast flowing and where soil may erode under the design flow conditions. It is used to expose the water to air as well as to reduce water energy. Riprap and gabion (wire mesh cages filled with rock) are usually placed over a filter blanket (i.e., a gravel layer or filter cloth). Riprap is either a uniform size or graded (different sizes) and is usually applied in an even layer throughout the stream. Reinforced concrete structures may require positive

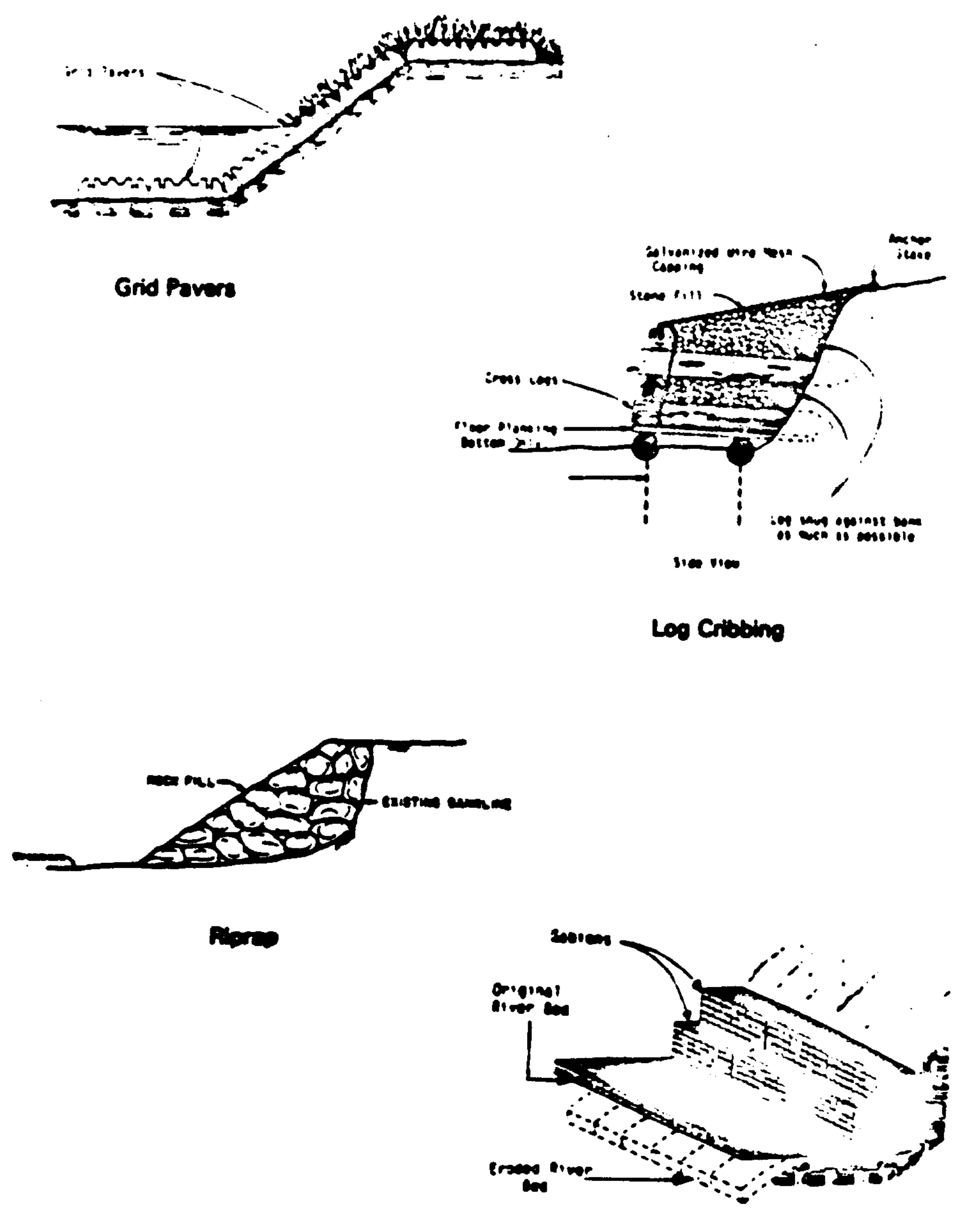

FIGURE 4.12 EXAMPLES OF STREAM BANK STABILIZATION PRACTICES
(Modified from Commonwealth of Virginia, 1980, and Commonwealth of Pennsylvania, 1990)

drainage behind the bulkhead or retaining wall to prevent erosion around the structure. Gabion and grid pavers should be installed according to manufacturers' recommendations.

Stream bank stabilization structures should be inspected regularly and after each large storm event. Structures should be maintained as installed. Structural damage should be repaired as soon as possible to prevent further damage or erosion to the stream bank.

Advantages of Stream Bank Stabilization
• Can provide control against erosive forces caused by the increase in storm water flows created during land development • Usually will not require as much maintenance as vegetative erosion controls • May provide wildlife habitats • Forms a dense, flexible, self-healing cover that will adapt well to uneven surfaces (riprap)
Disadvantages of Stream Bank Stabilization
• Does not provide the water quality or aesthetic benefits that vegetative practices could • Should be designed by qualified professional engineers, which may increase project costs • May be expensive (materials costs) • May require additional permits for structure • May alter stream dynamics which cause changes in the channel downstream • May cause negative impacts to wildlife habitats

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Mulching, Matting, and Netting

What Are They

Mulching is a temporary soil stabilization or erosion control practice where materials such as grass, hay, woodchips, wood fibers, straw, or gravel are placed on the soil surface. In addition to stabilizing soils, mulching can reduce the speed of storm water runoff over an area. When used together with seeding or planting, mulching can aid in plant growth by holding the seeds, fertilizers, and topsoil in place, by preventing birds from eating seeds, helping to retain moisture, and by insulating against extreme temperatures. Mulch mattings are materials (jute or other wood fibers) that have been formed into sheets of mulch that are more stable than normal mulch. Netting is typically made from jute, other wood fiber, plastic, paper, or cotton and can be used to hold the mulching and matting to the ground. Netting can also be used alone to stabilize soils while the plants are growing; however, it does not retain moisture or temperature well. Mulch binders (either asphalt or synthetic) are sometimes used instead of netting to hold loose mulches together.

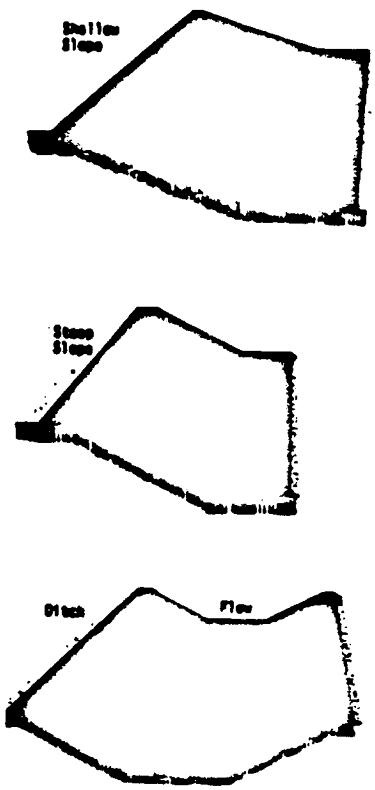

FIGURE 4.13 ORIENTATION OF MULCH NETTING AND MATTING
(Modified from County of Fairfax, 1987)

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When and Where to Use Them

Mulching is often used alone in areas where temporary seeding cannot be used because of the season or climate. Mulching can provide immediate, effective, and inexpensive erosion control. On steep slopes and critical areas such as waterways, mulch matting is used with netting or anchoring to hold it in place.

Mulch seeded and planted areas where slopes are steeper than 2:1, where runoff is flowing across the area, or when seedlings need protection from bad weather.

What to Consider

Use of mulch may or may not require a binder, netting, or the tacking of mulch to the ground. Effective netting and matting require firm, continuous contact between the materials and the soil. If there is no contact, the material will not hold the soil and erosion will occur underneath the material. Final grading is not necessary before mulching. Mulched areas should be inspected often to find where mulched material has been loosened or removed. Such areas should be reseeded (if necessary) and the mulch cover replaced immediately. Mulch binders should be applied at rates recommended by the manufacturer or, if asphalt is used, at rates of approximately 480 gallons per acre (Arapahoe County, 1988).

Advantages of Mulching, Matting, and Netting
• Provide immediate protection to soils that are exposed and that are subject to heavy erosion • Retain moisture, which may minimize the need for watering • Require no removal because of natural deterioration of mulching and matting
Disadvantages of Mulching, Matting, and Netting
• May delay germination of some seeds because cover reduces the soil surface temperature • Netting should be removed after usefulness is finished, then landfilled or composted

Temporary Seeding

What Is It

Temporary seeding means growing a short-term vegetative cover (plants) on disturbed site areas that may be in danger of erosion. The purpose of temporary seeding is to reduce erosion and sedimentation by stabilizing disturbed areas that will not be stabilized for long periods of time or where permanent plant growth is not necessary or appropriate. This practice uses fast-growing grasses whose root systems hold down the soils so that they are less apt to be carried offsite by storm water runoff or wind. Temporary seeding also reduces the problems associated with mud and dust from bare soil surfaces during construction.

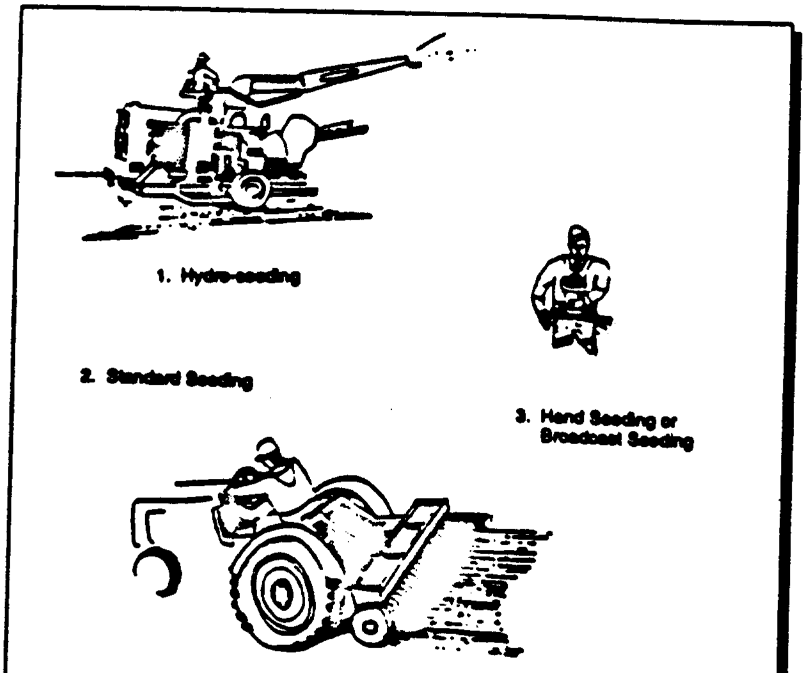

FIGURE 4.14 SEEDING PRACTICES
(Modified from Washington State, 1992)

When and Where to Use It

Temporary seeding should be performed on areas which have been disturbed by construction and which are likely to be redisturbed, but not for several weeks or more. Typical areas might include denuded areas, soil stockpiles, dikes, dams, sides of sediment basins, and temporary roadbanks. Temporary seeding should take place as soon as practicable after the last land disturbing activity in an area. Check the requirements of your permit for the maximum amount of time allowed between the last disturbance of an area and temporary stabilization. Temporary seeding may not be an effective practice in arid and semi-arid regions where the climate prevents fast plant growth, particularly during the dry seasons. In those areas, mulching or chemical stabilization may be better for the short-term (see sections on Mulching, Geotextiles, and Chemical Stabilization).

What to Consider

Proper seed bed preparation and the use of high-quality seed are needed to grow plants for effective erosion control. Soil that has been compacted by heavy traffic or machinery may need to be loosened. Successful growth usually requires that the soil be tilled before the seed is applied. Topsoiling is not necessary for temporary seeding; however, it may improve the chances of establishing temporary vegetation in an area. Seed bed preparation may also require applying fertilizer and/or lime to the soil to make conditions more suitable for plant growth. Proper fertilizer, seeding mixtures, and seeding rates vary depending on the location of the site, soil types, slopes, and season. Local suppliers, State and local regulatory agencies, and the USDA Soil Conservation Service will supply information on the best seed mixes and soil conditioning methods.

Seeded areas should be covered with mulch to provide protection from the weather. Seeding on slopes of 2:1 or more, in adverse soil conditions, during excessively hot or dry weather, or where heavy rain is expected should be followed by spreading mulch (see section on Mulching). Frequent inspections are necessary to check that conditions for growth are good. If the plants do not grow quickly or thick enough to prevent erosion, the area should be reseeded as soon as possible. Seeded areas should be kept adequately moist. If normal rainfall will not be enough, mulching, matting, and controlled watering should be done. If seeded areas are watered, watering rates should be watched so that over-irrigation (which can cause erosion itself) does not occur.

Advantages of Temporary Seeding
• Is generally inexpensive and easy to do
• Establishes plant cover fast when conditions are good
• Stabilizes soils well, is aesthetic, and can provide sedimentation controls for other site areas
• May help reduce costs of maintenance on other erosion controls (e.g., sediment basins may need to be cleaned out less often)
Disadvantages of Temporary Seeding
• Depends heavily on the season and rainfall rate for success
• May require extensive fertilizing of plants grown on some soils, which can cause problems with local water quality
• Requires protection from heavy use, once seeded
• May produce vegetation that requires irrigation and maintenance

Permanent Seeding and Planting

What Is It

Permanent seeding of grass and planting trees and brush provides stabilization to the soil by holding soil particles in place. Vegetation reduces sediments and runoff to downstream areas by slowing the velocity of runoff and permitting greater infiltration of the runoff. Vegetation also filters sediments, helps the soil absorb water, improves wildlife habitats, and enhances the aesthetics of a site.

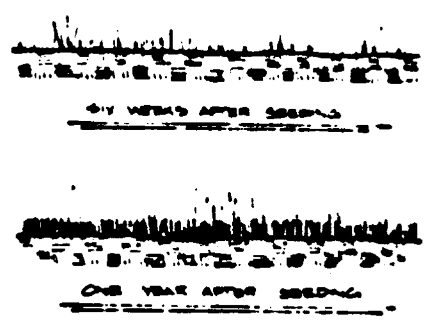

FIGURE 4.15 ESTABLISHING PERMANENT COVER WITH VEGETATION
(Modified from State of North Carolina, 1988)

When and Where to Use It

Permanent seeding and planting is appropriate for any graded or cleared area where long-lived plant cover is desired. Some areas where permanent seeding is especially important are filter strips, buffer areas, vegetated swales, steep slopes, and stream banks. This practice is effective on areas where soils are unstable because of their texture, structure, a high water table, high winds, or high slope. When seeding in northern areas during fall or winter, cover the area with mulch to provide a protective barrier against cold weather (see Mulching). Seeding should also be mulched if the seeded area slopes 4:1 or more, if soil is sandy or clayey, or if weather is excessively hot or dry. Plant when conditions are most favorable for growth. When possible, use low-maintenance local plant species. Install all other erosion control practices such as dikes, basins, and surface runoff control measures before planting.

What to Consider

For this practice to work, it is important to select appropriate vegetation, prepare a good seedbed, properly time planting, and water and fertilize. Planting local plants during their regular growing season will increase the chances for success and may lessen the need for watering. Check seeded areas frequently for proper watering and growth conditions.

Topsoil should be used on areas where topsoils have been removed, where the soils are dense or impermeable, or where mulching and fertilizers alone cannot improve soil quality. Topsoiling should be coordinated with the seeding and planting practices and should not be planned while the ground is frozen or too wet. Topsoil layers should be at least 2 inches deep (or similar to the existing topsoil depth).

To minimize erosion and sedimentation, remove as little existing topsoil as possible. All site controls should be in place before the topsoil is removed. If topsoils are brought in from another site, it is important that its texture is compatible with the subsoils onsite; for example, sandy topsoils are not compatible with clay subsoils.

Stockpiling of topsoils onsite requires good planning so soils will not obstruct other operations. If soil is to be stockpiled, consider using temporary seeding, mulching, or silt fencing to prevent or control erosion. Inspect the stockpiles frequently for erosion. After topsoil has been spread, inspect it regularly, and reseed or replace areas that have eroded.

Advantages of Permanent Seeding and Planting
• Improves the aesthetics of a site • Provides excellent stabilization • Provides filtering of sediments • Provides wildlife habitat • Is relatively inexpensive
Disadvantages of Permanent Seeding and Planting
• May require irrigation to establish vegetation • Depends initially on climate and weather for success

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Sodding

What Is It

Sodding stabilizes an area by establishing permanent vegetation, providing erosion and sedimentation controls, and providing areas where storm water can infiltrate the ground.

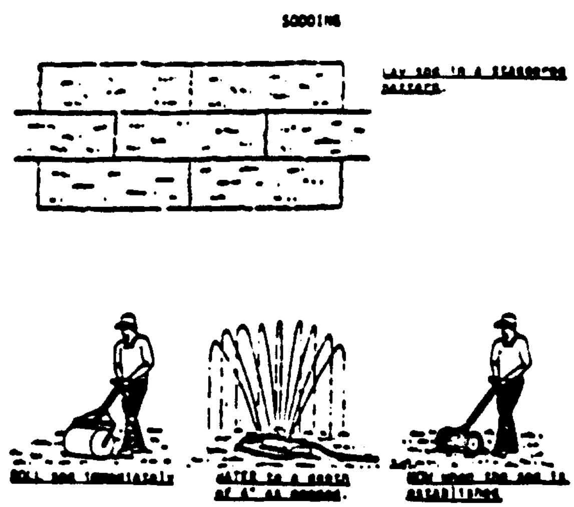

FIGURE 4.16 SODDING
(Modification from County of Fairfax, 1987)

When and Where to Use It

Sodding is appropriate for any graded or cleared area that might erode and where a permanent, long-lived plant cover is needed immediately. Examples of where sodding can be used are buffer zones, stream banks, dikes, swales, slopes, outlets, level spreaders, and filter strips.

What to Consider

The soil surface should be fine-graded before laying down the sod. Topsoil may be needed in areas where the soil textures are inadequate (see topsoil discussion in section on Permanent Seeding and Planting). Lime and fertilizers should be added to the soil to promote good growth conditions. Sodding can be applied in alternating strips or other patterns, or alternate areas can be seeded to reduce expense. Sod should not be planted during very hot or wet weather. Sod should not be placed on slopes that are greater than 3:1 if they are to be mowed. If placed on steep slopes, sod should be laid with staggered joints and/or be pegged. In areas such as steep slopes or next to running waterways, chicken wire, jute, or other netting can be placed over the sod for extra protection against lifting (see Mulching, Matting, and Netting). Rolled or compact immediately after installation to ensure firm contact with the underlying topsoil. Inspect the sod frequently after it is first installed, especially after large storm events, until it is established as permanent cover. Remove and replace dead sod. Watering may be necessary after planting and during periods of intense heat and/or lack of rain.

Advantages of Sodding
• Can provide immediate vegetative cover and erosion control • Provides more stabilizing protection than initial seeding through dense cover formed by sod • Produces lower weed growth than seeded vegetation • Can be used for site activities within a shorter time than can seeded vegetation • Can be placed at any time of the year as long as moisture conditions in the soil are favorable, except when the ground is frozen
Disadvantages of Sodding
• Purchase and installation costs are higher than for seeding • May require continued irrigation if the sod is placed during dry seasons or on sandy soils

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Chemical Stabilization

What Is It

Chemical stabilization practices, often referred to as a chemical mulch, soil binder, or soil palliative, are temporary erosion control practices. Materials made of vinyl, asphalt, or rubber are sprayed onto the surface of the soil to hold the soil in place and protect against erosion from storm water runoff and wind. Many of the products used for chemical stabilization are human-made, and many different products are on the market.

When and Where to Use It

Chemical stabilization can be used as an alternative in areas where temporary seeding practices cannot be used because of the season or climate. It can provide immediate, effective, and inexpensive erosion control anywhere erosion is occurring on a site.

What to Consider

The application rates and procedures recommended by the manufacturer of a chemical stabilization product should be followed as closely as possible to prevent the products from forming ponds and from creating large areas where moisture cannot get through.

Advantages of Chemical Stabilization
• Is easily applied to the surface of the soil • Is effective in stabilizing areas where plants will not grow • Provides immediate protection to soils that are in danger of erosion
Disadvantages of Chemical Stabilization
• Can create impervious surfaces (where water cannot get through), which may in turn increase the amount and speed of storm water runoff • May cause harmful effects on water quality if not used correctly • Is usually more expensive than vegetative cover

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4.5.2 Structural Erosion Prevention and Sediment Control Practices

Structural practices used in sediment and erosion control divert storm water flows away from exposed areas, convey runoff, prevent sediments from moving offsite, and can also reduce the erosive forces of runoff waters. The controls can either be used as permanent or temporary measures. Practices discussed include the following:

- Interceptor Dikes and Swales
- Pipe Slope Drains
- Subsurface Drains
- Filter Fence
- Straw Bale Barrier
- Brush Barrier
- Gravel or Stone Filter Berm
- Storm Drain Inlet Protection
- Sediment Trap
- Temporary Sediment Basin
- Outlet Protection
- Check Dams
- Surface Roughening
- Gradient Terraces.

Interceptor Dikes and Swales

What Are They

Interceptor dikes (ridges of compacted soil) and swales (excavated depressions) are used to keep upslope runoff from crossing areas where there is a high risk of erosion. They reduce the amount and speed of flow and then guide it to a stabilized outfall (point of discharge) (see section on Outlet Protection) or sediment trapping area (see sections on Level Spreaders, Vegetated Filter Strips, Sediment Traps, and Temporary Sediment Basins). Interceptor dikes and swales divert runoff using a combination of earth dike and vegetated swale. Runoff is channeled away from locations where there is a high risk of erosion by placing a diversion dike or swale at the top of a sloping disturbed area. Dikes and swales also collect overland flow, changing it into concentrated flows (i.e., flows that are combined). Interceptor dikes and swales can be either temporary or permanent storm water control structures.

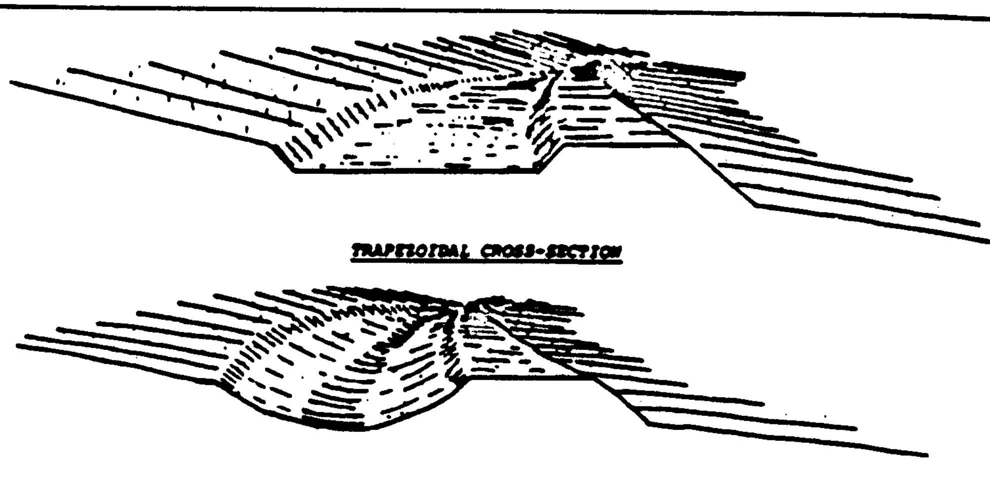

FIGURE 4.17 TYPICAL INTERCEPTOR DIKES AND SWALES
(Modified from State of Maryland, 1983)

When and Where to Use Them

Interceptor dikes and swales are generally built around the perimeter of a construction site before any major soil disturbing activity takes place. Temporary dikes or swales may also be used to protect existing buildings; areas, such as stockpiles; or other small areas that have not yet been fully stabilized. When constructed along the upslope perimeter of a disturbed or high-risk area (though not necessarily all the way around it), dikes or swales prevent runoff from uphill areas from crossing the unprotected slope. Temporary dikes or swales constructed on the down slope side of the disturbed or high-risk area will prevent runoff that contains sediment from leaving the site

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before sediment is removed. For short slopes, a dike or swale at the top of the slope reduces the amount of runoff reaching the disturbed area. For longer slopes, several dikes or swales are placed across the slope at intervals. This practice reduces the amount of runoff that accumulates on the face of the slope and carries the runoff safely down the slope. In all cases, runoff is guided to a sediment trapping area or a stabilized outfall before release.

What to Consider

Temporary dikes and swales are used in areas of overland flow; if they remain in place longer than 15 days, they should be stabilized. Runoff channeled by a dike or swale should be directed to an adequate sediment trapping area or stabilized outfall. Care should be taken to provide enough slope for drainage but not too much slope to cause erosion due to high runoff flow speed. Temporary interceptor dikes and swales may remain in place as long as 12 to 18 months (with proper stabilization) or be rebuilt at the end of each day's activities. Dikes or swales should remain in place until the area they were built to protect is permanently stabilized. Interceptor dikes and swales can be permanent controls. However, permanent controls: should be designed to handle runoff after construction is complete; should be permanently stabilized; and should be inspected and maintained on a regular basis. Temporary and permanent control measures should be inspected once each week on a regular schedule and after every storm. Repairs necessary to the dike and flow channel should be made promptly.

Advantages of Interceptor Dikes and Swales
• Are simple and effective for channeling runoff away from areas subject to erosion • Can handle flows from large drainage areas • Are inexpensive because they use materials and equipment normally found onsite
Disadvantages of Interceptor Dikes and Swales
• If constructed improperly, can cause erosion and sediment transport since flows are concentrated • May cause problems to vegetation growth if water flow is too fast • Require additional maintenance, inspections, and repairs

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Pipe Slope Drains

What Are They

Pipe slope drains reduce the risk of erosion by discharging runoff to stabilized areas. Made of flexible or rigid pipe, they carry concentrated runoff from the top to the bottom of a slope that has already been damaged by erosion or is at high risk for erosion. They are also used to drain saturated slopes that have the potential for soil slides. Pipe slope drains can be either temporary or permanent depending on the method of installation and material used.

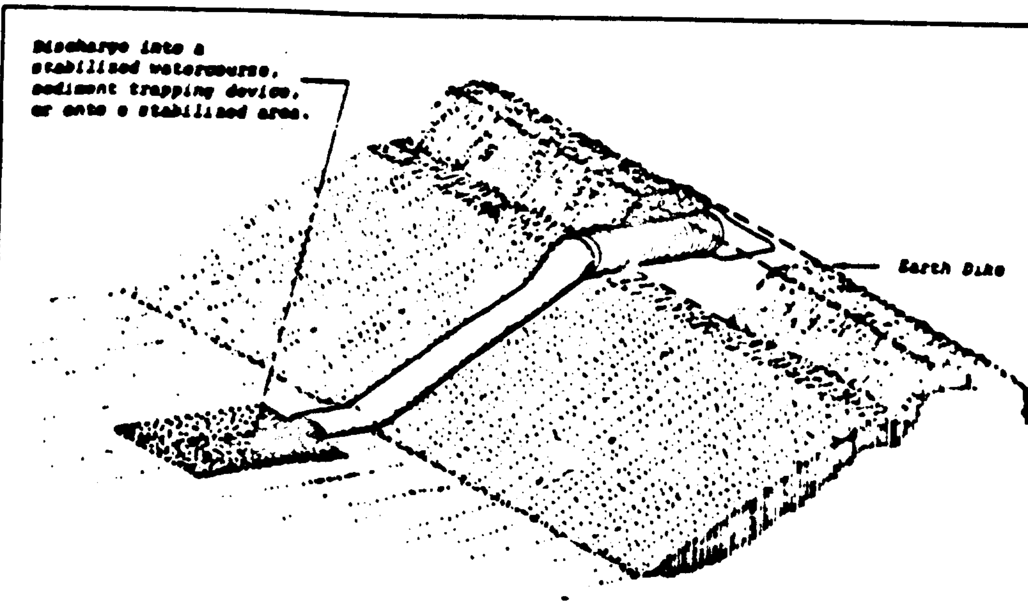

FIGURE 4.18 FLEXIBLE PIPE SLOPE DRAIN
(Modified from State of Maryland, 1983)

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When and Where to Use Them

Pipe slope drains are used whenever it is necessary to convey water down a slope without causing erosion. They are especially effective before a slope has been stabilized or before permanent drainage structures are ready for use. Pipe slope drains may be used with other devices, including diversion dikes or swales, sediment traps, and level spreaders (used to spread out storm water runoff uniformly over the surface of the ground). Temporary pipe slope drains, usually flexible tubing or conduit, may be installed prior to the construction of permanent drainage structures. Permanent slope drains may be placed on or beneath the ground surface; pipes, sectional downdrains, paved chutes, or clay tiles may be used.

Paved chutes may be covered with a surface of concrete or other impenetrable material. Subsurface drains can be constructed of concrete, PVC, clay tile, corrugated metal, or other permanent material.

What to Consider

The drain design should be able to handle the volume of flow. The effective life span of a temporary pipe slope drain is up to 30 days after permanent stabilization has been achieved. The maximum recommended drainage area for pipe slope drains is 10 acres (Washington State, 1992).

The inlets and outlets of a pipe slope drain should be stabilized. This means that a flared end section should be used at the entrance of the pipe. The soil around the pipe entrance should be fully compacted. The soil at the discharge end of the pipe should be stabilized with riprap (a combination of large stones, cobbles, and boulders). The riprap should be placed along the bottom of a swale which leads to a sediment trapping structure or another stabilized area.

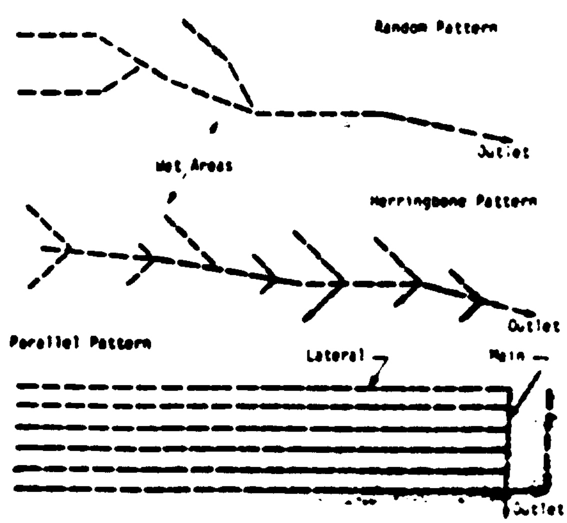
Pipe slope drains should be inspected on a regular schedule and after any major storm. Be sure that the inlet from the pipe is properly installed to prevent bypassing the inlet and undercutting the structure. If necessary, install a headwall, riprap, or sandbags around the inlet. Check the outlet point for erosion and check the pipe for breaks or clogs. Install outlet protection if needed and promptly clear breaks and clogs.

Advantages of Pipe Slope Drains
• Can reduce or eliminate erosion by transporting runoff down steep slopes or by draining saturated soils • Are easy to install and require little maintenance
Disadvantages of Pipe Slope Drains
• Require that the area disturbed by the installation of the drain should be stabilized or it, too, will be subject to erosion • May clog during a large storm

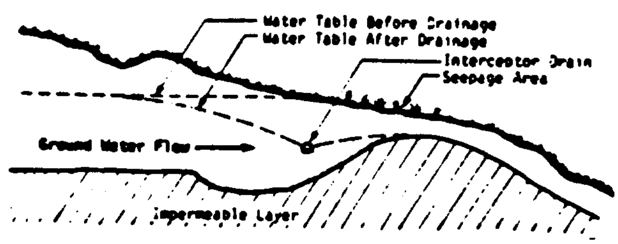
Subsurface Drains

What Are They

A subsurface drain is a perforated pipe or conduit placed beneath the surface of the ground at a designed depth and grade. It is used to drain an area by lowering the water table. A high water table can saturate soils and prevent the growth of certain types of vegetation. Saturated soils on slopes will sometimes "slip" down the hill. Installing subsurface drains can help prevent these problems.



Typical Subsurface Drain Patterns



Effect of Subsurface Drains on Water Table

FIGURE 4.19 SUBSURFACE DRAINS
(Modified from Commonwealth of Virginia, 1980)

When and Where to Use Them

There are two types of subsurface drains: relief drains and interceptor drains. Relief drains are used to dewater an area where ths water table is high. They may be placed in a gridiron, herringbone, or random pattern. Interceptor drains are used to remove water where sloping soils are excessively wet or subject to slippage. They are usually placed as single pipes instead of in patterns. Generally, subsurface drains are suitable only in areas where the soil is deep enough for proper installation. They are not recommended where they pass under heavy vehicle crossings.

What to Consider

Drains should be placed so that tree roots will not interfere with drainage pipes. The drain design should be adequate to handle the volume of flow. Areas disturbed by the installation of a drain should be stabilized or they, too, will be subject to erosion. The soil layer must be deep enough to allow proper installation.

Backfill immediately after the pipe is placed. Material used for backfill should be open granular soil that is highly permeable. The outlet should be stabilized and should direct sediment-laden storm water runoff to a sediment trapping structure or another stabilized area.

Inspect subsurface drains on a regular schedule and check for evidence of pipe breaks or clogging by sediment, debris, or tree roots. Remove blockage immediately, replace any broken sections, and restabilize the surface. If the blockage is from tree roots, it may be necessary to relocate the drain. Check inlets and outlets for sediment or debris. Remove and dispose of these materials properly.

Advantages of Subsurface Drains
• Provide an effective method for stabilizing wet sloping soils
• Are an effective way to lower the water table
Disadvantages of Subsurface Drains
• May be pierced and clogged by tree roots
• Should not be installed under heavy vehicle crossings
• Cost more than surface drains because of the expenses of excavation for installation

Filter Fence

What Is It

A silt fence, also called a "filter fence," is a temporary measure for sedimentation control. It usually consists of posts with filter fabric stretched across the posts and sometimes with a wire support fence. The lower edge of the fence is vertically trenched and covered by backfill. A silt fence is used in small drainage areas to detain sediment. These fences are most effective where there is overland flow (runoff that flows over the surface of the ground as a thin, even layer) or in minor swales or drainageways. They prevent sediment from entering receiving waters. Silt fences are also used to catch wind blown sand and to create an anchor for sand dune creation. Aside from the traditional wooden post and filter fabric method, there are several variations of silt fence installation including silt fence which can be purchased with pockets presewn to accept use of steel fence posts.

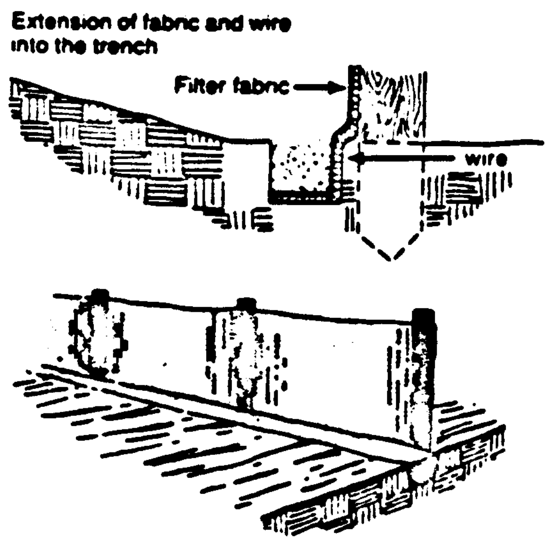


FIGURE 4.20 FILTER FENCE DETAILS
(Modified from State of North Carolina, 1988; and State of Wisconsin, 1988)

When and Where to Use It

A silt fence should be installed prior to major soil disturbance in the drainage area. Such a structure is only appropriate for drainage areas of 1 acre or less with velocities of 0.5 cfs or less (Washington State, 1992). The fence should be placed across the bottom of a slope or minor drainageway along a line of uniform elevation (perpendicular to the direction of flow). It can be used at the outer boundary of the work area. However, the fence does not have to surround the

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work area completely. In addition, a silt fence is effective where sheet and rill erosion may be a problem. Silt fences should not be constructed in streams or swales.

What to Consider

A silt fence is not appropriate for a large area or where the flow rate is greater than 0.5 cfs. This type of fence can be more effective than a straw bale barrier if properly installed and maintained. It may be used in combination with other erosion and sediment practices.

The effective life span for a silt fence is approximately 6 months. During this period, the fence requires frequent inspection and prompt maintenance to maintain its effectiveness. Inspect the fence after each rainfall. Check for areas where runoff eroded a channel beneath the fence, or where the fence was caused to sag or collapse by runoff flowing over the top. Remove and properly dispose of sediment when it is one-third to one-half the height of the fence or after each storm.

Advantages of a Filter Fence
• Removes sediments and prevents downstream damage from sediment deposits
• Reduces the speed of runoff flow
• Minimal clearing and grubbing required for installation
• Inexpensive
Disadvantages of a Filter Fence
• May result in failure from improper choice of pore size in the filter fabric or improper installation
• Should not be used in streams
• Is only appropriate for small drainage areas with overland flow
• Frequent inspection and maintenance is necessary to ensure effectiveness

Straw Bale Barrier

What Is It

Straw bales can be used as a temporary sediment barrier. They are placed end to end in a shallow excavated trench (with no gaps in between) and staked into place. If properly installed, they can detain sediment and reduce flow velocity from small drainage areas. A straw bale barrier prevents sediment from leaving the site by trapping the sediment in the barrier while allowing the runoff to pass through. It can also be used to decrease the velocity of sheetflow or channel flows of low-to-moderate levels.

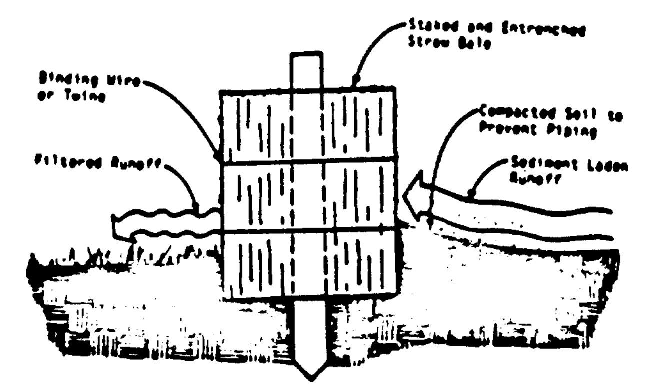

FIGURE 4.21 CROSS SECTION OF A PROPERLY INSTALLED STRAW BALE BARRIER
(Modified from State of Wisconsin, 1988)

When and Where to Use It

A straw bale barrier should be installed prior to major soil disturbance in the drainage area. This type of barrier is placed perpendicular to the flow, across the bottom of a slope or minor drainageway where there is sheetflow. It can be used at the perimeter of the work area, although is does not have to surround it completely. It can also be very effective when used in combination with other erosion and sediment control practices. A straw bale barrier may be used where the length of slope behind the barrier is less than 100 feet and where the slope is less than 2:1.

What to Consider

The success of a straw bale barrier depends on proper installation. The bales must be firmly staked into the entrenchment and the entrenchment must be properly backfilled. To function effectively, the bales must be placed end to end and there can be no gaps between the bales.

Straw bale barriers are useful for approximately 3 months. They must be inspected and repaired immediately after each rainfall or daily if there is prolonged rainfall. Damaged straw bales require immediate replacement. After each storm, or on a regular basis, trapped sediments must be removed and disposed of properly.

Advantages of a Straw Bale Barrier
• Can prevent downstream damage from sediment deposits if properly installed, used, and maintained
• Can be an inexpensive way to reduce or prevent erosion
Disadvantages of a Straw Bale Barrier
• May not be used in streams or large swales
• Poses a risk of washouts if the barrier is installed improperly or a storm is severe
• Has a short life span and a high inspection and maintenance requirement
• Is appropriate for only small drainage areas
• Is easily subject to misuse and can contribute to sediment problems

Brush Barrier

What Is It

A brush barrier is a temporary sediment barrier constructed from materials resulting from onsite clearing and grubbing. It is usually constructed at the bottom perimeter of the disturbed area. Filter fabric is sometimes used as an anchor over the barrier to increase its filtering efficiency. Brush barriers are used to trap and retain small amounts of sediment by intercepting the flow from small areas of soil disturbance.

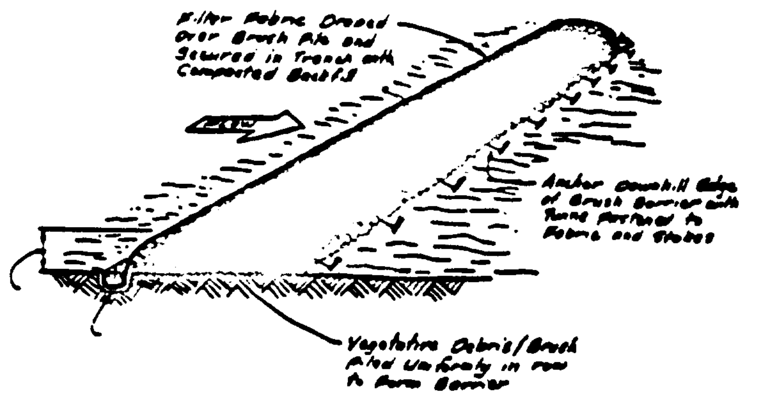

FIGURE 4.22 BRUSH BARRIER
(Modified from Washington State, 1992)

When and Where to Use It

A brush barrier should only be used to trap sediment from runoff which is from a small drainage area. The slope which the brush barrier is placed across should be very gentle. Do not place a brush barrier in a swale or any other channel. Brush barriers should be constructed below areas subject to erosion.

What to Consider

The construction of a brush barrier should be started as soon as clearing and grubbing has produced enough material to make the structure. Wood chips should not be included in the material used for the barrier because of the possibility of leaching. When the site has been stabilized and any excess sediment has been disposed of properly, the filter fabric can be removed. Over time, natural vegetation will establish itself within the barrier, and the barrier itself will decompose.

You will not have to maintain the brush barrier unless there is a very large amount of sediment being deposited. If used, the filter fabric anchor should be checked for tears and the damaged sections replaced promptly. The barrier should be inspected after each rainfall and checked for areas breached by concentrated flow. If necessary, repairs should be made promptly and excess sediment removed and disposed of properly.

Advantages of a Brush Barrier
• Can help prevent downstream damage from sediment deposits
• Is constructed of cleared onsite materials and, thus, is inexpensive
• Usually requires little maintenance, unless there are very heavy sediment deposits
Disadvantages of a Brush Barrier
• Does not replace a sediment trap or basin
• Is appropriate for only small drainage areas
• Has very limited sediment retention

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Gravel or Stone Filter Berm

What Is It

A gravel or stone filter berm is a temporary ridge constructed of loose gravel, stone, or crushed rock. It slows and filters flow, diverting it from an exposed traffic area. Diversions constructed of compacted soil may be used where there will be little or no construction traffic within the right-of way. They are also used for directing runoff from the right-of-way to a stabilized outlet.

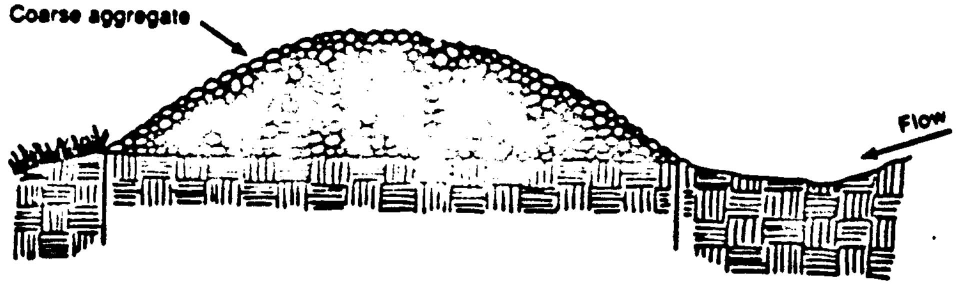

FIGURE 4.23 TYPICAL GRAVEL FILLER BERM
(Modified from Commonwealth of Virginia, 1980)

When and Where to Use It

This method is appropriate where roads and other rights-of-way under construction should accommodate vehicular traffic. Berms are meant for use in areas with shallow slopes. They may also be used at traffic areas within the construction site.

What to Consider

Berm material should be well graded gravel or crushed rock. The spacing of the berms will depend on the steepness of the slope: berms should be placed closer together as the slope increases. The diversion should be inspected daily, after each rainfall, or if breached by construction or other vehicles. All needed repairs should be performed immediately. Accumulated sediment should be removed and properly disposed of and the filter material replaced, as necessary.

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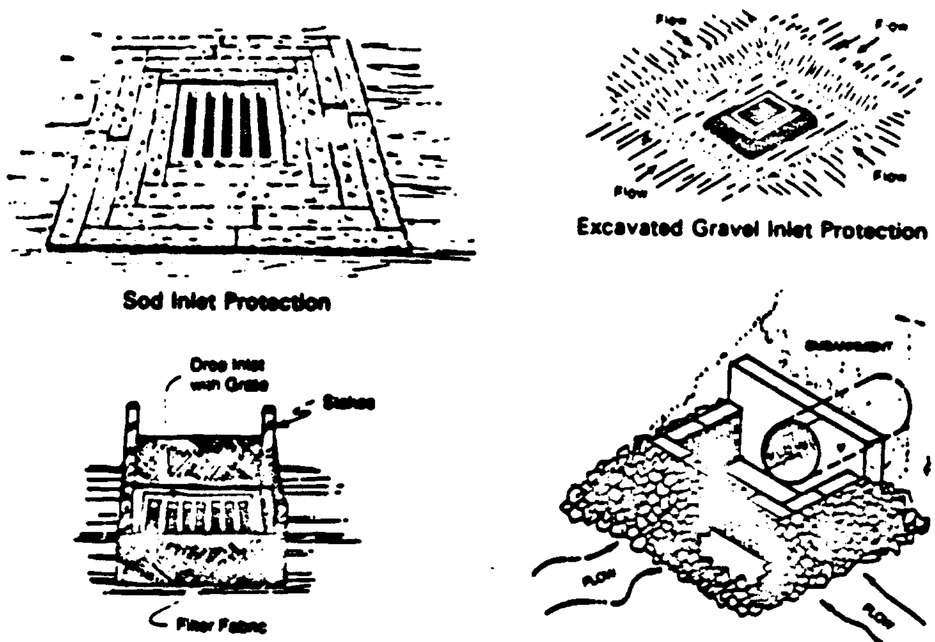
Advantages of a Gravel or Stone Filter Berm
• Is a very efficient method of sediment control
Disadvantages of a Gravel or Stone Filter Berm
• Is more expensive than methods that use onsite materials • Has a very limited life span • Can be difficult to maintain because of clogging from mud and soil on vehicle tires

Storm Drain Inlet Protection

What Is It

Storm drain inlet protection is a filtering measure placed around any inlet or drain to trap sediment. This mechanism prevents the sediment from entering inlet structures. Additionally, it serves to prevent the silting-in of inlets, storm drainage systems, or receiving channels. Inlet protection may be composed of gravel and stone with a wire mesh filter, block and gravel, filter fabric, or sod.



Sod Inlet Protection — Excavated Gravel Inlet Protection — Filter Fabric Inlet Protection — Block and Gravel Inlet Protection

FIGURE 4.24 EXAMPLES OF STORM DRAIN INLET PROTECTION
(Modified from State of North Carolina, 1988; Washington State, 1992; and County of Fairfax, 1987)

When and Where to Use It

This type of protection is appropriate for small drainage areas where storm drain inlets will be ready for use before final stabilization. Storm drain inlet protection is also used where a permanent storm drain structure is being constructed onsite. Straw bales are not recommended for this purpose. Filter fabric is used for inlet protection when storm water flows are relatively small with low velocities. This practice cannot be used where inlets are paved because the filter fabric should be staked. Block and gravel filters can be used where velocities are higher. Gravel and mesh filters can be used where flows are higher and subject to disturbance by site traffic. Sod inlet filters are generally used where sediments in the storm water runoff are low.

What to Consider

Storm drain inlet protection is not meant for use in drainage areas exceeding 1 acre or for large concentrated storm water flows. Installation of this measure should take place before any soil disturbance in the drainage area. The type of material used will depend on site conditions and the size of the drainage area. Inlet protection should be used in combination with other measures, such as small impoundments or sediment traps, to provide more effective sediment removal. Inlet protection structures should be inspected regularly, especially after a rainstorm. Repairs and silt removal should be performed as necessary. Storm drain inlet protection structures should be removed only after the disturbed areas are completely stabilized.

Advantages of Storm Drain Inlet Protection
• Prevents clogging of existing storm drainage systems and the siltation of receiving waters • Reduces the amount of sediment leaving the site
Disadvantages of Storm Drain Inlet Protection
• May be difficult to remove collected sediment • May cause erosion elsewhere if clogging occurs • Is practical only for low sediment, low volume flows

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Sediment Trap

What Is It

A sediment trap is formed by excavating a pond or by placing an earthen embankment across a low area or drainage swale. An outlet or spillway is constructed using large stones or aggregate to slow the release of runoff. The trap retains the runoff long enough to allow most of the silt to settle out.

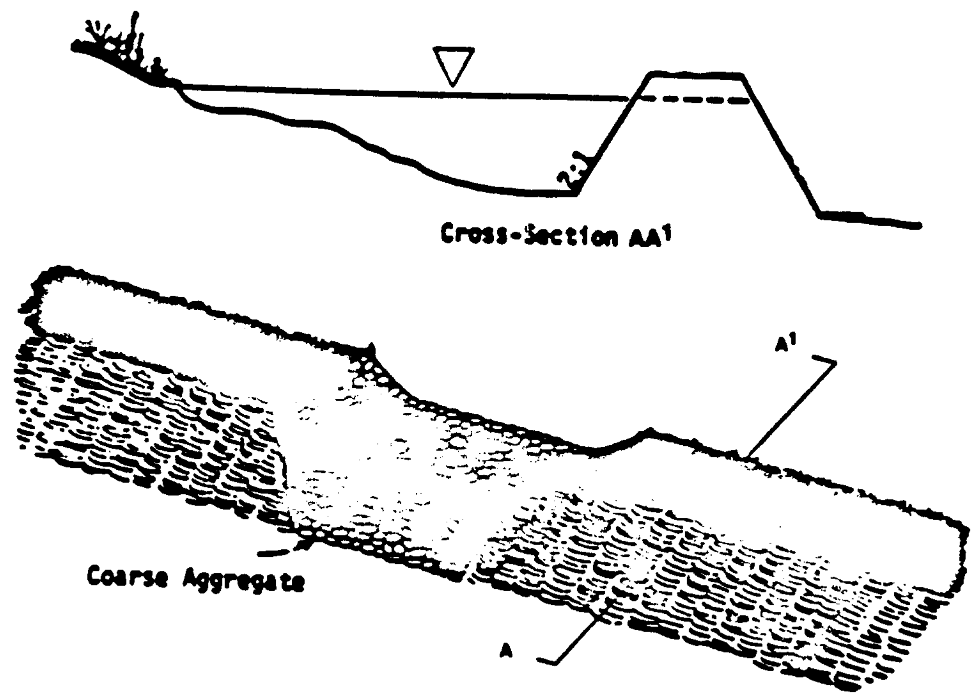

FIGURE 4.25 TYPICAL SEDIMENT TRAP
(Modified from Commonwealth of Virginia, 1980)

When and Where to Use It

A temporary sediment trap may be used in conjunction with other temporary measures, such as gravel construction entrances, vehicle wash areas, slope drains, diversion dikes and swales, or diversion channels. This device is appropriate for sites with short time schedules.

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What to Consider

Sediment traps are suitable for small drainage areas, usually no more than 10 acres, that have no unusual drainage features. The trap should be large enough to allow the sediments to settle and should have a capacity to store the collected sediment until it is removed. The volume of storage required depends upon the amount and intensity of expected rainfall and on estimated quantities of sediment in the storm water runoff. Check your Permit to see if it specifies a minimum storage volume for sediment traps.

A sediment trap is effective for approximately 18 months. During this period, the trap should be readily accessible for periodic maintenance and sediment removal. Traps should be inspected after each rainfall and cleaned when no more than half the design volume has been filled with collected sediment. The trap should remain in operation and be properly maintained until the site area is permanently stabilized by vegetation and/or when permanent structures are in place.

Advantages of a Sediment Trap
• Protects downstream areas from clogging or damage due to sediment deposits • Is inexpensive and simple to install • Can simplify the design process by trapping sediment at specific spots onsite
Disadvantages of a Sediment Trap
• Is suitable only for a limited area • Is effective only if properly maintained • Will not remove very fine silts and clays • Has a short life span

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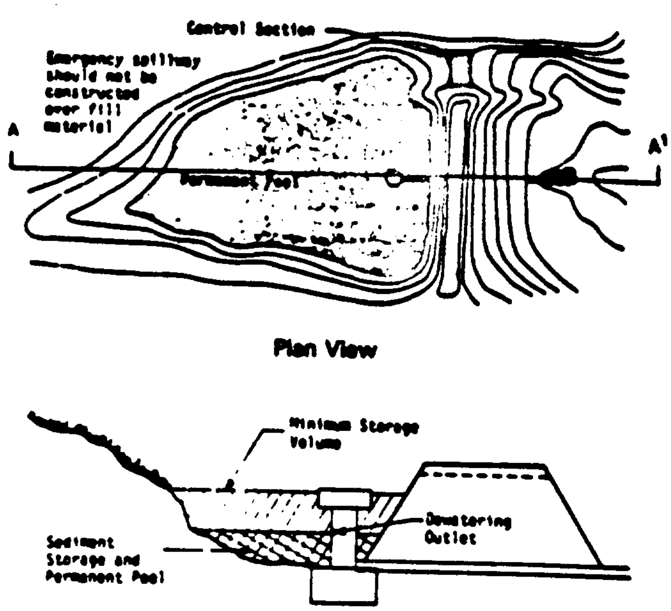
Temporary Sediment Basin

What Is It

A temporary sediment basin is a settling pond with a controlled storm water release structure used to collect and store sediment produced by construction activities. A sediment basin can be constructed by excavation or by placing an earthen embankment across a low area or drainage swale. Sediment basins can be designed to maintain a permanent pool or to drain completely dry. The basin detains sediment-laden runoff from larger drainage areas long enough to allow most of the sediment to settle out.

The pond has a gravel outlet or spillway to slow the release of runoff and provide some sediment filtration. By removing sediment, the basin helps prevent clogging of offsite conveyance systems and sediment-loading of receiving waterways. In this way, the basin helps prevent destruction of waterway habitats.



Cross Section AA'

FIGURE 4.26 TEMPORARY SEDIMENT BASIN
(Modified from Commonwealth of Virginia, 1980)

When and Where to Use It

A temporary sediment basin should be installed before clearing and grading is undertaken. It should not be built on an embankment in an active stream. The creation of a dam in such a site may result in the destruction of aquatic habitats. Dam failure can also result in flooding. A temporary sediment basin should be located only where there is sufficient space and appropriate topography. The basin should be made large enough to handle the maximum expected amount of site drainage. Fencing around the basin may be necessary for safety or vandalism reasons.

A temporary sediment basin used in combination with other control measures, such as seeding or mulching, is especially effective for removing sediments.

What to Consider

Temporary sediment basins are usually designed for disturbed areas larger than 5 acres. The pond should be large enough to hold runoff long enough for sediment to settle. Sufficient space should be allowed for collected sediments. Check the requirements of your permit to see if there is a minimum storage requirement for sediment basins. The useful life of a temporary sediment basin is about 12 to 18 months.

Sediment trapping efficiency is improved by providing the maximum surface area possible. Because finer silts may not settle out completely, additional erosion control measures should be used to minimize release of fine silt. Runoff should enter the basin as far from the outlet as possible to provide maximum retention time.

Sediment basins should be readily accessible for maintenance and sediment removal. They should be inspected after each rainfall and be cleaned out when about half the volume has been filled with sediment. The sediment basin should remain in operation and be properly maintained until the site area is permanently stabilized by vegetation and/or when permanent structures are in place. The embankment forming the sedimentation pool should be well compacted and stabilized with vegetation. If the pond is located near a residential area, it is recommended for safety reasons that a sign be posted and that the area be secured by a fence. A well built temporary sediment basin that is large enough to handle the post construction runoff volume may later be converted to use as a permanent storm water management structure.

Advantages of a Temporary Sediment Basin
• Protects downstream areas from clogging or damage due to sediment deposits generated during construction activities • Can trap smaller sediment particles than sediment traps can because of the longer detention time
Disadvantages of a Temporary Sediment Basin
• Is generally suitable for small areas • Requires regular maintenance and cleaning • Will not remove very fine silts and clays unless used in conjunction with other measures • Is a more expensive way to remove sediment than several other methods • Requires careful adherence to safety practices since ponds are attractive to children

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Outlet Protection

What Is It

Outlet protection reduces the speed of concentrated storm water flows and therefore it reduces erosion or scouring at storm water outlets and paved channel sections. In addition, outlet protection lowers the potential for downstream erosion. This type of protection can be achieved through a variety of techniques, including stone or riprap, concrete aprons, paved sections and settling basins installed below the storm drain outlet.

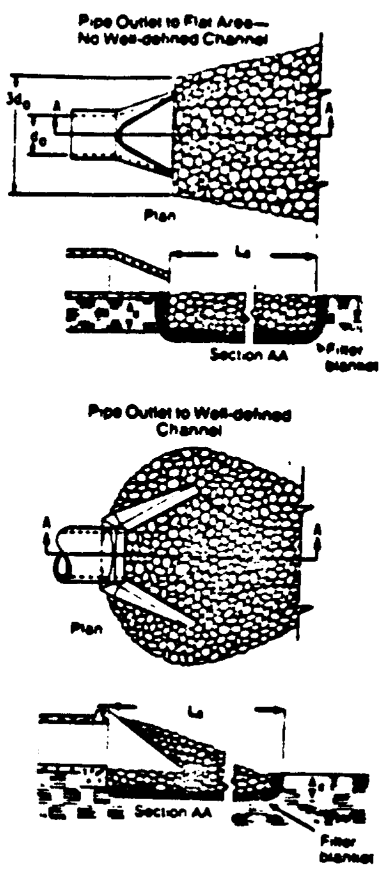

FIGURE 4.27 TYPICAL DETAILS FOR ROCK OUTLET PROTECTION
(Modified from State of North Carolina, 1988)

When and Where to Use It

Outlet protection should be installed at all pipe, interceptor dike, swale, or channel section outlets where the velocity of flow may cause erosion at the pipe outlet and in the receiving channel. Outlet protection should also be used at outlets where the velocity of flow at the design capacity may result in plunge pools (small permanent pools located at the inlet to or the outfall from BMPs). Outlet protection should be installed early during construction activities, but may be added at any time, as necessary.

What to Consider

The exit velocity of the runoff as it leaves the outlet protection structure should be reduced to levels that minimize erosion. Outlet protection should be inspected on a regular schedule to look for erosion and scouring. Repairs should be made promptly.

Advantages of Outlet Protection
• Provides, with riprap-line apron (the most common outlet protection), a relatively low cost method that can be installed easily on most sites • Removes sediment in addition to reducing flow speed • Can be used at most outlets where the flow speed is high • Is an inexpensive but effective measure • Requires less maintenance than many other measures
Disadvantages of Outlet Protection
• May be unsightly • May cause problems in removing sediment (without removing and replacing the outlet protection structure itself) • May require frequent maintenance for rock outlets with high velocity flows

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Check Dams

What Are They

A check dam is a small, temporary or permanent dam constructed across a drainage ditch, swale, or channel to lower the speed of concentrated flows. Reduced runoff speed reduces erosion and gullying in the channel and allows sediments and other pollutants to settle out.

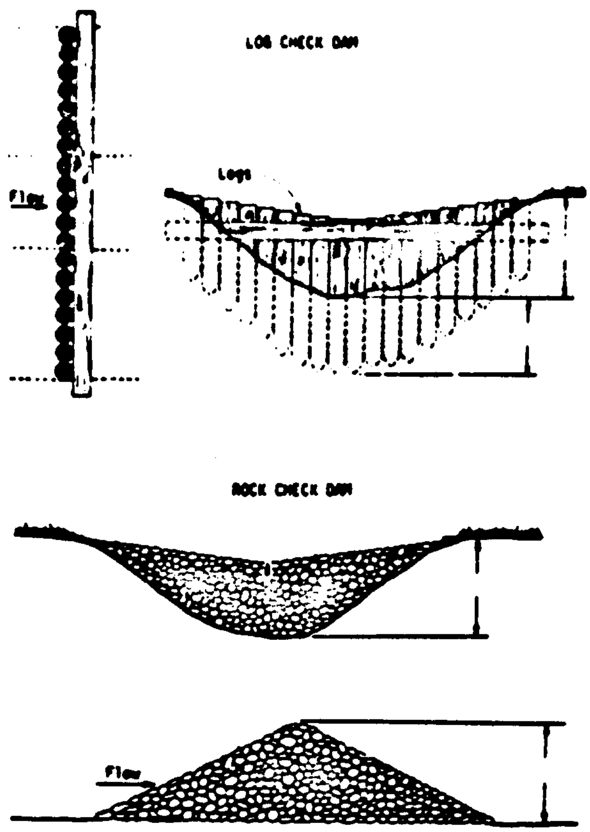

FIGURE 4.28 TYPICAL CHECK DAMS
(Modified from Commonwealth of Virginia, 1980)

When and Where to Use Them

A check dam should be installed in steeply sloped swales, or in swales where adequate vegetation cannot be established. A check dam may be built from logs, stone, or pea gravel-filled sandbags.

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What to Consider

Check dams should be used only in small open channels that drain 10 acres <u>or less</u>. The dams should not be placed in streams (unless approved by appropriate State authorities). The center section of the check dam should be lower than the edges. Dams should be spaced so that the toe of the upstream dam is at the same elevation as the top of the downstream dam.

After each significant rainfall, check dams should be inspected for sediment and debris accumulation. Sediment should be removed when it reaches one half the original dam height. Check for erosion at edges and repair promptly as required. After construction is complete, all stone and riprap should be removed if vegetative erosion controls will be used as a permanent erosion control measure. It will be important to know the expected erosion rates and runoff flow rate for the swale in which this measure is to be installed. Contact the State/local storm water program agency or a licensed engineer for assistance in designing this measure.

Advantages of Check Dams
• Are inexpensive and easy to install
• May be used permanently if designed properly
• Allow a high proportion of sediment in the runoff to settle out
• Reduce velocity and provide aeration of the water
• May be used where it is not possible to divert the flow or otherwise stabilize the channel
Disadvantages of Check Dams
• May kill grass linings in channels if the water level remains high after it rains or if there is significant sedimentation
• Are useful only for drainage areas of 10 acres or less

Surface Roughening

What is It

Surface roughening is a temporary erosion control practice. The soil surface is roughened by the creation of horizontal grooves, depressions, or steps that run parallel to the contour of the land. Slopes that are not fine-graded and that are left in a roughened condition can also control erosion. Surface roughening reduces the speed of runoff, increases infiltration, and traps sediment. Surface roughening also helps establish vegetative cover by reducing runoff velocity and giving seed an opportunity to take hold and grow.

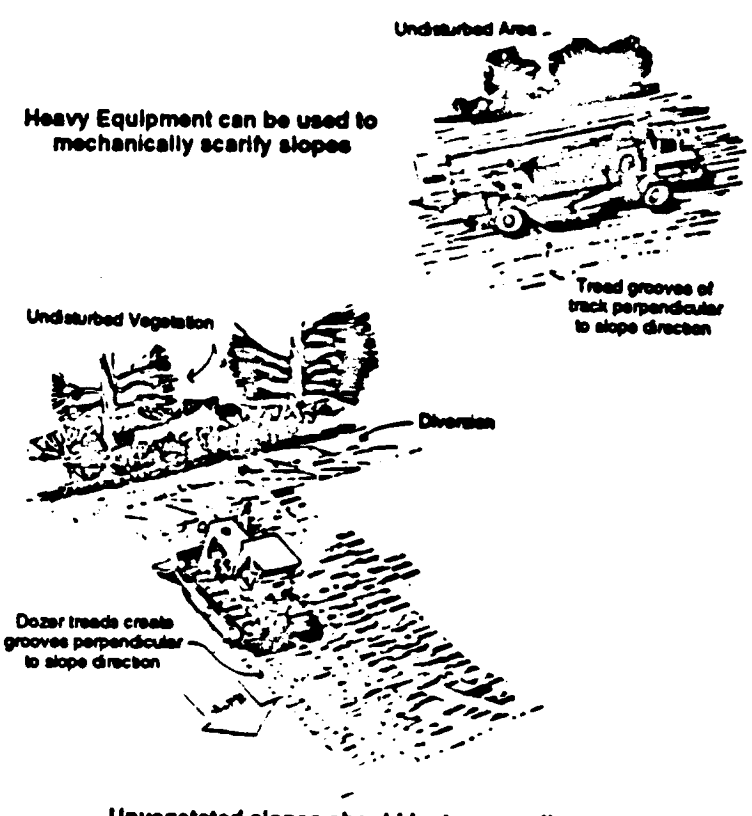

FIGURE 4.29 SURFACE ROUGHENING
(Modified from Washington State, 1992)

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When and Where to Use It

Surface roughening is appropriate for all slopes. To slow erosion, roughening should be done as soon as possible after the vegetation has been removed from the slope. Roughening can be used with both seeding and planting and temporary mulching to stabilize an area. For steeper slopes and slopes that will be left roughened for longer periods of time, a combination of surface roughening and vegetation is appropriate.

What to Consider

Different methods can be used to roughen the soil surface on slopes. They include stair-step grading, grooving (using disks, spring harrows, or teeth on a front-end loader), and tracking (driving a crawler tractor up and down a slope, leaving the cleat imprints parallel to the slope contour). The selection of an appropriate method depends on the grade of the slope, mowing requirements after vegetative cover is established, whether the slope was formed by cutting or filling, and type of equipment available.

Cut slopes with a gradient steeper than 3:1 but less than 2:1 should be stair-step graded or groove cut. Stair-step grading works well with soils containing large amounts of small rock. Each step catches material discarded from above and provides a level site where vegetation can grow. Stairs should be wide enough to work with standard earth moving equipment. Grooving can be done by any implement that can be safely operated on the slope, including those described above. Grooves should not be less than 3 inches deep nor more than 15 inches apart. Fill slopes with a gradient steeper than 3:1 but less than 2:1 should be compacted every 9 inches of depth. The face of the slope should consist of loose, uncompacted fill 4 to 6 inches deep that can be left rough or can be grooved as described above, if necessary.

Any cut or filled slope that will be mowed should have a gradient less than 3:1. Such a slope can be roughened with shallow grooves parallel to the slope contour by using normal tilling. Grooves should be close together (less than 10 inches) and not less than 1 inch deep. Any gradient with a slope greater than 2:1 should be stair-stepped.

It is important to avoid excessive compacting of the soil surface, especially when tracking, because soil compaction inhibits vegetation growth and causes higher runoff speed. Therefore, it is best to limit roughening with tracked machinery to sandy soils that do not compact easily and to avoid tracking on clay soils. Surface roughened areas should be seeded as quickly as possible. Also, regular inspections should be made of all surface roughened areas, especially after storms. If rills (small watercourses that have steep sides and are usually only a few inches deep) appear, they should be filled, graded again, and reseeded immediately. Proper dust control procedures should be followed when surface roughening.

Advantages of Surface Roughening
• Provides a degree of instant erosion protection for bare soil while vegetative cover is being established • Is inexpensive and simple for short-term erosion control
Disadvantages of Surface Roughening
• Is of limited effectiveness in anything more than a gentle rain • Is only temporary; if roughening or vegetative cover is washed away in a heavy storm or the vegetation does not take hold, the surface will have to be re-roughened and new seed laid

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Gradient Terraces

What Are They

Gradient terraces are earth embankments or ridge-and-channels constructed with suitable spacing and with an appropriate grade. They reduce erosion damage by capturing surface runoff and directing it to a stable outlet at a speed that minimizes erosion.

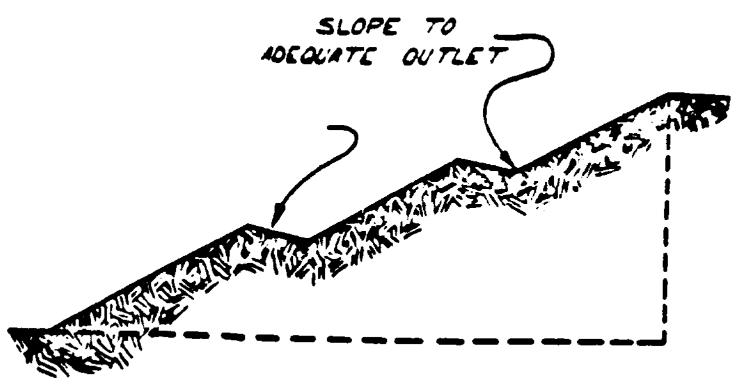

FIGURE 4.30 GRADIENT TERRACE
(Washington State, 1992)

When and Where to Use Them

Gradient terraces are usually limited to use on land that has no vegetation and that has a water erosion problem, or where it is anticipated that water erosion will be a problem. Gradient terraces should not be constructed on slopes with sandy or rocky soils. They will be effective only where suitable runoff outlets are or will be made available.

What to Consider

Gradient terraces should be designed and installed according to a plan determined by an engineering survey and layout. It is important that gradient terraces are designed with adequate outlets, such as a grassed waterway, vegetated area, or tile outlet. In all cases, the outlet should direct the runoff from the terrace system to a point where the outflow will not cause erosion or other damage. Vegetative cover should be used in the outlet where possible. The design elevation of the water surface of the terrace should not be lower than the design elevation of the water surface in the outlet at their junction, when both are operating at design flow. Terraces should be inspected regularly at least once a year and after major storms. Proper dust control procedures should be followed while constructing these features.

Advantages of Gradient Terraces
• Reduce runoff speed and increase the distance of overland runoff flow • Hold moisture better than do smooth slopes and minimize sediment loading of surface runoff
Disadvantages of Gradient Terraces
• May significantly increase cut and fill costs and cause sloughing if excessive water infiltrates the soil • Are not practical for sandy, steep, or shallow soils

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4.6 INFILTRATION PRACTICES

Infiltration practices are surface or subsurface measures that allow for quick infiltration of storm water runoff. Rapid infiltration is possible because the structures or soils used in these practices are very porous. Infiltration practices offer an advantage over other practices in that they provide some treatment of runoff, preserve the natural flow in streams, and recharge ground water. Many of the infiltration practices also can reduce the velocity of the runoff so that it will not cause damaging erosion. Another benefit of infiltration practices is that they reduce the need for expensive storm water conveyance systems. Construction and maintenance of these practices may, however, require some level of expertise to prevent clogging and to retain high effectiveness. The infiltration practices in this section have been divided into two categories: vegetative infiltration practices and infiltration structures.

Infiltration BMPs are not practical in all cases. These practices should not be used in areas where runoff is contaminated with pollutants other than sediment or oil and grease. Excessively drained (i.e., very sandy) soils may provide inadequate treatment of runoff, which could result in ground water contamination. Other site-specific conditions, such as depth to bedrock or depth to the water table, could limit their use or make it impossible to use infiltration BMPs. Also, infiltration practices should not be installed near wells, foundations, septic tank drainfields, or on unstable slopes.

Vegetative infiltration practices rely on vegetated soils that are well drained to provide storage for the infiltration of storm water. Soils used for this practice generally have not previously been disturbed or compacted so that they more easily allow infiltration. Once vegetation has been planted, use of the area must be limited or the practice may not operate efficiently. The practices that are discussed include vegetated filter strips, grassed swales, and level spreaders.

Infiltration structures are built over soils to aid in collection of storm water runoff and are designed to allow storm water to infiltrate into the ground. These structures generally require a level of expertise for both their design and construction so that they function properly. Maintenance activities are very important because infiltration structures are easily damaged by high sediment loads. Often, infiltration structures are used with other structures that pretreat the storm water runoff for sediments, oil, and grease. These pretreatment structures may be as simple as a buffer zone (see Buffer Zones) or may be something more complex, such as an oil and grease separator. The types of infiltration structures discussed include infiltration trenches, porous pavements, concrete grids, and modular pavements.

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Vegetated Filter Strips

What Are They

Vegetated filter strips are gently sloping areas of natural vegetation or are graded and artificially planted areas used to provide infiltration, remove sediments and other pollutants, and reduce the flow and velocity of the storm water moving across the terrain. Vegetated filter strips function similarly to vegetated or grassed swales. The filter strips, however, are fairly level and treat sheetflow, whereas grassed swales are indentations (see section on Grassed Swales) and treat concentrated flows. Vegetated filter strips provide permanent storm water control measures on a site.

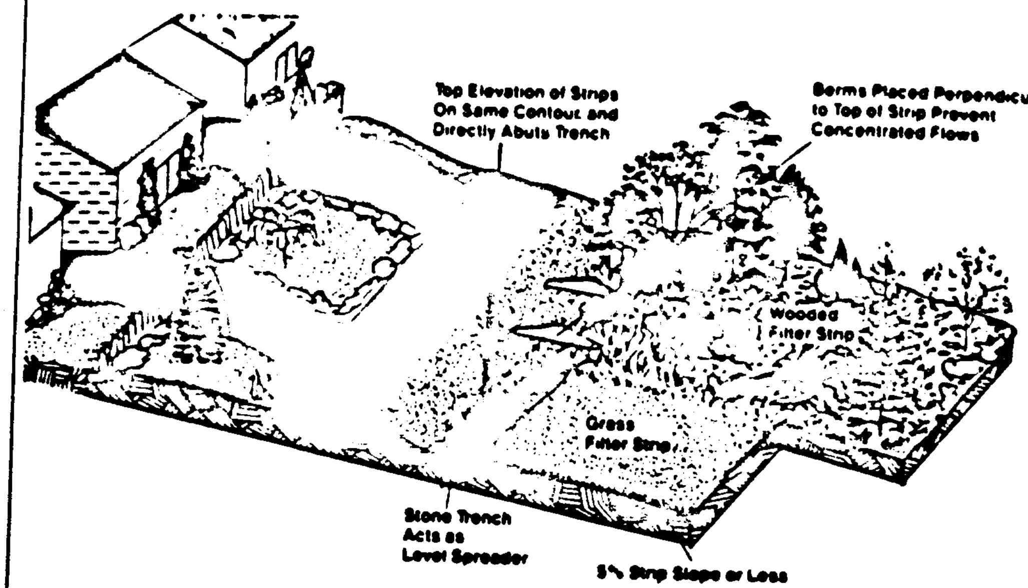

FIGURE 4.31 USE OF FILTER STRIPS
(Modified from MWCOG, 1987)

When and Where to Use Them

Vegetated filter strips are suited for areas where the soils are well drained or moderately well drained and where the bedrock and the water table are well below the surface. Vegetated filter strips will not function well on steep slopes, in hilly areas, or in highly paved areas because of the high velocity of runoff. Sites with slopes of 15 percent or more may not be suitable for filtering storm water flows. However, they should still be vegetated (MWCOG, 1987). This practice can be put into place at any time, provided that climatic conditions allow for planting.

What to Consider

At a minimum, a filter strip must be approximately 20 feet wide to function well. The length of the strip should be approximately 50 to 75 feet. Where slopes become steeper, the length of the strip must be increased. Forested strips are always preferred to vegetated strips, and existing vegetation is preferred to planted vegetation. In planning for vegetated strips, consider climatic conditions, since vegetation may not take hold in especially dry and/or cold regions.

Regular inspections are necessary to ensure the proper functioning of the filter strips. Removing sediments and replanting may be necessary on a regular basis. The entire area should be examined for damage due to equipment and vehicles. Vegetation should be dense. Also, the portions of the strip where erosion may have created ponding of runoff should be inspected. This situation can be eliminated by grading.

Advantages of Vegetated Filter Strips
• Provide low to moderate treatment of pollutants in storm water while providing a natural look to a site • Can provide habitat for wildlife • Can screen noise and views if trees or high shrubs are planted on the filter strips • Are easily constructed and implemented • Are inexpensive
Disadvantages of Vegetated Filter Strips
• Are not effective for high velocity flows (large paved areas or steep slopes) • Require significant land space • May have a short useful life due to clogging by sediments and oil and grease

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Grassed Swales

What Are They

Grassed swales are vegetated depressions used to transport, filter, and remove sediments. Grassed swales control high runoff rates by reducing the speed of the runoff and by reducing the volume of the runoff through infiltration of the storm water. Pollutants are removed because runoff travels slowly and infiltrates into the soil and because the vegetation in the grassed swale works as a filter or strainer.

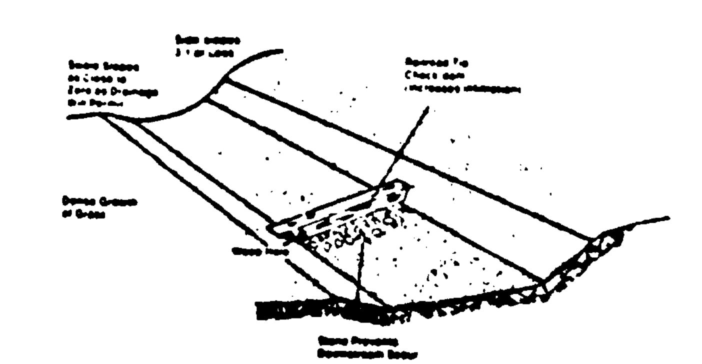

FIGURE 4.32 GRASSED SWALE WITH RAILROAD TIE CHECK DAM
(Modified from MWCOG, 1987)

When and Where to Use Them

Grassed swales are suitable for most areas where storm water runoff is low. Certain factors will affect the operation of grassed swales, including soil type, land features, and the depth of the soil from the surface to the water table (i.e., the top of the drenched portion of the soil or bedrock layer). The soil must be permeable for runoff to be able to infiltrate well. Sandy soils will not hold vegetation well nor form a stable channel structure. Steep slopes will increase runoff rates and create greater potential for erosion. Storm water flows will not be easily absorbed where the water table is near the surface. Swales are most useful for sites smaller than 10 acres (MWCOG, 1987). Even without highly permeable soils, swales reduce velocity and thus are useful.

Grassed swales usually do not work well for construction runoff because the runoff has high sediment loads.

What to Consider

The channel of the swale should be as level as possible to maximize infiltration. Side slopes in the swale should be designed to no steeper than 3:1 to minimize channel erosion (MWCOG, 1987). Plans should consider (1) the use of existing topography and existing drainage patterns and (2) the highest flow rate that is expected from a typical storm to determine the most practical size for the swale (in keeping with State or local requirements).

The swale should be tilled before grass is planted, and a dense cover of grasses should be planted in the swale. The location of the swale will determine the best type of vegetation (e.g., if the swale runs next to a road, then the grass chosen should be resistant to the use of de-icing salts in northern states).

Check dams (i.e., earthen or log structures) may be installed in the swales to reduce runoff speed and increase infiltration. Planners should also consider the design of the outlet at the end of the swale so that the runoff is released from the swale at a low rate (see section on Outlet Protection).

Maintenance activities for the swales include those practices needed to maintain healthy, dense vegetation and to retain efficient infiltration and movement of the storm water into and through the swale. Periodic mowing, reseeding, and weed control are required to maintain pollutant removal efficiency. The swale and channel outlet should be kept free from sediment buildup, litter, brush, or fallen tree limbs.

Periodic inspections will identify erosion problems or damaged areas. Damaged or eroded areas of the channel should be repaired. Areas with damaged vegetation should be reseeded immediately.

Advantages of Grassed Swales

- Are easily designed and constructed
- Provide moderate removal of sediments if properly constructed and maintained
- May provide a wildlife habitat
- Are inexpensive
- Can replace curb and gutter systems
- Can last for long periods of time if well maintained

Disadvantages of Grassed Swales

- Cannot control runoff from very large storms
- If they do not drain properly between storms, can encourage nuisance problems such as mosquitos, ragweed, dumping, and erosion
- Are not capable of removing significant amounts of soluble nutrients
- Cannot treat runoff with high sediment loadings

Level Spreaders

What Are They

Level spreaders are devices used at storm water outlets to spread out collected storm water flows into sheetflow (runoff that flows over ground surface in a thin, even layer). Typically, a level spreader consists of a depression in the soil surface that spreads the flow onto a flat area across a gentle slope. Level spreaders then release the storm water flow onto level areas stabilized by vegetation to reduce speed and increase infiltration.

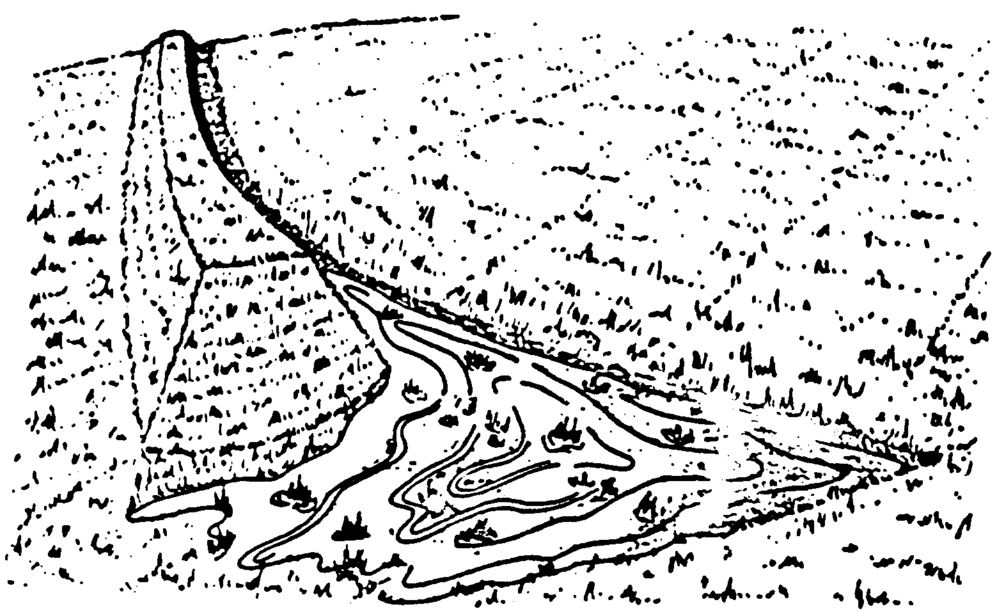

FIGURE 4.33 LEVEL SPREADERS
(Modified from Commonwealth of Virginia, 1990)

When and Where to Use Them

Level spreaders are most often used as an outlet for temporary or permanent storm water conveyances or dikes. Runoff that contains high sediment loads should be treated in a sediment trapping device prior to release into a level spreader.

What to Consider

The length of the spreader depends upon the amount of water that flows through the conveyance. Larger volumes of water need more space to even out. Level spreaders are generally used with filter strips (see Vegetated Filter Strips). The depressions are seeded with vegetation (see Permanent Seeding).

Level spreaders should not be used on soil that might erode easily. They should be constructed on natural soils and not on fill material. The entrance to the spreader should be level so that the flow can spread out evenly.

The spreader should be inspected after every large storm event to check for damage. Heavy equipment and other traffic should be kept off the level spreader because these vehicles may compact the soil or disturb the grade of the slope. If ponding or erosion channels develop, the spreader should be regraded. Dense vegetation should be maintained and damaged areas reseeded as needed.

Advantages of Level Spreaders
• Reduce storm water flow velocity, encourage sedimentation and infiltration • Are relatively inexpensive to install
Disadvantages of Level Spreaders
• Can easily develop "short circuiting" (concentration of flows into small streams instead of sheetflow over the spreader) because of erosion or other disturbance • Cannot handle large quantities of sediment-laden storm water

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Infiltration Trenches

What Are They

An infiltration trench usually consists of a long, narrow excavation ranging from 3 to 12 feet deep. The trench is filled with stone, which allows for temporary storage of storm water runoff in the open spaces between the stones. The stored storm water infiltrates into the surrounding soil or drains into underground pipes through holes and is then routed to an outflow point. Infiltration trenches are designed to remove both fine sediments and soluble pollutants rather than larger, coarse pollutants.

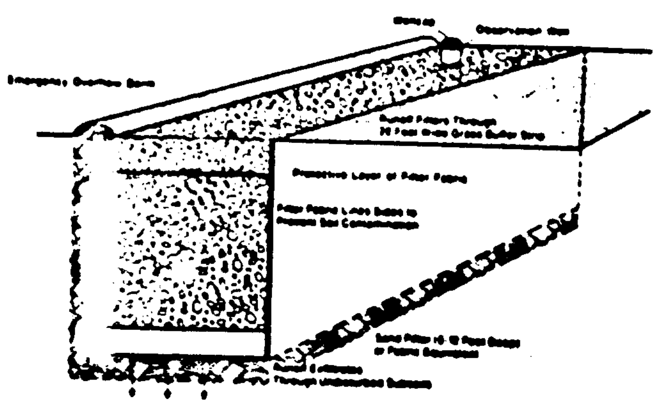

FIGURE 4.34 TYPICAL INFILTRATION TRENCH (Modified from MWCOG, 1987)

When and Where to Use Them

Infiltration trenches should be restricted to areas with certain soil, ground water, slope, area, and pollutant conditions. For example, infiltration trenches will not operate well in soils that have high clay contents, silt/clay soils, sandy/clay loams, or soils that have been compacted. Trenches should not be sited over fill soils because such soils are unstable. Hardened soils are often not suitable for infiltration trenches because these types of soils do not easily absorb water. Infiltration practices in general should not be used to manage contaminated storm water.

The drainage area contributing runoff to a single trench should not exceed 5 acres (State of Maryland, 1983). Construction of trenches should not start until after all land-disturbing activities have ceased so that runoff with high levels of sediment does not fill in the structure.

If slopes draining into the trench are steeper than 5 percent, the runoff will enter the trench too fast and will overwhelm the infiltration capacity of the soil, causing overflow. The depth from the bottom of the trench to the bedrock layer and the seasonal high water table must be at least three feet. Infiltration trenches may not be suitable in areas where there are cold winters and deep frost levels.

What to Consider

Pretreatment of runoff before it is channeled to the trench is important to efficient operation because pretreatment removes sediment, grit, and oil. Reducing the pollutant load in the runoff entering the trench lengthens trench life. One method of pretreatment is to install a buffer zone just above the trench to act as a filter (see Buffer Zones). In addition, a layer of filter fabric 1 foot below the bottom of the trench can be used to trap the sediments that get through the buffer strip. If excavation around the trenches is necessary, the use of light duty equipment will avoid compacting, which could cause a loss of infiltration capability.

Infiltration trenches should be inspected at least once per year and after major rainfall events. Debris should be removed from all areas of the trench, especially the inlets and overflow channels. Dense vegetative growth should be maintained in buffer areas surrounding the trench.

Test wells can be installed in every trench to monitor draining times and provide information on how well the system is operating. Daily test well monitoring is necessary, especially after large storm events. If the trench does not drain after 3 days, it usually means that the trench is clogged.

Advantages of Infiltration Trenches
• Preserve the natural water balance of the site
• Are effective for small sites
• Remove pollutants effectively
Disadvantages of Infiltration Trenches
• Require high maintenance when sediment loads are heavy
• Have short life span, especially if not maintained properly
• May be expensive (cost of excavation and fill material)

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Porous Pavements/Concrete Grids and Modular Pavements

What Are They

Porous pavement, concrete grids, and modular pavements allow storm water to infiltrate so that the speed and amount of runoff from a site can be reduced.

Porous Pavement–Can be either asphalt or concrete. With porous asphalt pavement, runoff infiltrates through a porous asphalt layer into a stone "reservoir" layer. Storm water runoff filters through the stone reservoir into the underlying subsoil or drains into underground pipes through holes and is routed away. The bottom and sides of the stone reservoir are lined with filter fabric to prevent the movement of soils into the reservoir area.

Porous Concrete Pavement–Is made out of a special concrete mix that has a high number of open spaces between the particles and a coarse surface texture. These open spaces allow runoff to pass through the surface to lower levels. This type of pavement can be placed directly on graded soils. When a subbase is used for stability, 6 inches of sand is placed under the concrete mixture. Up to 6 inches of storm water can be held on the surface of the pavement and within the concrete.

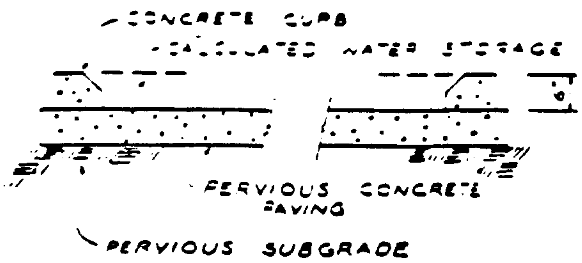
Concrete Gride and Modular Pavement–Are made out of precast concrete, poured-in-place concrete, brick, or granite. These types of pavements can also reduce the loading and concentration of pollutants in the runoff. Concrete grids and modular pavements are designed and/ or constructed so that they have open spaces within the pavement through which storm water can infiltrate into the ground. These open spaces can be filled with gravel or sand or have vegetation growing out of them.

When and Where to Use Them

These structures are usually only suitable for low-volume parking areas (1/4 acre to 10 acres) (State of Maryland, 1983) and lightly used access roads. However, areas that are expected to get moderate or high volumes of traffic or heavy equipment can use conventional pavements (for the heavy traffic areas) that are sloped to drain to areas with the porous pavements. These pavements are not effective in drainage areas that receive runoff containing high levels of sediment.

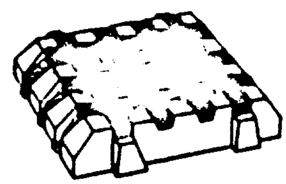
The soil types over which concrete grids and modular pavement are to be placed should allow for rapid drainage through the pores in the pavement. These pavements are not recommended for sites with slopes steeper than 5 percent (MWCOG, 1987) or sites with high water tables, shallow bedrock, fill soils, or localized clay lenses, which are conditions that would limit the ability of the runoff to infiltrate into surface soils. For example, the water table and bedrock should be at least 3 feet below the bottom of the stone reservoir. Porous pavement will not operate well in windy areas where sediment will be deposited on the porous pavement.

Construction of these pavements should be timed so that installation occurs on the site after other construction activities are finished and the site has been stabilized. Therefore, sediments are less likely to be tracked or carried on to the surface.

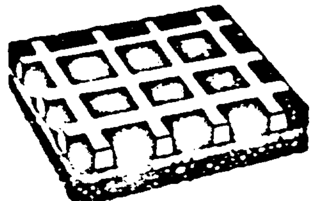


Detail of Pervious Concrete Pavement

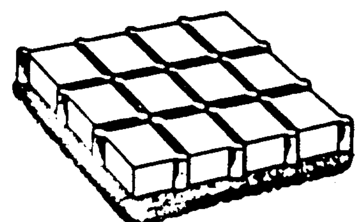
Poured-in-Place Slab



Castellated Unit

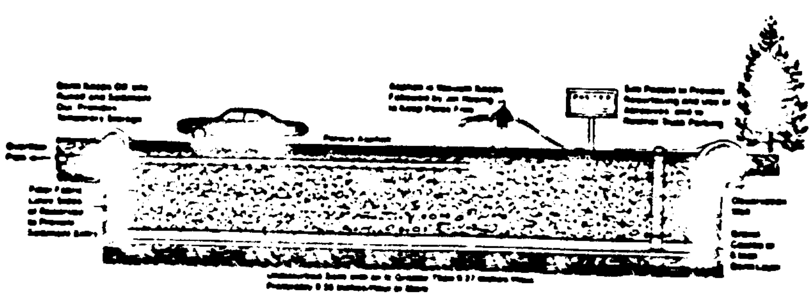


Lattice Unit



Modular Unit

Types of Grid and Modular Pavements



Cross Section of Porous Asphalt Pavement

FIGURE 4.35 POROUS PAVEMENTS, CONCRETE GRIDS, AND MODULAR PAVEMENTS
(Modified from Commonwealth of Virginia, 1980; MWCOG, 1987; and Washington State, 1992)

What to Consider

Proper installation of these pavements requires a high level of construction expertise and workmanship. Only contractors who are familiar with the installation of these pavements should be used.

Designers of porous pavement areas should consider sediment and erosion control. Sediments must kept away from the pavement area because they can clog the pores. Controls to consider for sediments include a diversion berm (i.e., earthen mound) around the edge of the pavement area to block the flow of runoff from certain drainages onto the pavement, or other filtering controls such as silt fences. De-icing salt mixtures, sands, or ash also may clog pores and should not be used for snow removal. Signs should be posted to prohibit these activities.

Since the infiltration of storm water runoff may contaminate ground water sources, these pavements are not suitable for areas close to drinking water wells (at least 100 feet away is recommended) (State of Maryland, 1983).

Maintenance of the surface is very important. For porous pavements, this includes vacuum sweeping at least four times per year followed by high-pressure hosing to reduce the chance of sediments clogging the pores of the top layer. Potholes and cracks can be filled with typical patching mixes unless more than 10 percent of the surface area needs repair. Spot clogging may be fixed by drilling half-inch holes through the porous pavement layer every few feet.

The pavement should be inspected several times the first few months after installation and then annually. Inspections after large storms are necessary to check for pools of water. These pools may indicate clogging. The condition of adjacent vegetated filter strips, silt fences, or diversion dikes should also be inspected.

Concrete grids and modular pavements should be designed in accordance with manufacturers' recommendations. Designers also need information on soils, depth to the water table, and storm water runoff quantity and quality.

Maintenance of concrete grids and modular pavements is similar to that of the porous pavements; however, turf maintenance such as mowing, fertilizing, and irrigation may be needed where vegetation is planted in the open spaces.

Advantages of Porous Pavements/Concrete Grids and Modular Pavements
• Provide erosion control by reducing the speed and quantity of the storm water runoff from the site • Provide some treatment to the water by removing pollutants • Reduce the need for curbing and storm sewer installation and expansion • Improve road safety by providing a rougher surface • Provide some recharge to local aquifers • Are cost effective because they take the place of more expensive and complex treatment systems
Disadvantages of Porous Pavements/Concrete Grids and Modular Pavements
• Can be more expensive than typical pavements • Are easily clogged with sediment and/or oil; however, pretreatment and proper maintenance will prevent this problem • May cause ground water contamination • Are not structurally suited for high-density traffic or heavy equipment • Asphalt pavements may break down if gasoline is spilled on the surface • Are less effective when the subsurface is frozen

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APPENDIX A

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REFERENCES

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APPENDIX B

GLOSSARY

GLOSSARY

Aeration: A process which promotes biological degradation of organic matter. The process may be passive (as when waste is exposed to air) or active (as when a mixing or bubbling device introduces the air).

Backfill: Earth used to fill a trench or an excavation.

Baffles: Fin-like devices installed vertically on the inside walls of liquid waste transport vehicles that are used to reduce the movement of the waste inside the tank.

Berm: An earthen mound used to direct the flow of runoff around or through a structure.

Best Management Practice (BMP): Schedules of activities, prohibitions of practices, maintenance procedures, and other management practices to prevent or reduce the pollution of waters of the United States. BMPs also include treatment requirements, operating procedures, and practices to control facility site runoff, spillage or leaks, sludge or waste disposal, or drainage from raw material storage.

Biodegradable: The ability to break down or decompose under natural conditions and processes.

Boom: 1. A floating device used to contain oil on a body of water. 2. A piece of equipment used to apply pesticides from ground equipment such as a tractor or truck.

Buffer Strip or Zone: Strips of grass or other erosion-resistant vegetation between a waterway and an area of more intensive land use.

By-product: Material, other than the principal product, that is generated as a consequence of an industrial process.

Calibration: A check of the precision and accuracy of measuring equipment.

CERCLA: Comprehensive Environmental Response, Compensation, and Liability Act.

Chock: A block or wedge used to keep rolling vehicles in place.

Clay Lens: A naturally occurring, localized area of clay that acts as an impermeable layer to runoff infiltration.

Concrete aprons: A pad of nonerosive material designed to prevent scour holes developing at the outlet ends of culverts, outlet pipes, grade stabilization structures, and other water control devices.

Conduit: Any channel or pipe for transporting the flow of water.

Conveyance: Any natural or manmade channel or pipe in which concentrated water flows.

Corrosion: The dissolving and wearing away of metal caused by a chemical reaction such as between water and the pipes that the water contacts, chemicals touching a metal surface, or contact between two metals.

Culvert: A covered channel or a large-diameter pipe that directs water flow below the ground level.

CWA: Clean Water Act (formerly referred to as the Federal Water Pollution Control Act or Federal Water Pollution Control Act Amendments of 1972).

Denuded: Land stripped of vegetation such as grass, or land that has had vegetation worn down due to impacts from the elements or humans.

Dike: An embankment to confine or control water, often built along the banks of a river to prevent overflow of lowlands; a levee.

Director: The Regional Administrator or an authorized representative.

Discharge: A release or flow of storm water or other substance from a conveyance or storage container.

Drip Guard: A device used to prevent drips of fuel or corrosive or reactive chemicals from contacting other materials or areas.

Emission: Pollution discharged into the atmosphere from smokestacks, other vents, and surface areas of commercial or industrial facilities and from motor vehicle, locomotive, or aircraft exhausts.

Erosion: The wearing away of land surface by wind or water. Erosion occurs naturally from weather or runoff but can be intensified by land-clearing practices related to farming, residential or industrial development, road building, or timber-cutting.

Excavation: The process of removing earth, stone, or other materials.

Fertilizer: Materials such as nitrogen and phosphorus that provide nutrients for plants. Commercially sold fertilizers may contain other chemicals or may be in the form of processed sewage sludge.

Filter Fabric: Textile of relatively small mesh or pore size that is used to (a) allow water to pass through while keeping sediment out (permeable), or (b) prevent both runoff and sediment from passing through (impermeable).

Filter Strip: Usually long, relatively narrow area of undisturbed or planted vegetation used to retard or collect sediment for the protection of watercourses, reservoirs, or adjacent properties.

Flange: A rim extending from the end of a pipe; can be used as a connection to another pipe.

Flow Channel Liner: A covering or coating used on the inside surface of a flow channel to prevent the infiltration of water to the ground.

Flowmeter: A gauge that shows the speed of water moving through a conveyance.

General Permit: A permit issued under the NPDES program to cover a certain class or category of storm water discharges. These permits allow for a reduction in the administrative burden associated with permitting storm water discharges associated with industrial activities. For example, EPA is planning to issue two general permits: NPDES General Permits for Storm Water Discharges From Construction Activities that are classified as "Associated with Industrial Activity" and NPDES General Permits for Storm Water Discharges from Industrial Activities that are classified as "Associated with Industrial Activities." EPA is also encouraging delegated States which have an approved general permits program to issue general permits.

Grading: The cutting and/or filling of the land surface to a desired slope or elevation.

Hazardous Substance: 1. Any material that poses a threat to human health and/or the environment. Hazardous substances can be toxic, corrosive, ignitable, explosive, or chemically reactive. 2. Any substance named required by EPA to be reported if a designated quantity of the substance is spilled in the waters of the United States or if otherwise emitted into the environment.

Hazardous Waste: By-products of human activities that can pose a substantial or potential hazard to human health or the environment when improperly managed. Possesses at least one of four characteristics (ignitability, corrosivity, reactivity, or toxicity), or appears on special EPA lists.

Holding Pond: A pond or reservoir, usually made of earth, built to store polluted runoff for a limited time.

Illicit Connection: Any discharge to a municipal separate storm sewer that is not composed entirely of storm water except discharges authorized by an NPDES permit (other than the NPDES permit for discharges from the municipal separate storm sewer) and discharges resulting from fire fighting activities.

Infiltration: 1. The penetration of water through the ground surface into sub-surface soil or the penetration of water from the soil into sewer or other pipes through defective joints, connections, or manhole walls. 2. A land application technique where large volumes of wastewater are applied to land, allowed to penetrate the surface and percolate through the underlying soil.

Inlet: An entrance into a ditch, storm sewer, or other waterway.

Intermediates: A chemical compound formed during the making of a product.

Irrigation: Human application of water to agricultural or recreational land for watering purposes.

Jute: A plant fiber used to make rope, mulch, netting, or matting.

Lagoon: A shallow pond where sunlight, bacterial action, and oxygen work to purify wastewater.

Land Application Units: An area where wastes are applied onto or incorporated into the soil surface (excluding manure spreading operations) for treatment or disposal.

Land Treatment Units: An area of land where materials are temporarily located to receive treatment. Examples include: sludge lagoons, stabilization pond.

Landfills: An area of land or an excavation in which wastes are placed for permanent disposal, and which is not a land application unit, surface impoundment, injection well, or waste pile.

Large and Medium Municipal Separate Storm Sewer System: All municipal separate storm sewers that are either: (i) located in an incorporated place (city) with a population of 100,000 or more as determined by the latest Decennial Census by the Bureau of Census (these cities are listed in Appendices F and G of 40 CFR Part 122); or (ii) located in the counties with unincorporated urbanized populations of 100,000 or more, except municipal separate storm sewers that are located in the incorporated places, townships, or towns within such counties (these counties are listed in Appendices H and I of 40 CFR Part 122); or (iii) owned or operated by a municipality other than those described in paragraph (i) or (ii) and that are designated by the Director as part of the large or medium municipal separate storm sewer system.

Leaching: The process by which soluble constituents are dissolved in a solvent such as water and carried down through the soil.

Level Spreader: A device used to spread out storm water runoff uniformly over the ground surface as sheetflow (i.e., not through channels). The purpose of level spreaders are to prevent concentrated, erosive flows from occurring and to enhance infiltration.

Liming: Treating soil with lime to neutralize acidity levels.

Liner: 1. A relatively impermeable barrier designed to prevent leachate from leaking from a landfill. Liner materials include plastic and dense clay. 2. An insert or sleeve for sewer pipes to prevent leakage or infiltration.

Liquid Level Detector: A device that provides continuous measures of liquid levels in liquid storage areas or containers to prevent overflows.

Material Storage Areas: Onsite locations where raw materials, products, final products, by-products, or waste materials are stored.

Mulch: A natural or artificial layer of plant residue or other materials covering the land surface which conserves moisture, holds soil in place, aids in establishing plant cover, and minimizes temperature fluctuations.

Noncontact Cooling Water: Water used to cool machinery or other materials without directly contacting process chemicals or materials.

Notice of Intent (NOI): An application to notify the permitting authority of a facility's intention to be covered by a general permit; exempts a facility from having to submit an individual or group application.

NPDES: EPA's program to control the discharge of pollutants to waters of the United States. See the definition of "National Pollutant Discharge Elimination System" in 40 CFR 122.2 for further guidance.

NPDES Permit: An authorization, license, or equivalent control document issued by EPA or an approved State agency to implement the requirements of the NPDES program.

Oil and Grease Traps: Devices which collect oil and grease, removing them from water flows.

Oil Sheen: A thin, glistening layer of oil on water.

Oil/Water Separator: A device installed, usually at the entrance to a drain, which removes oil and grease from water flows entering the drain.

Organic Pollutants: Substances containing carbon which may cause pollution problems in receiving streams.

Organic Solvents: Liquid organic compounds capable of dissolving solids, gases, or liquids.

Outfall: The point, location, or structure where wastewater or drainage discharges from a sewer pipe, ditch, or other conveyance to a receiving body of water.

Permeability: The quality of a soil that enables water or air to move through it. Usually expressed in inches/hour or inches/day.

Permit: An authorization, license, or equivalent control document issued by EPA or an approved State agency to implement the requirements of an environmental regulation; e.g., a permit to operate a wastewater treatment plant or to operate a facility that may generate harmful emissions.

Permit Issuing Authority (or Permitting Authority): The State agency or EPA Regional office which issues environmental permits to regulated facilities.

Plunge pool: A basin used to slow flowing water, usually constructed to a design depth and shape. The pool may be protected from erosion by various lining materials.

Pneumatic Transfer: A system of hoses which uses the force of air or other gas to push material through; used to transfer solid or liquid materials from tank to tank.

Point Source: Any discernible, confined, and discrete conveyance, including but not limited to any pipe, ditch, channel, tunnel, conduit, well, discrete fissure, container, rolling stock, concentrated animal feeding operation, or vessel or other floating craft, from which pollutants are or may be discharged. This term does not include return flows from irrigated agriculture or agricultural storm water runoff.

Pollutant: Any dredged spoil, solid waste, incinerator residue, filter backwash, sewage, garbage, sewage sludge, munitions, chemical wastes, biological materials, radioactive materials (except those regulated under the Atomic Energy Act of 1954, as amended (42 (U.S.C. 2011 et seq.)), heat, wrecked or discharged equipment, rock, sand, cellar dirt, and industrial, municipal, and agricultural waste discharged into water. It does not mean:
(i) Sewage from vessels; or
(ii) Water, gas, or other material which is injected into a well to facilitate production of oil or gas, or water derived in association with oil and gas production and disposed of in a well, if the well used either to facilitate production or for disposal purposes is approved by the authority of the State in which the well is located, and if the State determines that the injection or disposal will not result in the degradation of ground or surface water resources [Section 502(6) of the CWA].

Radioactive materials covered by the Atomic Energy Act are those encompassed in its definition of source, byproduct, or special nuclear materials. Examples of materials not covered include radium and accelerator-produced isotopes. See Train v. Colorado Public Interest Research Group, Inc., 426 U.S. 1 (1976).

Porous Pavement: A human-made surface that will allow water to penetrate through and percolate into soil (as in porous asphalt pavement or concrete). Porous asphalt pavement is comprised of irregular shaped crush rock precoated with asphalt binder. Water seeps through into lower layers of gravel for temporary storage, then filters naturally into the soil.

Precipitation: Any form of rain or snow.

Preventative Maintenance Program: A schedule of inspections and testing at regular intervals intended to prevent equipment failures and deterioration.

Process Wastewater: Water that comes into direct contact with or results from the production or use of any raw material, intermediate product, finished product, by-product, waste product, or wastewater.

PVC (Polyvinyl Chloride): A plastic used in pipes because of its strength; does not dissolve in most organic solvents.

Raw Material: Any product or material that is converted into another material by processing or manufacturing.

RCRA: Resource Conservation and Recovery Act.

Recycle: The process of minimizing the generation of waste by recovering usable products that might otherwise become waste. Examples are the recycling of aluminum cans, wastepaper, and bottles.

Reportable Quantity (RQ): The quantity of a hazardous substance or oil that triggers reporting requirements under CERCLA or the Clean Water Act. If a substance is released in amounts exceeding its RQ, the release must be reported to the National Response Center, the State Emergency Response Commission, and community emergency coordinators for areas likely to be affected (see Appendix I for a list of RQs).

Residual: Amount of pollutant remaining in the environment after a natural or technological process has taken place, e.g., the sludge remaining after initial wastewater treatment, or particulates remaining in air after the air passes through a scrubbing or other pollutant removal process.

Retention: The holding of runoff in a basin without release except by means of evaporation, infiltration, or emergency bypass.

Retrofit: The modification of storm water management systems in developed areas through the construction of wet ponds, infiltration systems, wetland plantings, stream bank stabilization, and other BMP techniques for improving water quality. A retrofit can consist of the construction of a new BMP in the developed area, the enhancement of an older storm water management structure, or a combination of improvement and new construction.

Rill Erosion: The formation of numerous, closely spread streamlets due to uneven removal of surface soils by storm water or other water.

Riparian Habitat: Areas adjacent to rivers and streams that have a high density, diversity, and productivity of plant and animal species relative to nearby uplands.

Runon: Storm water surface flow or other surface flow which enters property other than that where it originated.

Runoff: That part of precipitation, snow melt, or irrigation water that runs off the land into streams or other surface water. It can carry pollutants from the air and land into the receiving waters.

Sanitary Sewer: A system of underground pipes that carries sanitary waste or process wastewater to a treatment plant.

Sanitary Waste: Domestic sewage.

SARA: Superfund Amendments and Reauthorization Act.

Scour: The clearing and digging action of flowing water, especially the downward erosion caused by stream water in sweeping away mud and silt from the stream bed and outside bank of a curved channel.

Sealed Gate: A device used to control the flow of liquid materials through a valve.

Secondary Containment: Structures, usually dikes or berms, surrounding tanks or other storage containers and designed to catch spilled material from the storage containers.

Section 313 Water Priority Chemical: A chemical or chemical categories which are: (1) are listed at 40 CFR 372.65 pursuant to Section 313 of the Emergency Planning and Community Right-to-Know Act (EPCRA) [also known as Title III of the Superfund Amendments and Reauthorization Act (SARA) of 1986]; (2) are present at or above threshold levels at a facility subject to EPCRA Section 313 reporting requirements; and (3) that meet at least one of the following criteria: (i) are listed in Appendix D of 40 CFR Part 122 on either Table II (organic priority pollutants), Table III (certain metals, cyanides, and phenols), or Table V (certain toxic pollutants and hazardous substances); (ii) are listed as a hazardous substance pursuant to Section 311(b)(2)(A) of the CWA at 40 CFR 116.4; or (iii) are pollutants for which EPA has published acute or chronic water quality criteria. See Addendum B of this permit. (List is included as Appendix I.)

Sediment Trap: A device for removing sediment from water flows; usually installed at outfall points.

Sedimentation: The process of depositing soil particles, clays, sands, or other sediments that were picked up by flowing water.

Sediments: Soil, sand, and minerals washed from land into water, usually after rain. They pile up in reservoirs, rivers, and harbors, destroying fish-nesting areas and holes of water animals and cloud the water so that needed sunlight might not reach aquatic plants. Careless farming, mining, and building activities will expose sediment materials, allowing them to be washed off the land after rainfalls.

Sheet Erosion: Erosion of thin layers of surface materials by continuous sheets of running water.

Sheetflow: Runoff which flows over the ground surface as a thin, even layer, not concentrated in a channel.

Shelf Life: The time for which chemicals and other materials can be stored before becoming unusable due to age or deterioration.

Significant Materials: Include, but are not limited to: raw materials; fuels; materials such as solvents, detergents and plastic pellets; finished materials such as metallic products; raw materials used in food processing or production; hazardous substances designated under section 101(14) of the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA); any chemical the facility is required to report pursuant to section 313 of Title III of the Superfund Amendments and Reauthorization Act (SARA); fertilizers; pesticides; and waste products such as ashes, slag, and sludge that have a potential to be released with storm water discharges [122.26(b)(12)].

Significant Spills: Includes, but is not limited to: releases of oil or hazardous substances in excess of reportable quantities under Section 311 of the CWA (see 40 CFR 110.10 and CFR 117.21) or Section 102 of CERCLA (see 40 CFR 302.4).

Slag: Non-metal containing waste leftover from the smelting and refining of metals.

Slide Gate: A device used to control the flow of water through storm water conveyances.

Sloughing: The movement of unstabilized soil layers down a slope due to excess water in the soils.

Sludge: A semi-solid residue from any of a number of air or water treatment processes. Sludge can be a hazardous waste.

Soil: The unconsolidated mineral and organic material on the immediate surface of the earth that serves as a natural medium for the growth of plants.

Solids Dewatering: A process for removing excess water from solids to lessen the overall weight of the wastes.

Source Control: A practice or structural measure to prevent pollutants from entering storm water runoff or other environmental media.

Spent Solvent: A liquid solution that has been used and is no longer capable of dissolving solids, gases, or liquids.

Spill Guard: A device used to prevent spills of liquid materials from storage containers.

Spill Prevention Control and Countermeasures Plan (SPCC): Plan consisting of structures, such as curbing, and action plans to prevent and respond to spills of hazardous substances as defined in the Clean Water Act.

Stopcock Valve: A small valve for stopping or controlling the flow of water or other liquid through a pipe.

Storm Drain: A slotted opening leading to an underground pipe or an open ditch for carrying surface runoff.

Storm Water: Runoff from a storm event, snow melt runoff, and surface runoff and drainage.

Storm Water Discharge Associated with Industrial Activity: The discharge from any conveyance which is used for collecting and conveying storm water and which is directly related to manufacturing, processing or raw materials storage areas at an industrial plant. The term does not include discharges from facilities or activities excluded from the NPDES program under 40 CFR Part 122. For the categories of industries identified in subparagraphs (i) through (x) of this subsection, the term includes, but is not limited to, storm water discharges from industrial plant yards; immediate access roads and rail lines used or traveled by carriers of raw materials, manufactured products, waste material, or by-products used or created by the facility; material handling sites; refuse sites; sites used for the application or disposal of process waste waters (as defined at 40 CFR 401); sites used for the storage and maintenance of material handling equipment; sites used for residual treatment, storage, or disposal; shipping and receiving areas; manufacturing buildings; storage areas (including tank farms) for raw materials, and intermediate and finished products; and areas where industrial activity has taken place in the past and significant materials remain and are exposed to storm water. For the categories of industries identified in subparagraph (xi), the term includes only storm water discharges from all the areas (except access roads and rail lines) that are listed in the previous sentence where material handling equipment or activities, raw materials, intermediate products, final products, waste material, by-products, or industrial machinery <u>are exposed to storm water</u>. For the purposes of this paragraph, material handling activities include the: storage, loading and unloading, transportation, or conveyance of any raw material, intermediate product, finished product, by-product or waste product. The term excludes areas located on plant lands separate from the plant's industrial activities, such as office buildings and accompanying parking lots as long as the drainage from the excluded areas is not mixed with storm water drained from the above described areas. Industrial facilities (including industrial facilities that are Federally, State, or municipally owned or operated that meet the description of the facilities listed in this paragraph (i)-(xi) include those facilities designated under the provision of 122.26(a)(1)(v). The following categories of facilities are considered to be engaging in "industrial activity" for purposes of this subsection:

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(i) Facilities subject to storm water effluent limitations guidelines, new source performance standards, or toxic pollutant effluent standards under 40 CFR Subchapter N (except facilities with toxic pollutant effluent standards which are excepted under category (xi) of this paragraph);
(ii) Facilities classified as Standard Industrial Classifications 24 (except 2434), 26 (except 265 and 267), 28 (except 283 and 285) 29, 311, 32 (except 323), 33, 3441, 372;
(iii) Facilities classified as Standard Industrial Classifications 10 though 14 (mineral industry) including active or inactive mining operations (except for areas of coal mining operations no longer meeting the definition of a reclamation area under 40 CFR 434.11(l) because the performance bond issued to the facility by the appropriate SMCRA authority has been released, or except for areas of non-coal mining operations which have been released from applicable State or Federal reclamation requirements after December 17, 1990 and oil and gas exploration, production, processing, or treatment operations, or transmission facilities that discharge storm water contaminated by contact with or that has come into contact with, any overburden, raw material, intermediate products, finished products, byproducts or waste products located on the site of such operations; (inactive mining operations are mining sites that are not being actively mined, but which have an identifiable owner/operator; inactive mining sites do not include sites where mining claims are being maintained prior to disturbances associated with the extraction, beneficiation, or processing of mined materials, nor sites where minimal activities are undertaken for the sole purpose of maintaining mining claim);
(iv) Hazardous waste treatment, storage, or disposal facilities, including those that are operating under interim status or a permit under Subtitle C of RCRA;
(v) Landfills, land application sites, and open dumps that receive or have received any industrial wastes (waste that is received from any of the facilities described under this subsection) including those that are subject to regulation under Subtitle D of RCRA;
(vi) Facilities involved in the recycling of materials, including metal scrapyards, battery reclaimers, salvage yards, and automobiles junkyards, including but limited to those classified as Standard Industrial Classification 5015 and 5093;
(vii) Steam electric power generating facilities, including coal handling sites;
(viii) Transportation facilities classified as Standard Industrial Classifications 40, 41, 42 (except 4221-25), 43, 44, 45, and 5171 which have vehicle maintenance shops, equipment cleaning operations, or airport deicing operations. Only those portions of the facility that are either involved in vehicle maintenance (including vehicle rehabilitation, mechanical repairs, painting, fueling, and lubrication), equipment cleaning operations, airport deicing operations, or which are otherwise identified under paragraphs (i)-(vii) or (ix)-(xi) of this subsection are associated with industrial activity;
(ix) Treatment works treating domestic sewage or any other sewage sludge or wastewater treatment device or system, used in the storage treatment, recycling, and reclamation of municipal or domestic sewage, including land dedicated to the disposal of sewage sludge that are located within the confines of the facility, with a design flow of 1.0 mgd or more, or required to have an approved pretreatment program under 40 CFR 403. Not included are farm lands, domestic gardens or lands used for sludge management where sludge is beneficially reused and which are not physically located in the confines of the facility, or areas that are in compliance with Section 405 of the CWA;
(x) Construction activity including clearing, grading and excavation activities except: operations that result in the disturbance of less than five acres of total land area which are not part of a larger common plan of development or sale;
(xi) Facilities under Standard Industrial Classification 20, 21, 22, 23, 2434, 25, 265, 267, 27, 283, 285, 30, 31 (except 311), 323, 34 (except 3441), 35, 36, 37 (except 373), 38, 39, 4221-25, (and which are not otherwise included within categories (ii)-(x));

Note: The Transportation Act of 1991 provides an exemption from storm water permitting requirements for certain facilities owned or operated by municipalities with a population of less than 100,000. Such municipalities must submit storm water discharge permit applications for only airports, power plants, and uncontrolled sanitary landfills that they own or operate, unless a permit is otherwise required by the permitting authority.

Subsoil: The bed or stratum of earth lying below the surface soil.

Sump: A pit or tank that catches liquid runoff for drainage or disposal.

Surface Impoundment: Treatment, storage, or disposal of liquid wastes in ponds.

Surface Water: All water naturally open to the atmosphere (rivers, lakes, reservoirs, streams, wetlands impoundments, seas, estuaries, etc.); also refers to springs, wells, or other collectors which are directly influenced by surface water.

Swale: An elongated depression in the land surface that is at least seasonally wet, is usually heavily vegetated, and is normally without flowing water. Swales direct storm water flows into primary drainage channels and allow some of the storm water to infiltrate into the ground surface.

Tarp: A sheet of waterproof canvas or other material used to cover and protect materials, equipment, or vehicles.

Topography: The physical features of a surface area including relative elevations and the position of natural and human-made features.

Toxic Pollutants: Any pollutant listed as toxic under Section 501(a)(1) or, in the case of "sludge use or disposal practices," any pollutant identified in regulations implementing Section 405(d) of the CWA. Please refer to 40 CFR Part 122 Appendix D.

Treatment: The act of applying a procedure or chemicals to a substance to remove undesirable pollutants.

Tributary: A river or stream that flows into a larger river or stream.

Underground Storage Tanks (USTs): Storage tanks with at least 10 percent or more of its storage capacity underground (the complete regulatory definition is at 40 CFR Part 280.12).

Waste: Unwanted materials left over from a manufacturing or other process.

Waste Pile: Any noncontainerized accumulation of solid, nonflowing waste that is used for treatment or storage.

Water Table: The depth or level below which the ground is saturated with water.

Waters of the United States:
"(a) All waters, which are currently used, were used in the past, or may be susceptible to use in interstate or foreign commerce, including all waters which are subject to the ebb and flow of the tide;
(b) All interstate waters, including interstate "wetlands;"
(c) All other waters such as intrastate lakes, rivers, streams (including intermittent streams), mudflats, sandflats, "wetlands," sloughs, prairie potholes, wet meadows, playa lakes, or natural ponds, the use, degradation, or destruction of which would affect or could affect interstate or foreign commerce including any such waters:
(1) Which are or could be used by interstate or foreign travelers for recreational or other purposes;

(2) From which fish or shellfish are or could be taken and sold in interstate or foreign commerce; or
(3) Which are used or could be used for industrial purposes by industries in interstate commerce;
(d) All impoundments of waters otherwise defined as waters of the United States under this definition;
(e) Tributaries of waters identified in paragraphs (a) through (d) of this definition;
(f) The territorial sea; and
(g) "Wetlands" adjacent to waters (other than waters that are themselves wetlands) identified in paragraphs (a) through (f) of this definition.
Waste treatment systems, including treatment ponds or lagoons designed to meet the requirements of CWA (other than cooling ponds as defined in 40 CFR 423.11(m) which also meet the criteria of this definition) are not waters of the United States. This exclusion applies only to manmade bodies of water which neither were originally created in waters of the United States (such as disposal area in wetlands) nor resulted from the impoundment of waters of the United States.

Waterway: A channel for the passage or flow of water.

Wet Well: A chamber used to collect water or other liquid and to which a pump is attached.

Wetlands: An area that is regularly saturated by surface or ground water and subsequently is characterized by a prevalence of vegetation that is adapted for life in saturated soil conditions. Examples include: swamps, bogs, fens, marshes, and estuaries.

Wind Break: Any device designed to block wind flow and intended for protection against any ill effects of wind.

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APPENDIX C

MODEL STORM WATER POLLUTION PREVENTION PLAN

R0044096

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Double Scoop Ice Cream Company

40 Wonka Drive
Anytown, OK 12345

December 1992

Storm Water Pollution Prevention Plan	
Emergency Contact: Cheryl Glenn	Work Phone: (101) 555-1234
Title: Plant Manager	Emergency Phone: (101) 555-6929
Secondary Contact: Rachel Meyers	Work Phone: (101) 555-3923
Title: Engineering Supervisor	Emergency Phone: (101) 555-6789
Type of Manufacturer: Ice Cream Manufacturer	
Operating Schedule: 8:00 a.m. - 11:30 p.m.	
Number of Employees: The plant has 21 employees, including part time staff. Shifts overlap all day.	
Average Wastewater Discharge: 5,000 gallons per week	
NPDES Permit Number: OK1234567	

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R0044097

POLLUTION PREVENTION TEAM MEMBER ROSTER	Worksheet #1 Completed by: Cheryl Glenn Title: Plant Manager Date: December 12, 1992

Leader: Cheryl Glenn Title: Plant Manager

Office Phone: (101) 555-1234

Responsibilities: Signatory authority; coordinate all stages of plan development and implementation; coordinate employee training program; keep all records and ensure reports are submitted.

Members:

(1) Stephen Michaels Title: Production Supervisor

Office Phone: (101) 555-3923

Responsibilities: Note any process changes; help conduct inspections.

(2) Rachel Meyers Title: Engineering Dept. Supervisor

Office Phone: (101) 555-5890

Responsibilities: Responsible for implementing the Preventive Maintenance program; oversee inspections

(3) Isaac Feldman Title: Maintenance Dept. Supervisor

Office Phone: (101) 555-0482

Responsibilities: Mr. Feldman is the spill response coordinator; Oversees "good housekeeping."

(4) Group Activities Title:

Office Phone:

Responsibilities: Developing the plan elements, chosing storm water management options.

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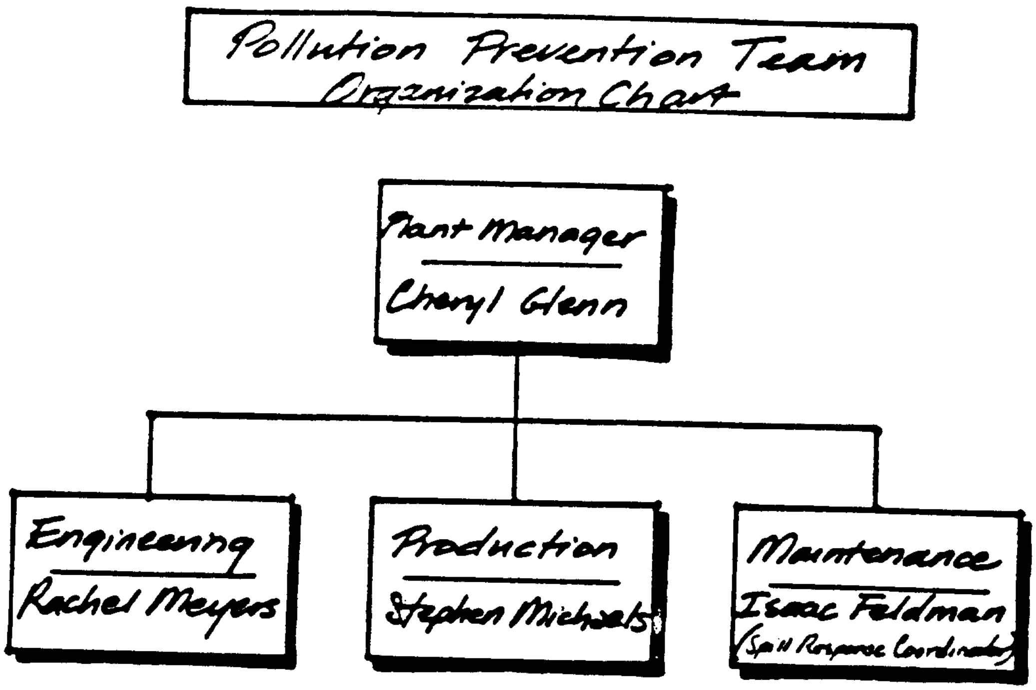
R0044098


Pollution Prevention Team
Organization Chart
Plant Manager
Cheryl Glenn
Engineering
Rachel Meyers
Production
Stephen Michaels
Maintenance
Isaac Feldman
(Spill Response Coordinator)

Double Scoop Ice Cream Company

Storm Water Pollution Prevention Plan
Comparison with SPCC Plan

Double Scoop Ice Cream Plant has an SPCC plan in operation for its aboveground fuel storage tank. Overlaps are noted below:

- Isaac Feldman is the SPCC Coordinator and reports directly to Cheryl Glenn. He will be the Storm Water Spill Prevention and Response Coordinator.
- A complete description of potential for oil to contaminate storm water discharges including quantity of oil that could be discharged.
- Curbing around aboveground fuel storage tank identified on site map.
- Expanded SPCC schedules and procedures to include Storm Water Pollution Prevention Plan requirements.
- Incorporated SPCC plan training into storm water training programs on spill prevention and response.
- Relevant portions of the SPCC plan will be included in this plan.

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DEVELOPING A SITE MAP	Worksheet #2 Completed by: Cheryl Glenn Title: Plant Manager Date: December 12, 1992

Instructions: Draw a map of your site including a footprint of all buildings, structures, paved areas, and parking lots. The information below describes additional elements required by EPA's General Permit (see example maps in Figures 2.3 and 2.4).

EPA's General Permit requires that you indicate the following features on your site map:

- All outfalls and storm water discharges
- Drainage areas of each storm water outfall
- Structural storm water pollution control measures, such as:
  - Flow diversion structures
  - Retention/detention ponds
  - Vegetative swales
  - Sediment traps
- Name of receiving waters (or if through a Municipal Separate Storm Sewer System)
- Locations of exposed significant materials (see Section 2.2.2)
- Locations of past spills and leaks (see Section 2.2.3)
- Locations of high-risk, waste-generating areas and activities common on industrial sites such as:
  - Fueling stations
  - Vehicle/equipment washing and maintenance areas
  - Area for unloading/loading materials
  - Above-ground tanks for liquid storage
  - Industrial waste management areas (landfills, waste piles, treatment plants, disposal areas)
  - Outside storage areas for raw materials, by-products, and finished products
  - Outside manufacturing areas
  - Other areas of concern (specify:________________)

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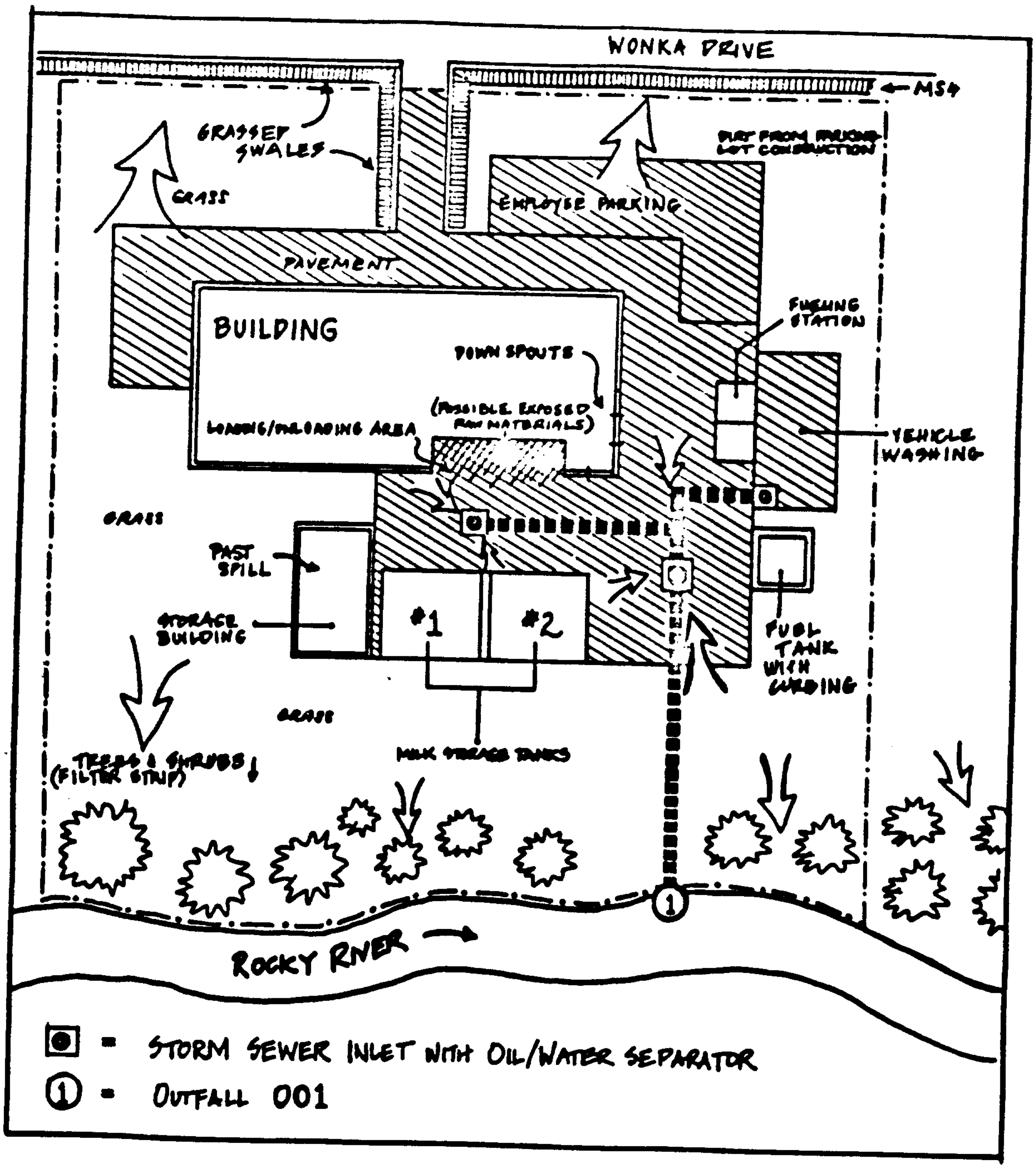
R0044101



DOUBLE SCOOP ICE CREAM COMPANY

PRE-BMP SITE MAP
MARCH 1, 1993

R0044102

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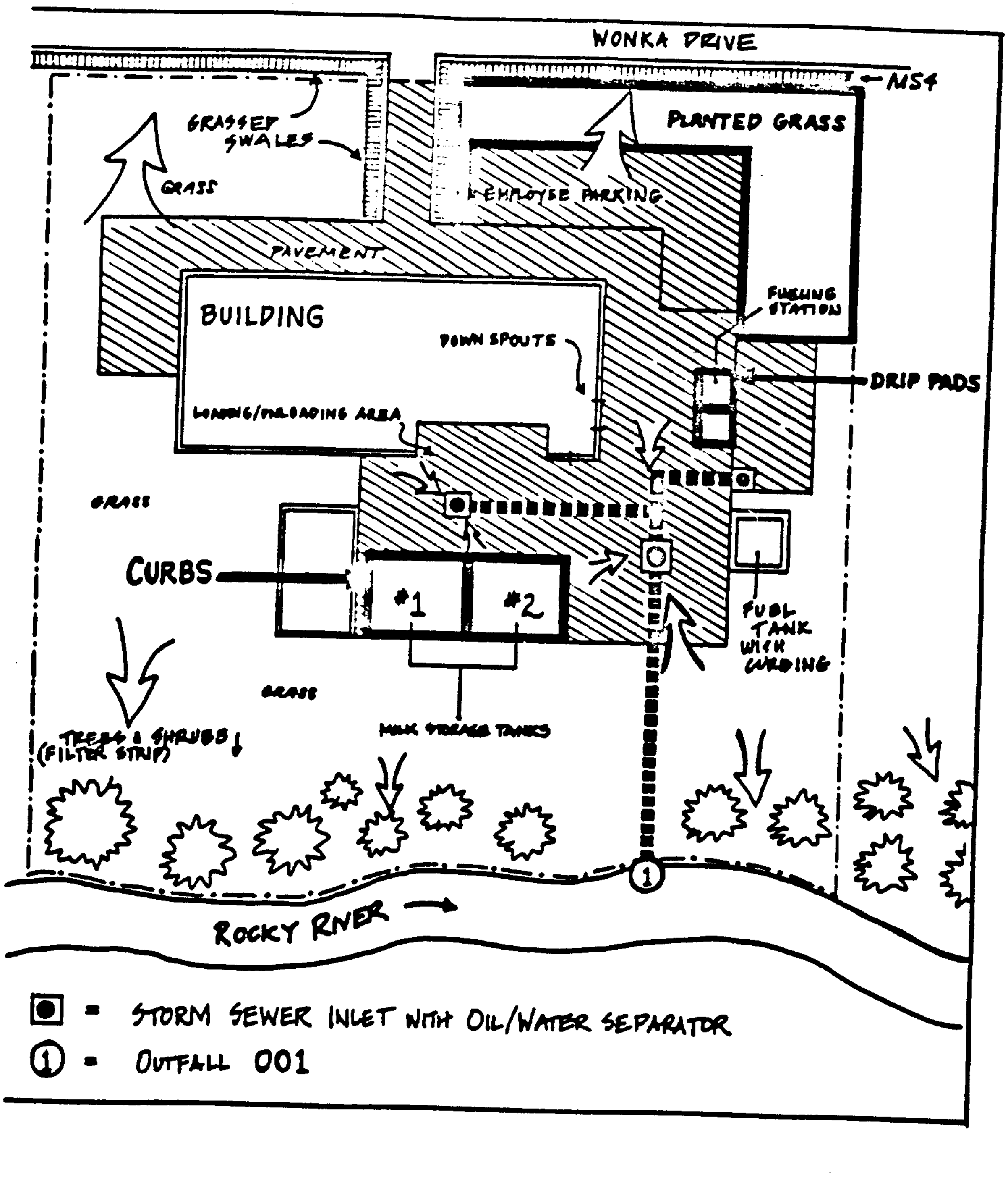

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DOUBLE SCOOP ICE CREAM COMPANY

POST-BMP SITE MAP
MARCH 1, 1993

R0044103

MATERIAL INVENTORY

Worksheet #3
Completed by: Cheryl Glenn
Title: Plant Manager
Date: December 12, 1992

Instructions: List all materials used, stored, or produced onsite. Assess and evaluate these materials for their potential to contribute pollutants to storm water runoff. Also complete Worksheet 3A if the material has been exposed during the last three years.

Material	Purpose/Location	Quantity (units) Used	Quantity (units) Produced	Quantity (units) Stored	Quantity Exposed in Last 3 Years	Likelihood of contact with storm water. If yes, describe reason.	Past Significant Spill or Leak: Yes	Past Significant Spill or Leak: No
Butter fat, Milk solids, Whey solids	truck unloading area during transfer to liquid ingredient storage and milk vat storage.	72,600 gal/wk	—	2,000 gal/wk	NO	Truck loading area outside and possible exposure with ruptured tanks.		✓
Corn Syrup, Liquid sugar	Truck unloading area during transfer to sweetener storage.	7,100 gal/wk	—	—	yes	Truck loading area outside with possible exposure as a result of leaking tanks.	✓	
Ice cream	Inside freezers for final product shipping.		35-40,000 Lbs.		NO	NO		✓
Cleansers:								
Granular Chlorshire-O, H.D.C.-3R, Power Spray-R	Dry cleansers in dry storage area (indoors)	400 lb/wk	—	—	NO	Yes. Possible storage exposure during transfer to dry storage area.		✓

MATERIAL INVENTORY

Page 2

Worksheet #3
Completed by: Cheryl Glenn
Title: Plant Manager
Date: December 12, 1992

Instructions: List all materials used, stored, or produced onsite. Assess and evaluate these materials for their potential to contribute pollutants to storm water runoff. Also complete Worksheet 3A if the material has been exposed during the last three years.

Material	Purpose/Location	Quantity (units) Used	Produced	Stored	Quantity Exposed in Last 3 Years	Likelihood of contact with storm water. If yes, describe reason.	Past Significant Spill or Leak: Yes	No
Cleansers:								
liquid	Cleansers are	100 gal/yr	—	—	NO	Yes-if material tanks		✓
M.R.S.-200-0	stored outside					stored outside.		
Acidize-0	under cover							
Microsan								
Fuels:								
gasoline	above ground	250 gal/yr	—	—	No			✓
motor oil	750 gallon storage tank	20 gal/yr	—	—	NO	Yes - possible exposure		✓
						in the event of		
soaps		40 gal/yr	—	—	No	defective tanks or		✓
detergents						transfer of materials		
						from tanks to containers		

DESCRIPTION OF EXPOSED SIGNIFICANT MATERIAL

Worksheet #3A
Completed by: Cheryl Glenn
Title: Plant Manager
Date: December 12, 1992

Instructions: Based on your material inventory, describe the significant materials that were exposed to storm water during the past three years and/or are currently exposed. For the definition of "significant materials" see Appendix B of the manual.

Description of Exposed Significant Material	Period of Exposure	Quantity Exposed (units)	Location (as indicated on the site map)	Method of Storage or Disposal (e.g., pile, drum, tank)	Description of Material Management Practice (e.g., pile covered, drum sealed)
liquid sugar	1/21/92	10 gal.	Storage building Tank #2	50 gal. tanks (2)	Leak was contained and mopped up. Remainder of liquid sugar transferred to tank that did not have a leaky valve.

LIST OF SIGNIFICANT SPILLS AND LEAKS

Worksheet #4
Completed by: Cheryl Glenn
Title: Plant Manager
Date: December 12, 1992

Directions: Record below all significant spills and significant leaks of toxic or hazardous pollutants that have occurred at the facility in the three years prior to the effective date of the permit.

Definitions: Significant spills include, but are not limited to, releases of oil or hazardous substances in excess of reportable quantities.

1st Year Prior

Date (month/day/year)	Spill	Leak	Location (as indicated on site map)	Description: Type of Material	Description: Quantity	Description: Source, If Known	Description: Reason	Response Procedure: Amount of Material Recovered	Response Procedure: Material No Longer Exposed to Storm Water (True/False)	Preventive Measures Taken
				N	O	N	E			

2nd Year Prior

Date (month/day/year)	Spill	Leak	Location (as indicated on site map)	Description: Type of Material	Description: Quantity	Description: Source, If Known	Description: Reason	Response Procedure: Amount of Material Recovered	Response Procedure: Material No Longer Exposed to Storm Water (True/False)	Preventive Measures Taken
1/21/91		✓	STORAGE BLDG.	LIQUID SUGAR	10 ga.	Tank #2	leaky valve	contained and mopped spill — transferred	true	installing curbing ~~around~~ tank - [illegible] completed • 2/93

3rd Year Prior

Date (month/day/year)	Spill	Leak	Location (as indicated on site map)	Description: Type of Material	Description: Quantity	Description: Source, If Known	Description: Reason	Response Procedure: Amount of Material Recovered	Response Procedure: Material No Longer Exposed to Storm Water (True/False)	Preventive Measures Taken
				N	O	N	E			

R0044107

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NON-STORM WATER DISCHARGE ASSESSMENT AND CERTIFICATION

Worksheet #5
Completed by: Rachel Meyers
Title: Engineering Department Supervisor
Date: 3/1/93

Date of Test or Evaluation	Outfall Directly Observed During the Test (identify as indicated on the site map)	Method Used to Test or Evaluate Discharge	Describe Results from Test for the Presence of Non-Storm Water Discharge	Identify Potential Significant Sources	Name of Person Who Conducted the Test or Evaluation
12/24/92	001	visual inspection	No discharge observed		R. Meyers and S. Goodhope
1/19/93	001	visual inspection	Significant flow; oil	vehicle wash ongoing at time	R. Meyers and S. Goodhope
2/5/93	001	visual inspection	small amount of discharge observed; clear	suspected to be delayed storm water discharge from storm that occurred 2/1/93	R. Meyers and S. Goodhope

*See details in attached field notebook.

CERTIFICATION

I, Cheryl Glenn (responsible corporate official), certify under penalty of law that this document and all attachments were prepared under my direction or supervision in accordance with a system designed to assure that qualified personnel properly gather and evaluate the information submitted. Based on my inquiry of the person or persons who manage the system or those persons directly responsible for gathering the information, the information submitted is, to the best of my knowledge and belief, true, accurate, and complete. I am aware that there are significant penalties for submitting false information, including the possibility of fine and imprisonment for knowing violations.

A. Name & Official Title (type or print): Cheryl Glenn

B. Area Code and Telephone No.: (101) 555-1239

C. Signature: Cheryl Glenn

D. Date Signed: 3/2/93

FIELD NOTEBOOK

for non-storm water discharge inspections

INSPECTION TEAM:
R. Meyers
S. Goodhope

Completed by: Rachel Meyers
Date: 12/24/92
Time: 10:50 am

Time since last rain: 42 hours
Quantity of last rain: 0.12 inches
Flow observed: NO

SIGNATURE: Rachel Meyers

Completed by: Rachel Meyers
Date: 1/19/93
Time: 3:20 pm

Time since last rain: 5 days
Quantity of last rain: 0.5 inches
Flow observed: YES
DESCRIPTION: No odor; clear color (soap suds); oily sheen; some sediment.
Temperature: cold (37.5°F)
Volume: collected ten gallons/minute in buckets
Comments: Vehicle wash ongoing at time of inspection. This was the source of the flow.

SIGNATURE: Rachel Meyers

Completed by: Rachel Meyers
Date: 2/5/93
Time: 12:15 pm.

Time since last rain: 96 hours
Quantity of last rain: 2.5 inches
Flow observed: YES
DESCRIPTION: No odor; clear; some sediments; few small pieces of paper (trash)
Temperature: cold (42.3°F)
Volume: Collected one gallon in 5 minutes.
Comments: We suspect that the flow was left over from storm that occurred on 2/1/93 (4 days ago)

SIGNATURE: Rachel Meyers

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Double Scoop Ice Cream Company

Site Assessment Inspection

February 10, 1993

Evaluate the site for pollutants.

There are five areas where material handling and storage activities take place.

- The storage building contains tanks of corn syrup, liquid sugar, and the granular cleansers. The tanks were examined for possible leaks. We found that the valve on the liquid sugar tank #2 was faulty and had leaked approximately 10 gallons of liquid sugar. Although this leak occurred on 1/21/92, the faulty valve was not discovered until now. All other tanks are secure. Areas around the tanks were swept clean to determine if leaks or spills were prevalent.
- The milk storage tanks were then examined for leaks or exposure. Upon closer examination, it was found that the number 1 tank was leaking a small amount of milk to the drainage system. This leak may be the reason for the high concentration of biochemical oxygen demand found in the sample taken from the storm water discharge. The tank was temporarily fixed to ensure that no further contamination would result. A replacement tank was ordered on February 6, 1993, and was expected to arrive within 5 business days. The milk storage tanks shall be examined on a daily basis to further prevent possible exposure to the storm water collection system and receiving stream.
- We inspected the fueling station to see if there were any leaks. The general area surrounding the fueling station was clean but we observed that gasoline and motor oil falls during fueling. In accordance with standard operating conditions, facility personnel hose down the area during vehicle washing and the drain is connected to the storm sewer. We detected this connection on 1/19/93 during one of the non-storm water discharge assessment visual inspections. Since this discharge is not allowed under our general permit, we are in the process of submitting a separate permit application specifically for the discharge of vehicle wash water.
- We examined the fueling station which is adjacent to the vehicle washing area. Vehicle washing cleaners are used here and any empty or open containers were removed from the area.

- We next looked at the loading and unloading docks where raw materials and various cleansers are delivered. The transfer of goods from incoming trucks to storage areas is a source of pollution. Although no problems were noticed, the pollution prevention team has developed a spill prevention and response plan to clean up spills quickly and report them if necessary.

- The last area we inspected was the runoff field below the employee parking lot. Here we noticed a significant amount of erosion resulting from recent construction to expand the parking lot.

Describe existing management practices.

Grass was lightly planted around the parking lot after recent construction. The fuel storage tank has curbing around it in accordance with our SPCC plan. Also, the maintenance crew regularly picks up trash and empty containers from around the storage tanks, loading and unloading areas, and the vehicle washing areas. Used oils are collected in containers and taken to a recycling facility. In addition, we installed two oil/water separators at the drains into our underground storm sewer leading to the Rocky River. These separators are indicated on the site map.

Double Scoop Ice Cream Company

Existing Monitoring Data

Although our NPDES permit for process wastewater does not require storm water sampling, we sampled our storm water on one occasion in response to a questionnaire we received from the National Association of Ice Cream Makers. They were collecting information to submit as part of their comments on EPA's proposed general permit.

Date of Sampling	8/30/91
Outfall Sampled	001
Type of Storm	1 inch light rainfall (lasted 2 days)
Type of Samples	Grab samples taken during first hour of flow

Data		
Parameter	**Quantity**	**Sample Type**
BOD	250 mg/l	Grab
TSS	100 mg/l	Grab
pH	7.2 s.u.	Grab
Oil and grease	5.0 mg/l	Grab

Based upon the high concentration of BOD in the storm water samples collected, pollution prevention team is considering possible potential sources of BOD. We will look at storage areas housing butter fat, milk, and whey solids tanks.

Double Scoop Ice Cream Company

Summary of Pollutant Sources

March 5, 1993

Based on the site assessment inspection conducted on 12/1/92, the pollution prevention team identified four potential sources of pollutants:

- Oil and grease stains on the pavement in the fueling area indicate oil and grease may be picked up by storm water draining to the storm sewer. This area drains into the storm sewer leading to the Rocky River.
- Sediment and erosion potential in the field below the employee parking lot because of thinly planted grass.
- Potential for spills or leaks from liquid storage tanks, including the fuel storage tank, based on a spill that occurred on 1/21/92 and the leak that was detected in the milk storage tank. These pollutants would drain into the piped outfall into the Rocky River.
- Use of a toxic cleaning agent may result in a pollution problem if handled improperly.

Double Scoop Ice Cream Company

Description of Storm Water Management Measures Taken Based on Site Assessment Phase

March 5, 1993

These measures correspond to the pollutant sources identified on the preceding page.

Oil and grease from fueling area.

We installed drip pads around the fuel pumps to pick up spilled gas and oil during truck refueling. These will be inspected regularly to make sure they are working well.

Sediment and erosion in the field below the employee parking lot.

We planted grass in this area to reduce potential for erosion.

Leaks/spills from liquid storage tanks.

We are in the process of installing curbing around the outdoor liquid storage tanks that will contain the volume of he largest tank in case a spill should occur. The spill response team has developed procedures to clean up this area should a spill occur. We are incorporating spill response procedures from our SPCC plan.

Toxic cleaning agent.

We have discontinued the use of this agent and are replacing it with a non-toxic cleaning agent.

POLLUTANT SOURCE IDENTIFICATION **(Section 2.2.6)**	**Worksheet #7** **Completed by:** Cheryl Glenn **Title:** Plant Manager **Date:** 3/5/93

Instructions: List all identified storm water pollutant sources and describe existing management practices that address those sources. In the third column, list BMP options that can be incorporated into the plan to address remaining sources of pollutants.

Storm Water Pollutant Sources	Existing Management Practices	Description of New BMP Options
1. Oil and grease on pavement in fueling area	Oil and water separators installed in storm water drain	Install drip pads
2. Erosion in field below employee parking lot	Planted some grass after construction; grassed swales along Wonka Drive	Plant more grass
3. Potential for spills from liquid storage tanks (leak detected in milk tank #2 + past spill on 1/21/92)	Curbing around fuel storage tanks (see SPCC plan)	Replace milk tank #2; replace valve on liquid storage tank #2; install curbing around other outside tanks; spill prevention response plans, inspection
4. Use of toxic cleaning agent		Use non-toxic cleaning agent
5. Trash in loading/unloading fueling areas	Regular trash pick up (daily) by maintenance crew; collect and recycle used oil	Train staff in good housekeeping practices
6.		
7.		
8.		
9.		
10.		

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BMP IDENTIFICATION (Section 2.3.1)	Worksheet #7a Completed by: Cheryl Glenn Title: Plant Manager Date: 3/5/93

Instructions: Describe the Best Management Practices that you have selected to include in your plan. For each of the baseline BMPs, describe actions that will be incorporated into facility operations. Also describe any additional BMPs [activity-specific (Chapter 3) and site-specific BMPs (Chapter 4)] that you have selected. Attach additional sheets if necessary.

BMPs	Brief Description of Activities
Good Housekeeping	Collect and recycle used oil; regular trash pick up; train staff in basic clean up procedures (sweeping loading & unloading areas, etc.)
Preventive Maintenance	Daily inspection of outside milk tanks; replace faulty valve on sugar tank #2; replace leaking milk tank #1
Inspections	Daily inspection of outside milk tanks; bi-monthly inspections of drip pads, curbing, loading/unloading areas, grassed areas, drainage system.
Spill Prevention Response	Install curbing around outside liquid storage tanks; fuel tank has curbing; install drip pads at fueling station
Sediment and Erosion Control	Plant grass around new parking area.
Management of Runoff	Grassed swales along Wonka Drive; (2) oil/water separators in storm drain system
Additional BMPs (Activity-specific and Site-specific)	Order non-toxic cleaning agent.

Double Scoop Ice Cream Company

Employee Training Program

Who:

Line Workers
Maintenance Crew
Shipping and Receiving Crew

When:

Employee meetings held the first Monday of each month to discuss:

- Any environmental/health and safety incidents
- Upcoming training sessions
- Brief reminders on good housekeeping, spill prevention and response procedures, and material handling practices
- Announce any changes to the plan
- Announce any new management practices

In-depth pollution prevention training for new employees

Refresher courses held every 6 months (October and March) addressing:

- Good housekeeping
- Spill prevention and response procedures
- Materials handling and storage

Employee Training Program Topics:

Good Housekeeping

- Review and demonstrate basic cleanup (sweeping and vacuuming) procedures.
- Clearly indicate proper disposal locations.
- Post signs in materials handling areas reminding staff of good housekeeping procedures.
- Be sure employees know where routine clean-up equipment is located.

Spill Prevention and Response

- Clearly identify potential spill areas and drainage routes
- Familiarize employees with past spill events -- why they happened and the environmental impact (use slides)
- Post warning signs in spill areas with emergency contacts and telephone numbers
- Introduce Isaac Feldman as the Spill Response Coordinator and introduce his "team"
- Drill on spill clean-up procedures
- Post the locations of spill clean-up equipment and the persons responsible for operating the equipment

Materials Handling and Storage

- Be sure employees are aware which materials are hazardous and where those materials are stored
- Point out container labels
- Tell employees to use the oldest materials first
- Explain recycling practices
- Demonstrate how valves are tightly closed and how drums should be sealed
- Show how to fuel vehicles and avoid "topping off"

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IMPLEMENTATION (Section 2.4.1)	Worksheet #8 Completed by: Cheryl Glenn Title: Plant Manager Date: 3/30/93

Instructions: Develop a schedule for implementing each BMP. Provide a brief description of each BMP, the steps necessary to implement the BMP (i.e., any construction or design), the schedule for completing those steps (list dates) and the person(s) responsible for implementation.

BMPs	Description of Action(s) Required for Implementation	Scheduled Completion Date(s) for Req'd. Action	Person Responsible for Action	Notes
Good Housekeeping	1. Develop training program	3/10/93	Glenn	
	2. Conduct training	6/1/93	Glenn	
	3.			
Preventive Maintenance	1. Replace valve on sugar tank #2	3/1/93	Feldman	
	2. Install new milk tank #2	2/15/93	Feldman	
	3.			
Inspections	1. Develop inspections schedule	4/1/93	Glenn	
	2.			
	3.			
Spill Prevention and Response	1. Install curbing around milk storage tanks	4/30/93	Meyers	
	2. Install drip pads	4/1/93	Feldman	
	3. Develop/Implement Spill Prevention/Response training	4/1/93 - DEVELOP 6/1/93 - TRAIN	Feldman	
Sediment and Erosion Control	1. Plant grass around parking area	4/15/93	Feldman	
	2.			
	3.			
Management of Runoff	1. BMPs already in place			
	2.			
	3.			
Additional BMPs (Actively-specific and site-specific)	1. Substitute non-toxic cleaning agent	2/28/93	Michaels	
	2.			
	3.			

EMPLOYEE TRAINING (Section 2.4.2)	Worksheet #9 Completed by: Cheryl Glenn Title: Plant Manager Date: 3/2/93

Instructions: Describe the employee training program for your facility below. The program should, at a minimum, address spill prevention and response, good housekeeping, and material management practices. Provide a schedule for the training program and list the employees who attend training sessions.

Training Topics	Brief Description of Training Program/Materials (e.g., film, newsletter course)	Schedule for Training (list dates)	Attendees
Spill Prevention and Response	locate spill areas by signs; drill spill response procedures; show slides of past spills.	October/March	Maintenance/shipping & receiving
Good Housekeeping	Demonstration; post signs at disposal sites.	October/March	Maintenance/shipping & receiving
Material Management Practices	introduce hazardous materials labels; discuss recycling.	October/March	Lineworkers/shipping and receiving/maintenance
Other Topics	Environmental/health incidents; Reminders of pollution prevention plan issues.	1st Monday of each month	All employees.

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APPENDIX D

STORM WATER AND POLLUTION PREVENTION CONTACTS AND ADDITIONAL POLLUTION PREVENTION INFORMATION

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STATE STORM WATER AND POLLUTION PREVENTION CONTACTS		
State	Storm Water Contact	Pollution Prevention Contact
*Alabama	John Poole 205-271-7852	Daniel E. Cooper 205-271-7939
Alaska	Michael Menge 907-465-5260	David Wigglesworth 907-465-5275
Arizona	See Region IX Contact	Stephanie Wilson 602-257-2318
*Arkansas	Marysia Jastrzebski 501-562-7444	Robert J. Finn 501-570-2861
*California	Don Parrin 916-657-1288	Kim Wilhelm 916-324-1807
*Colorado	Patricia Nelzon 303-331-4590	Kate Kramer 303-331-4510
*Connecticut	Dick Mason 203-566-7167	Rita Lomasney (ConnTap) 203-241-0777
*Delaware	Sarah Cooksey 302-739-5731	Andrea Farrell 302-739-3822
District of Columbia	James Collier 202-404-1120	Hampton Cross 202-939-7116
Florida	Eric Livingston 904-488-0782	Janet A. Campbell 904-488-0300
*Georgia	Mike Creason 404-656-4887	Susan Hendricks 404-656-2833
*Hawaii	Steve Chang 808-586-4309	Jane Dewell 808-586-4226
Idaho	Jerry Yoder 208-334-5898	Joy Palmer 208-334-5879
*Illinois	Tim Kluge 217-782-0610	Mike Hayes 217-782-8700
*Indiana	Lonnie Brumfield 317-232-8705	Joanna Joyce 317-232-8172
*Iowa	Monica Wnuk 515-281-7017	John Konefes 319-273-2079
*Kansas	Don Carlson 913-296-5555	Tom Gross 913-296-1603
*Kentucky	Douglas Allgeier 502-564-3410	Joyce St. Clair 502-588-7260

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STATE STORM WATER AND POLLUTION PREVENTION CONTACTS		
State	Storm Water Contact	Pollution Prevention Contact
Louisiana	Jim Delahoussaye 504-765-0525	Gary Johnson 504-765-0720
Maine	Norm Marcotte 207-289-3901	Scott Whittier 207-289-2651
*Maryland	Vince Berg 410-631-3553	Harry Benson 301-631-3315
Massachusetts	Cynthia Hall 617-292-5656	Barbara Kelly 617-727-3260
*Michigan	Gary Boersen 517-373-1982	Larry E. Hartwig 517-335-1178
*Minnesota	Scott Thompson 612-296-7203	Cindy McComas (MNTAP) 612-296-4646
*Mississippi	Jerry Cain 601-961-5171	Caroline Hill 601-325-8454
*Missouri	Bob Hentges 314-751-6825	Becky Shannon 314-751-3176
*Montana	Fred Shewman 406-444-2406	Bill Potts 406-444-2821
*Nebraska	Clark Smith 402-471-4239	Teri Swarts 402-471-4217
*Nevada	Rob Saunders 702-687-4670	Kevin Dick 702-784-1717
New Hampshire	Jeff Andrews 603-271-2457	Vincent R. Perelli 603-271-2902
*New Jersey	Sandra Cohen 609-633-7021	Jean Herb 609-777-0518
New Mexico	Glen Saums 505-827-2827	Alex Puglisi 505-827-2804
*New York	Ken Stevens 518-457-1157	John Ianotti 518-457-7267
*North Carolina	Coleen Sullins 919-733-5083	Gary Hunt 919-571-4100
*North Dakota	Sheila McClenatahan 701-221-5210	Neil Knatterud 703-221-5166
*Ohio	Robert Phelps 614-644-2034	Mike Kelly 614-644-3492

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STATE STORM WATER AND POLLUTION PREVENTION CONTACTS		
State	Storm Water Contact	Pollution Prevention Contact
Oklahoma	Brooks Kirlin 504-231-2500	Chris Varga 405-271-7047
*Oregon	Ranei Nomura 503-229-5256	Roy W. Brower 503-229-6585
*Pennsylvania	R.B. Patel 717-787-8184	Greg Harder 717-772-2724
*Rhode Island	Ed Symanski 401-244-3931	Janet Keller 401-277-3434
*South Carolina	Brigit McDade 803-734-5300	Jeffrey DeBossonet 803-734-4715
South Dakota	Glenn Pieritz 605-773-3351	Vonnie Kallmeyn 605-773-3153
*Tennessee	Robert Haley 615-741-2275	James Ault 615-742-6547
Texas	Randy Wilburn 512-463-8446	Priscilla Seymour 512-463-7761
*Utah	Harry Campbell 801-538-6146	Sonja Wallace 801-538-6170
*Vermont	Brian Kooiker 802-244-5674	Gary Gulka 802-244-8702
*Virgin Islands	Marc Pacifico 809-773-0565	See Region II Contact
*Virginia	Martin Ferguson, Jr. 804-527-5030	Sharon Kenneally-Baxter 804-371-8716
*Washington	Peter Birch 206-438-7076	Stan Springer 206-438-7541
*West Virginia	Jerry Ray 304-348-0375	Dale Moncer 304-348-4000
*Wisconsin	Ann Mauel 608-267-7634	Lynn Persson 608-267-3763
*Wyoming	John Wagner 307-777-7082	David Finley 307-777-7752

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EPA REGIONAL STORM WATER AND POLLUTION PREVENTION CONTACTS		
State	**Storm Water Contact**	**Pollution Prevention Contact**
REGION I	Veronica Harrington 617-565-3525	Mark Mahoney 617-565-1155
REGION II	Jose Rivera 212-264-2911	Janet Sapadin 212-264-1925
REGION III	Kevin Magerr 215-597-1651	Roy Denmark 215-597-8327
REGION IV	Roosevelt Childress 404-347-3379	Carol Monell 404-347-7109
REGION V	Peter Swenson 312-886-0236	Louis Blume 312-353-4135
REGION VI	Brent Larsen 214-655-7175	Laura Townsend 214-655-6525
REGION VII	Ralph Summers 913-551-7418	Alan Wehmeyer 913-551-7336
REGION VIII	Vern Berry 303-293-1630	Sharon Childs 303-293-1456
REGION IX	Eugene Bromley 415-744-1906	Jesse Baskir 415-744-2189
REGION X	Steve Bubnick 206-553-8399	Carolyn Gangmark 206-553-4072

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ADDITIONAL POLLUTION PREVENTION INFORMATION

State pollution prevention programs have people who are knowledgeable about pollution prevention and are willing to provide information and sometimes technical assistance on pollution prevention. The EPA has pollution prevention experts located in a number of different program offices, laboratories, and EPA Regional offices. These experts can provide information on starting a pollution prevention program or on specific waste reduction BMPs. This Appendix lists State and Federal pollution prevention contacts above. Trade associations are another good source of pollution prevention information. Trade associations can often provide you with pollution prevention assistance directly or refer you to someone who can.

A comprehensive listing of pollution prevention resources, documents, courses, and programs, including names and phone numbers, is contained in a new annual EPA publication. Copies of this document -- *Pollution Prevention Training Opportunities in 1992* -- may be obtained by calling the PPIC/PIES support number at (703) 821-4800.

One good source of information on pollution prevention is EPA's Pollution Prevention Information Clearinghouse (PPIC). PPIC contains technical, policy, programmatic, legislative, and financial information on pollution prevention efforts in the United States and abroad. The PPIC may be reached by personal computer modem, telephone hotline, or mail. The PIES, or Pollution Prevention Information Exchange System, is a free 24-hour electronic bulletin board consisting of message centers, technical data bases, issue-specific "mini-exchanges," and a calendar of pollution prevention events. The PIES allows a user to access the full range of infirmation in the PPIC. For information on how to use the PPIC/PIES, call (703) 821-4800. To log on to the PIES system using a modem and a PC, call (703) 506-1025 (set your communication software at 8 bits and no parity).

EPA and State programs have developed manuals and fact sheets containing specific pollution prevention information. These manuals and fact sheets listed below can be ordered free of charge by calling the EPA Pollution Prevention Information Clearinghouse at (703) 821-4800.

INDUSTRY-SPECIFIC POLLUTION PREVENTION GUIDANCE MANUALS AVAILABLE FROM THE PPIC

Guides to Pollution Prevention:	*Automotive Refinishing Industry*	EPA/625/7-91/016
Guides to Pollution Prevention:	*Auto Repair Industry*	EPA/625/7-91/013
Guides to Pollution Prevention:	*The Commercial Printing Industry*	EPA/625/7-90/008
Guides to Pollution Prevention:	*The Fabricated Metal Industry*	EPA/625/7-90/006
Guides to Pollution Prevention:	*Fiberglass Reinforced and Composite Plastics*	EPA/625/7-91/014
Guides to Pollution Prevention:	*Marine Maintenance and Repair*	EPA/625/7-91/015
Guides to Pollution Prevention:	*The Paint Manufacturing Industry*	EPA/625/7-90/005
Guides to Pollution Prevention:	*The Pesticide Formulating Industry*	EPA/625/7-90/004
Guides to Pollution Prevention:	*Pharmaceutical Preparation*	EPA/625/7-91/017
Guides to Pollution Prevention:	*Photoprocessing Industry*	EPA/625/7-91/012
Guides to Pollution Prevention:	*The Printed Circuit Board Manufacturing Industry*	EPA/625/7-90/00
Guides to Pollution Prevention:	*Research and Educational Institutions*	EPA/625/7-90/010
Guides to Pollution Prevention:	*Selected Hospital Waste Streams*	EPA/625/7-90-009

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FACT SHEETS AVAILABLE FROM PPIC

General/Introductory Information

- Conservation Tips for Business
- General Guidelines
- Getting More Use Out of What We Have
- Glossary of Waste Reduction Terms
- Guides to Pollution Prevention
- Hazardous Waste Fact Sheet for Minnesota Generators
- Hazardous Waste Minimization
- How Business Organizations Can Help
- Increase Your Corporate and Product Image
- Industrial Hazardous Wastes in Minnesota
- Local Governments and Pollution Prevention
- Pollution Prevention (General)
- Pollution Prevention Fees
- Pollution Prevention Training and Education
- Pollution Prevention Through Waste Reduction
- Recent Publications
- Reduce Hazardous Waste
- Reuse Strategies for Local Government
- Source Reduction Techniques for Local Government
- U.S. EPA's Pollution Prevention Program
- Video Tapes Available from the Virginia Waste Minimization Program
- Waste Exchange: Everybody Wins!
- Waste Exchange Services
- Waste Minimization Fact Sheet
- Waste Minimization in the Workplace
- Waste Reduction Can Work For You
- Waste Reduction Overview
- Waste Reduction/Pollution Prevention: Getting Started
- Waste Reduction Tips for All Businesses
- Waste Source Reduction Checklist
- What is Pollution Prevention?
- Why Reduce Waste?

Legislative Information/ EPA and State Initiatives

- About Minnesota's "But Recycled Campaign"
- Alaska State Agency Waste Reduction and Recycling
- EPA's 2% Set Aside Pollution Prevention Projects
- EPA's "List of Lists" Projects
- EPA's Pollution Prevention Enforcement Settlement Policy
- EPA's Pollution Prevention Incentives for States
- EPA's Pollution Prevention Strategy
- Introducing the Colorado Pollution Prevention Program
- Michigan's Solid Waste Reduction Strategy
- Minnesota's Toxic Pollution Prevention Act
- New Form R Reporting Requirements
- Oregon's Toxic Use Reduction Act
- Pollution Prevention Act of 1990
- Promoting Pollution Prevention in Minnesota State Government

Setting Up A Program

- 1991 Small Business Pollution Prevention Grants
- An Organization Strategy for Pollution Prevention
- Considerations in Selecting a Still for Onsite Recycling
- Colorado Technical Information Center
- Onsite Assistance (Colorado only)
- Pollution Prevention Grant Program Summaries and Reports
- Procuring Recycled Products
- Recycling Market Development Program
- Selecting a Supplier, Hauler, and Materials Broker
- Solid Waste Management Financial Assistance Program
- Source Reduction at Your Facility
- Starting Your Own Waste Reduction Program
- The Alexander Motor's Success Story
- The Eastside Plating Success Story
- The Tektronics Payoff
- The Wacker Payoff
- Waste Reduction Checklists:
  - General
  - Cleaning
  - Coating/Painting
  - Formulating
  - Machining
  - Operating Procedures
  - Plating/Metal Finishing
- Waste Source Reduction: Implementing a Program

Process/Material Specific

- Aerosol Containers
- Aircraft Rinsewater Disposal
- Acids/Bases
- Chemigation Practices to Prevent Ground Water Contamination
- Corrugated Cardboard Waste Reduction
- Demolition
- Empty Containers
- Gunwasher Maintenance
- Lead Acid Batteries
- Machine Coolants:
  - Prolonging Coolant Life
  - Waste Reduction
- Metal Recovery:
  - Dragout Reduction
  - Ion Exchange/Electrolytic Recovery
  - Etchant Substitution
- Metals Recycling
- Office Paper Waste Reduction
- Old Paints, Inks, Residuals, and Related Materials
- Pesticides:
  - Disposal of Unused Pesticides, Tank Mixes, and Rinsewater
  - In-Filled Sprayer Rinse System to Reduce Pesticide Wastes
  - Pesticide Container Disposal
  - Preventing Pesticide Pollution of Surface and Ground Water

- Preventing Well Contamination by Pesticides
- Protecting Mountain Springs from Pesticide Contamination
- Reducing and Saving Money Using Integrated Pest Management

- Plastics:
  - The Facts About Production, Use, and Disposal
  - The Facts on Degradable Plastics
  - The Facts on Recycling Plastics
  - The Facts on Source Reduction
- Printing Equipment
- Refrigerant Reclamation Equipment/ Services
- Reverse Osmosis
- Safety Kleen, Inc., Users
- Shop Rags from Printers
- Small Silver Recovery Units
- Solvents:
  - Alternatives to CFC-113 Used in the Cleaning of Electronic Circuit Boards
  - Onsite Solvent Reclamation
  - Reducing Shingle Waste at a Manufacturing Facility
  - Reducing Solvent Emissions from Vapor Degreasers
  - Small Solvent Recovery Systems
  - Solvent Loss Control
  - Solvent Management: Printing Press
  - Solvent Recovery: Fiber Production Plant
  - Solvent Reduction in Metal Parts Cleaning
  - Solvent Reuse: Technical Institute
  - Trichloroethylene and Stoddard Solvent Reduction Alternatives
- Ultrafiltration
- Used Containers: Management
- Used Oil Recycling
- Waste Management Guidance for Oil Clean-Up
- Water and Chemical Reduction for Cooling Towers
- Waste Water Treatment Opportunities

Industry-Specific Information

- Aerospace Industry
- Auto Body Shops
- Automotive Painting
- Automotive/Vehicle Repair Shops
- Auto Salvage Yards
- Asbestos Handling, Transport, and Disposal
- Chemical Production
- Coal Mining
- Concrete Panel Manufacturers
- Dairy Industry:
  - Cut Waste and Reduce Surcharges for Your Dairy Plant
  - Dairy CEOs: Do You Have a $500 Million Opportunity?
  - Liquid Assets for Your Dairy Plant
  - Water and Wastewater Management in a Dairy Processing Plant
- Dry Cleaners
- Electrical Power Generators

- Electroplating Industry:
  - Dragout Management for Electroplaters
  - Plating with Trivalent Chrome Instead of Cr+6
  - Water Conservation Using Counter Current Rinsing
  - Water Conservation: Tank Design
  - Water Conservation: Rinsewater Reuse
  - What Should I Do With My Electroplating Sludge?
- Fabricated Metal Manufacturers
- Fiberglass Fabricators: Volatile Emissions Reduction
- Machine Toolers
- Metal Finishers:
  - General
  - Effluent Minimization
  - Rinsewater Reduction
- Oil Refiners
- Paint Formulators
- Paper Manufacturers
- Pesticide Formulating Industry
- Photofinishers/Photographic Processors
- Poultry Industry:
  - Poultry CEOs: You May Have a $60 Million Opportunity
  - Poultry Processors: You Can Reduce Waste Load and Cut Sewer Surcharges
  - Survey Shows That Poultry Processors Can Save Money By Conserving Water
  - Systems for Recycling Water in Poultry Processing
- Printed Circuit Board Manufacturers
- Printing Industry
- Radiator Service Firms
- Shrimp Processors
- Steel Manufacturers
- Textile Industry:
  - Dye Bath and Bleach Bath Reconstitution
  - Water Conservation
- Wire Milling Operations: Process Water Reduction

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APPENDIX E

BMP FACT SHEETS

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SILT FENCE

September 1992

Design Criteria

- Silt fences are appropriate at the following general locations:
  - Immediately upstream of the point(s) of runoff discharge from a site before flow becomes concentrated (maximum design flow rate should not exceed 0.5 cubic feet per second).
  - Below disturbed areas where runoff may occur in the form of overland flow.
- Ponding should not be allowed behind silt fences since they will collapse under high pressure; the design should provide sufficient outlets to prevent overtopping.
- The drainage area should not exceed 0.25 acre per 100 feet of fence length.
- For slopes between 50:1 and 5:1, the maximum allowable upstream flow path length to the fence is 100 feet; for slopes of 2:1 and steeper, the maximum is 20 feet.
- The maximum upslope grade perpendicular to the fence line should not exceed 1:1.
- Synthetic silt fences should be designed for 6 months of service; burlap is only acceptable for periods of up to 60 days.

Materials

- Synthetic filter fabric should be a pervious sheet of polypropylene, nylon, polyester, or polyethylene yarn conforming to the requirements in Table 1 below.

TABLE 1. SYNTHETIC FILTER FABRIC REQUIREMENTS

Physical Property	Requirements
Filtering Efficiency	75% - 85% (minimum)
Tensile Strength at 20% (maximum) Elongation	Standard Strength - 30 lb/linear inch (minimum)
	Extra Strength - 50 lb/linear inch (minimum)
Slurry Flow Rate	0.3 gal/ft²/min (minimum)

- Synthetic filter fabric should contain ultraviolet ray inhibitors and stabilizers to provide a minimum of 6 months of expected usable construction life at a temperature range of 0 to 120°F.
- Burlap of 10 ounces per square yard of fabric can also be used.
- The filter fabric should be purchased in a continuous roll to avoid joints.
- While not required, wire fencing may be used as a backing to reinforce standard strength filter fabric. The wire fence (14 gauge minimum) should be at 22-48 inches wide and should have a maximum mesh spacing of 6 inches.
- Posts should be 2-4 feet long and should be composed of either 2" x 2-4" pine (or equivalent) or 1.00 to 1.33 lb/linear ft steel. Steel posts should have projections for fastening wire and fabric to them.

Construction Specifications

- The maximum height of the filter fence should range between 18 and 36 inches above the ground surface (depending on the amount of upslope ponding expected).

- Posts should be spaced 8 to 10 feet apart when a wire mesh support fence is used and no more than 6 feet apart when extra strength filter fabric (without a wire fence) is used. The posts should extend 12 to 30 inches into the ground.
- A trench should be excavated 4 to 8 inches wide and 4 to 12 inches deep along the upslope side of the line of posts.
- If standard strength filter fabric is to be used, the optional wire mesh support fence may be fastened to the upslope side of the posts using 1 inch heavy duty wire staples, tie wires, or hog rings. Extend the wire mesh support to the bottom of the trench. The filter fabric should then be stapled or wired to the fence, and 8 to 20 inches of the fabric should extend into the trench (Figure 1).
- Extra strength filter fabric does not require a wire mesh support fence. Staple or wire the filter fabric directly to the posts and extend 8 to 20 inches of the fabric into the trench (Figure 1).
- Where joints in the fabric are required, the filter cloth should be spliced together only at a support post, with a minimum 6-inch overlap, and securely sealed.
- Do not attach filter fabric to trees.
- Backfill the trench with compacted soil or 0.75 inch minimum diameter gravel placed over the filter fabric.

Maintenance

- Inspect filter fences daily during periods of prolonged rainfall, immediately after each rainfall event, and weekly during periods of no rainfall. Make any required repairs immediately.
- Sediment must be removed when it reaches one-third to one-half the height of the filter fence. Take care to avoid damaging the fence during cleanout.
- Filter fences should not be removed until the upslope area has been permanently stabilized. Any sediment deposits remaining in place after the filter fence has been removed should be dressed to conform with the existing grade, prepared, and seeded.

Cost

- Silt fence installation costs approximately $6.00 per linear foot.

Sources

- Commonwealth of Virginia - County of Fairfax, 1987. 1987 Check List For Erosion And Sediment Control - Fairfax County, Virginia.
- State of North Carolina, 1988. Erosion and Sediment Control Planning and Design Manual. North Carolina Sedimentation Control Commission, Department of Natural Resources and Community Development.
- Maryland Department of the Environment, 1991. 1991 Maryland Standards And Specifications For Soil Erosion And Sediment Control - Draft.

Design Criteria

- Pipe Slope Drains (PSD) are appropriate in the following general locations:
  - On cut or fill slopes before permanent storm water drainage structures have been installed.
  - Where earth dikes or other diversion measures have been used to concentrate flows.
  - On any slope where concentrated runoff crossing the face of the slope may cause gullies, channel erosion, or saturation of slide-prone soils.
  - As an outlet for a natural drainageway.
- The drainage area may be up to 10 acres; however, many jurisdictions consider 5 acres the recommended maximum.
- The PSD design should handle the peak runoff for the 10-year storm. Typical relationships between area and pipe diameter are shown in Table 2 below.

TABLE 2. RELATIONSHIP BETWEEN AREA AND PIPE DIAMETER

Maximum Drainage Area (Acres)	Pipe Diameter (D) (Inches)
0.5	12
0.75	15
1.0	18

Materials

- Pipe may be heavy duty flexible tubing designed for this purpose, e.g., nonperforated, corrugated plastic pipe, corrugated metal pipe, bituminous fiber pipe, or specially designed flexible tubing.
- A standard flared end section secured with a watertight fitting should be use for the inlet. A standard T-section fitting may also be used.
- Extension collars should be 12-inch long sections of corrugated pipe. All fittings must be watertight.

Construction Specifications

- Place the pipe slope drain on undisturbed or well-compacted soil.
- Soil around and under the entrance section must be hand-tamped in 4-inch to 8-inch lifts to the top of the dike to prevent piping failure around the inlet.
- Place filter cloth under the inlet and extend 5 feet in front of the inlet and be keyed in 6-inches on all sides to prevent erosion. A 6-inch metal toe plate may also be used for this purpose.
- Ensure firm contact between the pipe and the soil at all points by backfilling around and under the pipe with stable soil material hand compacted in lifts of 4-inches to 8-inches.
- Securely stake the PSD to the slope using grommets provided for this purpose at intervals of 10 feet or less.
- Ensure that all slope drain sections are securely fastened together and have watertight fittings.

- Extend the pipe beyond the toe of the slope and discharge at a nonerosive velocity into a stabilized area (e.g., rock outlet protection may be used) or to a sedimentation trap or pond.
- The PSD should have a minimum slope of 3 percent or steeper.
- The height at the centerline of the earth dike should range from a minimum of 1.0 foot over the pipe to twice the diameter of the pipe measured from the invert of the pipe. It should also be at least 6 inches higher than the adjoining ridge on either side.
- At no point along the dike will the elevation of the top of the dike be less than 6 inches higher than the top of the pipe.
- Immediately stabilize all areas disturbed by installation or removal of the PSD.

Maintenance

- Inspect regularly and after every storm. Make any necessary repairs.
- Check to see that water is not bypassing the inlet and undercutting the inlet or pipe. If necessary, install headwall or sandbags.
- Check for erosion at the outlet point and check the pipe for breaks or clogs. Install additional outlet protection if needed and immediately repair the breaks and clean any clogs.
- Do not allow construction traffic to cross the PSD and do not place any material on it.
- If a sediment trap has been provided, clean it out when the sediment level reaches 1/3 to 1/2 the design volume.
- The PSD should remain in place until the slope has been completely stabilized or up to 30 days after permanent slope stabilization.

Cost

- Pipe slope drain costs are generally based upon the pipe type and size (generally, flexible PVC at $5.00 per linear foot). Also adding to this cost are any expenses associated with inlet and outlet structures.

Sources

- Commonwealth of Virginia - County of Fairfax, 1987. 1987 Check List For Erosion And Sediment Control - Fairfax County, Virginia.
- State of North Carolina, 1988. Erosion and Sediment Control Planning and Design Manual. North Carolina Sedimentation Control Commission, Department of Natural Resources and Community Development.
- Maryland Department of the Environment, 1991. 1991 Maryland Standards And Specifications For Soil Erosion And Sediment Control - Draft.
- Storm Water Management Manual for the Puget Sound Basin. State of Washington, Department of Ecology, 1991.
- Cost Data:
  - Draft Sediment and Erosion Control, An Inventory of Current Practices, April 20, 1990. Prepared by Kamber Engineering for the U.S. Environmental Protection Agency, Office of Water Enforcement and Permits, Washington, D.C. 20460.

FILTER FABRIC INLET PROTECTION

September 1992

Design Criteria

- Inlet protection is appropriate in the following locations:
  - In small drainage areas (less than 1 acre) where the storm drain inlet is functional before the drainage area has been permanently stabilized.
  - Where there is danger of sediment silting in an inlet which is in place prior to permanent stabilization.

- Filter fabric inlet protection is appropriate for most types of inlets where the drainage area is one acre or less.
- The drainage area should be fairly flat with slopes of 5.. or less and the area immediately surrounding the inlet should not exceed a slope of 1%.
- Overland flow to the inlet should be no greater than 0.5 cfs.
- This type of inlet protection is not appropriate for use in paved areas because the filter fabric requires staking.
- To avoid failure caused by pressure against the fabric when overtopping occurs, it is recommended that the height of the filter fabric be limited to 1.5 feet above the crest of the drop inlet.
- It is recommended that a sediment trapping sump of 1 to 2 feet in depth with side slopes of 2:1 be provided.

Materials

- Filter fabric (see the fabric specifications for silt fence).
- Wooden stakes 2" x 2" or 2"x 4" with a minimum length of 3 feet.
- Heavy-duty wire staples at least ½ inch in length.
- Washed gravel ¾ inches in diameter.

Construction Specifications

- Place a stake at each corner of the inlet and around the edges at no more than 3 feet apart. Stakes should be driven into the ground 18 inches or at a minimum 8 inches.
- For stability a framework of wood strips should be installed around the stakes at the crest of the overflow area 1.5 feet above the crest of the drop inlet.
- Excavate a trench of 8 inches to 12 inches in depth around the outside perimeter of the stakes. If a sediment trapping sump is being provided then the excavation may be as deep as 2 feet.
- Staple the filter fabric to the wooden stakes with heavy-duty staples, overlapping the joints to the next stake. Ensure that between 12 inches to 32 inches of filter fabric extends at the bottom so it can be formed into the trench.
- Place the bottom of the fabric in the trench and backfill the trench all the way around using washed gravel to a minimum depth of 4 inches.

Maintenance

- Inspect regularly and after every storm. Make any repairs necessary to ensure the measure is in good working order.
- Sediment should be removed and the trap restored to its original dimensions when sediment has accumulated to ½ the design depth of the trap.
- If the filter fabric becomes clogged it should be replaced immediately.
- Make sure that the stakes are firmly in the ground and that the filter fabric continues to be securely anchored.
- All sediments removed should be properly disposed.
- Inlet protection should remain in place and operational until the drainage area is completely stabilized or up to 30 days after the permanent site stabilization is achieved.

Cost

- The cost of storm drain inlet protection varies dependent upon the size and type of inlet to be protected but generally is about $300.00 per inlet.

Sources

- Commonwealth of Virginia - County of Fairfax, 1987. 1987 Check List For Erosion And Sediment Control - Fairfax County, Virginia.
- State of North Carolina, 1988. Erosion and Sediment Control Planning and Design Manual. North Carolina Sedimentation Control Commission, Department of Natural Resources and Community Development.
- Maryland Department of the Environment, 1991. 1991 Maryland Standards And Specifications For Soil Erosion And Sediment Control - Draft.
- Storm Water Management Manual for the Puget Sound Basin. State of Washington, Department of Ecology, 1991.
- Cost Data:
  - Draft Sediment and Erosion Control, An Inventory of Current Practices, April 20, 1990. Prepared by Kamber Engineering for the U.S. Environmental Protection Agency, Office of Water Enforcement and Permits, Washington, D.C. 20460.

EXCAVATED GRAVEL INLET PROTECTION

September 1992

Design Criteria

- Inlet protection is appropriate in the following locations:
  - In small drainage areas (less than 1 acre) where the storm drain inlet is functional before the drainage area has been permanently stabilized.
  - Where there is danger of sediment silting in an inlet which is in place prior to permanent stabilization.
  - Where ponding around the inlet structure could be a problem to traffic on site.
- Excavated gravel and mesh inlet protection may be used with most inlets where overflow capability is needed and in areas of heavy flows, 0.5 cfs or greater.
- The drainage area should not exceed 1 acre.
- The drainage area should be fairly flat with slopes of 5% or less.
- The trap should have a sediment trapping sump of 1 to 2 feet measured from the crest of the inlet. Side slopes should be 2:1. The recommended volume of excavation is 35 yd^3/acre disturbed.
- To achieve maximum trapping efficiency the longest dimension of the basin should be oriented toward the longest inflow area.

Materials

- Hardware cloth or wire mesh with ½ inch openings.
- Filter fabric (see the fabric specifications for silt fence).
- Washed gravel ¾ inches to 4 inches in diameter.

Construction Specifications

- Remove any obstructions to excavating and grading. Excavate sump area, grade slopes and properly dispose of soil.
- The inlet grate should be secured to prevent seepage of sediment laden water.
- Place wire mesh over the drop inlet so that the wire extends a minimum of 1 foot beyond each side of the inlet structure. Overlap the strips of mesh if more than one is necessary.
- Place filter fabric over the mesh extending it at least 18 inches beyond the inlet opening on all sides. Ensure that weep holes in the inlet structure are protected by filter fabric and gravel.
- Place stone-gravel over the fabric/wire mesh to a depth of at least 1 foot.

Maintenance

- Inspect regularly and after every storm. Make any repairs necessary to ensure the measure is in good working order.
- Sediment should be removed and the trap restored to its original dimensions when sediment has accumulated to ½ the design depth of the trap.
- Clean or remove and replace the stone filter or filter fabric if they become clogged.
- Inlet protection should remain in place and operational until the drainage area is completely stabilized or up to 30 days after the permanent site stabilization is achieved.

Cost

- The cost of storm drain inlet protection varies dependent upon the size and type of inlet to be protected but generally is about $300.00 per inlet.

Sources

- Commonwealth of Virginia - County of Fairfax, 1987. 1987 Check List For Erosion And Sediment Control - Fairfax County, Virginia.
- State of North Carolina, 1988. Erosion and Sediment Control Planning and Design Manual. North Carolina Sedimentation Control Commission, Department of Natural Resources and Community Development.
- Maryland Department of the Environment, 1991. 1991 Maryland Standards And Specifications For Soil Erosion And Sediment Control - Draft.
- Storm Water Management Manual for the Puget Sound Basin. State of Washington, Department of Ecology, 1991.
- Cost Data:
  - Draft Sediment and Erosion Control, An Inventory of Current Practices, April 20, 1990. Prepared by Kamber Engineering for the U.S. Environmental Protection Agency, Office of Water Enforcement and Permits, Washington, D.C. 20460.

BLOCK AND GRAVEL INLET PROTECTION

September 1992

Design Criteria

- Inlet protection is appropriate in the following locations:
  - In drainage areas (less than 1 acre) where the storm drain inlet is functional before the drainage area has been permanently stabilized.
  - Where there is danger of sediment silting in an inlet which is in place prior to permanent stabilization.
- Block and gravel inlet protection may be used with most types of inlets where overflow capability is needed and in areas of heavy flows 0.5 cfs or greater.
- The drainage area should not exceed 1 acre.
- The drainage area should be fairly flat with slopes of 5% or less.
- To achieve maximum trapping efficiency the longest dimension of the basin should be oriented toward the longest inflow area.
- Where possible the trap should have sediment trapping sump of 1 to 2 feet in depth with side slopes of 2:1.
- There are several other types of inlet protection also used to prevent siltation of storm drainage systems and structures during construction, they are:
  - Filter Fabric Inlet Protection
  - Excavated Gravel Inlet Protection

Materials

- Hardware cloth or wire mesh with ½ inch openings
- Filter fabric (see the fabric specifications for silt fence)
- Concrete block 4 inches to 12 inches wide.
- Washed gravel ¾ inches to 4 inches in diameter

Construction Specifications

- The inlet grate should be secured to prevent seepage of sediment laden water.
- Place wire mesh over the drop inlet so that the wire extends a minimum of 12 inches to 18 inches beyond each side of the inlet structure. Overlap the strips of mesh if more than one is necessary.
- Place filter fabric (optional) over the mesh and extend it at least 18 inches beyond the inlet structure.
- Place concrete blocks over the filter fabric in a single row lengthwise on their sides along the sides of the inlet. The foundation should be excavated a minimum of 2 inches below the crest of the inlet and the bottom row of blocks should be against the edge of the structure for lateral support.
- The open ends of the block should face outward not upward and the ends of adjacent blocks should abut. Lay one block on each side of the structure on its side to allow for dewatering of the pool.
- The block barrier should be at least 12 inches high and may be up to a maximum of 24 inches high and may be from 4 inches to 12 inches in depth depending on the size of block used.
- Prior to backfilling, place wire mesh over the outside vertical end of the blocks so that stone does not wash down the inlet.
- Place gravel against the wire mesh to the top of the blocks.

BLOCK AND GRAVEL INLET PROTECTION

Maintenance

- Inspect regularly and after every storm. Make any repairs necessary to ensure the measure is in good working order.
- Sediment should be removed and the trap restored to its original dimensions when sediment has accumulated to ½ the design depth of the trap.
- All sediments removed should be properly disposed of.
- Inlet protection should remain in place and operational until the drainage area is completely stabilized or up to 30 days after the permanent site stabilization is achieved.

Cost

- The cost of storm drain inlet protection varies dependent upon the size and type of inlet to be protected but generally is about $300.00 per inlet.

Sources

- Commonwealth of Virginia - County of Fairfax, 1987. 1987 Check List For Erosion And Sediment Control - Fairfax County, Virginia.
- State of North Carolina, 1988. Erosion and Sediment Control Planning and Design Manual. North Carolina Sedimentation Control Commission, Department of Natural Resources and Community Development.
- Maryland Department of the Environment, 1991. 1991 Maryland Standards And Specifications For Soil Erosion And Sediment Control - Draft.
- Storm Water Management Manual for the Puget Sound Basin. State of Washington, Department of Ecology, 1991.
- Cost Data:
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Design Criteria

- Temporary sediment traps are appropriate in the following locations:
  - At the outlet of the perimeter controls installed during the first stage of construction.
  - At the outlet of any structure which concentrates sediment-laden runoff, e.g. at the discharge point of diversions, channels, slope drains, or other runoff conveyances.
  - Above a storm water inlet that is in line to receive sediment-laden runoff.
- Temporary sediment traps may be constructed by excavation alone or by excavation in combination with an embankment.
- Temporary sediment traps are often used in conjunction with a diversion dike or swale.
- The drainage area for the sediment trap should not exceed 5 disturbed acres.
- The trap must be accessible for ease of regular maintenance which is critical to its functioning properly.
- Sediment traps are temporary measures and should not be planned to remain in place longer than between 18 and 24 months.
- The capacity of the sedimentation pool should provide storage volume for 3,600 cubic feet/acre drainage area.
- The outlet should be designed to provide a 2 foot settling depth and an additional sediment storage area 1 ½ feet deep at the bottom of the trap.
- The embankment may not exceed 5 feet in height.
- The recommended minimum width at the top of the embankment is between 2 feet and 5 feet.
- The minimum recommended length of the weir is between 3 feet and 4 feet, and the maximum is 12 feet in length.
- Table 5 illustrates the typical relationship between the embankment height, the height of the outlet (H_o), and the width (W) at the top of the embankment.

TABLE 5. EMBANKMENT HEIGHT vs. OUTLET HEIGHT AND WIDTH

H	H_o	W
1.5	0.5	2.0
2.0	1.0	2.0
2.5	1.5	2.5
3.0	2.0	2.5
3.5	2.5	3.0
4.0	3.0	3.0
4.5	3.5	4.0
5.0	4.0	4.5

Materials

- Filter fabric (see fabric requirement for silt fence)
- Coarse aggregate or riprap 2 inches to 14 inches in diameter
- Washed gravel ¾ to 1 ½ inches in diameter
- Seed and mulch for stabilization

Construction Specifications

- Clear the area of all trees, brush, stumps or other obstructions.
- Construct the embankment in 8 inch lifts compacting each lift with the appropriate earth moving equipment. Fill material must be free of woody vegetation, roots, or large stones.
- Keep cut and fill slopes between 3:1 and 2:1 or flatter.
- Line the outlet area with filter fabric prior to placing stone or gravel.
- Construct the gravel outlet using heavy stones between 6 inches and 14 inches in diameter and face the upstream side with a 12 inch layer of ¾ inch to 1½ inch washed gravel on the upstream side.
- Seed and mulch the embankment as soon as possible to ensure stabilization.

Maintenance

- Inspect regularly and after every storm. Make any repairs necessary to ensure the measure is in good working order.
- Frequent removal of sediment is critical to the functioning of this measure. At a minimum sediment should be removed and the trap restored to its original volume when sediment reaches ½ of the original volume.
- Sediment removed from the trap must be properly disposed.
- Check the embankment regularly to make sure it is structurally sound.

Cost

- Costs for a sediment trap vary widely based upon their size and the amount of excavation and stone required, they usually can be installed for $500 to $7,000.

Sources

- Commonwealth of Virginia - County of Fairfax, 1987. 1987 Check List For Erosion And Sediment Control - Fairfax County, Virginia.
- State of North Carolina, 1988. Erosion and Sediment Control Planning and Design Manual. North Carolina Sedimentation Control Commission, Department of Natural Resources and Community Development.
- Maryland Department of the Environment, 1991. 1991 Maryland Standards And Specifications For Soil Erosion And Sediment Control - Draft.
- Storm Water Management Manual for the Puget Sound Basin. State of Washington, Department of Ecology, 1991.
- Cost Data:
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APPENDIX F

TESTS FOR NON-STORM WATER DISCHARGES

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TESTS FOR NON-STORM WATER DISCHARGES

DYE TESTING

Dye testing can be used to establish positively if certain facilities or fixtures are connected to a storm water collection system. The dye is simply introduced into the suspected waste stream, and storm water outfalls are examined for detections of the dye. Specially manufactured dyes are available for this type of testing. Check with your local sewer authority before conducting this test—dyes can be toxic and thus harmful to the municipal sewage treatment plant

Equipment

Two types of safe and harmless but effective dyes are available for dye testing. Powder in cans or containers is measured by a spoon or small dipper. Tablets of the dye are slower to dissolve than the powder form, but are less messy and are sometimes more desirable than the powder for this reason. The dye is the only piece of equipment needed. Regardless of the type of dye, dissolve it in the flow. A tablet may sink into a sump or wet well and not circulate with the usual flow.

CAUTION: Some dyes may leave a stain if spilled. These stains can be very difficult to remove.

Contact the water pollution control agency to determine if there are any regulations regarding the use of dyes.

Operation

While one operator applies the dye to the suspected location, another operator maintains a watch at the next downstream manhole from the location.

- Where a plumbing fixture is used, such as a water closet bowl or basin, the water is turned on and the dye powder or tablet is dropped directly into the drain.
- Where there is no immediate supply of water, such as a roof gutter or storm drain in dry weather, pouring a bucket of water with the dye powder is suggested. The amount of water and dye needed depends on the distance to the next manhole and the existing flow.
- Based on the assumed velocity of flow, an estimate may be made of the expected flow time to the downstream manhole. Allow plenty of time because the dye often takes much longer than expected.
- Use of powdered dye can be difficult and messy on a windy day. When the wind blows, either pre-mix the dye in water or enclose a quantity of the powder dye in either tissue or toilet paper. Wind can scatter a powdered dye, the dye is impossible to collect. The dye may land on the property of nearby residents and businesses, and when wet, cause stains on buildings, autos, clothes, and landscaping.
- When a number of dye tests are to be conducted on the same line or section of a sewer system, the dye testing should start at the facility farthest downstream and progressively work upstream for the other dye tests. Otherwise, if you dye the facilities upstream first, the flow is then contaminated with dye, and you then must wait several hours or until the next day to conduct additional tests.
- When tests are completed, record whether or not the service is connected to the sewer.

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APPENDIX G

COMPARISON OF OTHER ENVIRONMENTAL PLANS

POTENTIALLY RELEVANT ELEMENTS OF OTHER FACILITY ENVIRONMENTAL PLANS

Required Elements of Each Plan	Storm Water Pollution Prevention Plan	Preparedness Prevention and Contingency Plan (40 CFR 264 and 265)	Spill Control and Countermeasures (40 CFR 112)	NPDES Toxic Organic Management Plan (40 CFR 413, 433, 469)	OSHA Emergency Action Plan (29 CFR 1910)
Identification of Pollutants of Concern	• Description of potential pollutant sources • Risk identification • Material inventory • Test for illicit connections	• Requires identification of hazardous wastes handled at the facility and associated hazards	• Requires prediction of direction, rate of flow and total quantity of oil that could be discharged	• Requires identification of toxic organic compounds used	• Requires list of major workplace fire and emergency hazards
Coordinator	• Pollution prevention planner or team under supervision of plant manager	• Emergency coordinator at facility or on call at all times to coordinate emergency response.	• Designated person who is accountable for oil spill prevention and who reports to line management	Not specifically addressed	Not specifically addressed
Operational Controls	• Preventive maintenance program • Good housekeeping • Spill prevention and response procedures • Site-specific storm water BMPs • Activity-specific BMPs	• Requires that personnel involved in hazardous waste activities have access to emergency communication device	• Requires appropriate spill prevention and containment procedures	• Requires method of disposal used instead of dumping into drain be specified • Procedures for assuring that toxic organics do not routinely spill or leak into wastewater	• Requires employer to control accumulations of flammable and combustible waste • Maintain equipment and systems to prevent accidental ignition of combustible materials
Structural Controls	• Sediment and erosion control • Site-specific storm water BMPs • Activity-specific BMPs • BMPs for non-storm water discharges • Enclosure of salt storage piles • *Provide containment, drainage control, and/or diversionary structures to prevent contamination of storm water discharges associated with industrial activity from facilities subject to EPCRA Section 313* • *Security for EPCRA Section 313 facilities*	• Maintain aisle space for movement of emergency equipment and personnel • Specific requirements for storage tanks	• Appropriate containment and/or diversionary structures or equipment (detailed suggestions provided in reg.) • Security - including fences and gates, locks for flow and drain valves and pumps, and lighting	• Specify method of disposal used instead of dumping into drain • Procedures for assuring that toxic organics do not routinely spill or leak into wastewater	Not specifically addressed

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POTENTIALLY RELEVANT ELEMENTS OF OTHER FACILITY ENVIRONMENTAL PLANS (Continued)

Required Elements of Each Plan	Storm Water Pollution Prevention Plan	Preparedness Prevention and Contingency Plan (40 CFR 264 and 265)	Spill Control and Countermeasures (40 CFR 112)	NPDES Toxic Organic Management Plan (40 CFR 413, 433, 469)	OSHA Emergency Action Plan (29 CFR 1910)
Inspections	• Routine visual inspection of designated equipment and plant areas, including materials handling, by qualified plant personnel who will also develop procedures to ensure follow up • Annual site inspection to verify the accuracy of pollutant source description, drainage map and controls	Not specifically addressed	• Testing and inspection of pollution prevention/control equipment by owner/operator on a scheduled, periodic basis • Inspections should be in accordance with written procedures developed for the facility by the owner/operator	Not specifically addressed	Not specifically addressed
Employee Training	• Training for employee at all levels in: - spill response - good housekeeping - materials management • Specify periodic training dates in plan	Not specifically addressed	• Owners/operators are responsible for properly training personnel on applicable regulations and in the operation and maintenance of equipment to prevent discharges • Owners/operators should schedule and conduct spill prevention briefings for operating personnel	Not specifically addressed	• Designate and train a sufficient number of persons to assist in safe evacuation
Coordinate with Local Authorities	• Facilities which discharge storm water to large or medium municipal separate storm sewer systems must comply with applicable conditions in municipal storm water management programs	• Familiarize local police and fire departments, hospitals and emergency response teams - layout of facility - properties of hazardous wastes - types of injuries • Coordinate arrangements for plan implementation authorities	• Follow contingency plan provisions of 40 CFR 109 including consultation with State and local governments	Not specifically addressed	Not specifically addressed

POTENTIALLY RELEVANT ELEMENTS OF OTHER FACILITY ENVIRONMENTAL PLANS (Continued)

Required Elements of Each Plan	Storm Water Pollution Prevention Plan	Preparedness Prevention and Contingency Plan (40 CFR 264 and 265)	Spill Control and Countermeasures (40 CFR 112)	NPDES Toxic Organic Management Plan (40 CFR 413, 433, 469)	OSHA Emergency Action Plan (29 CFR 1910)
Emergency/ Spill Response Equipment	• Necessary equipment to implement a spill clean up	• List describing emergency equipment and its location: - Internal communications (intercom or alarm) - Immediately accessible line of communication to summon emergency assistance (fire/police) - fire extinguishers - water supplies - decontamination equipment - spill control equipment • All equipment must be tested and maintained	• Appropriate containment and/or diversionary structures or equipment • If impractical, a written commitment of equipment and materials required to expeditiously control and remove any harmful quantities of oil discharged	Not specifically addressed	• Alarm system

POTENTIALLY RELEVANT ELEMENTS OF OTHER FACILITY ENVIRONMENTAL PLANS (Continued)

Required Elements of Each Plan	Storm Water Pollution Prevention Plan	Preparedness Prevention and Contingency Plan (40 CFR 264 and 265)	Spill Control and Countermeasures (40 CFR 112)	NPDES Toxic Organic Management Plan (40 CFR 413, 433, 469)	OSHA Emergency Action Plan (29 CFR 1910)
Notification/ Record Keeping Procedures	• Record spills and other discharges • Record storm water quality/ quantity information • Document inspection and maintenance activities • Certify that discharge has been tested for the presence of non-storm water discharges or certify where such testing is not feasible	• In case of imminent or actual emergency situation: - activate alarms/ communication systems to notify facility personnel - notify State/local agencies - identify the character, exact source, amount and areal extent of release - assess hazards to human health and the environment and respond - facilitate containment - coordinate clean up - submit incident report	• Written procedures for and records of inspections should be made part of the SPCC and maintained for 3 years • Detailed notification requirements apply if a facility has a single spill event of more than 1000 gallons of oil or has discharged oil in harmful quantities in two spill events within the last 12 months	Not specifically addressed	• Means of reporting fires and other emergencies
Evacuation Procedures	Not specifically addressed	• Evacuation plan describing: - signals to begin evacuation - primary and alternate routes	Not specifically addressed	Not specifically addressed	• Emergency escape routes • Procedures to account for all employees • Procedures for employees who remain behind to perform critical functions

POTENTIALLY RELEVANT ELEMENTS OF OTHER FACILITY ENVIRONMENTAL PLANS (Continued)

Required Elements of Each Plan	Storm Water Pollution Prevention Plan	Preparedness Prevention and Contingency Plan (40 CFR 264 and 265)	Spill Control and Countermeasures (40 CFR 112)	NPDES Toxic Organic Management Plan (40 CFR 413, 433, 469)	OSHA Emergency Action Plan (29 CFR 1910)
Plan Location/ Distribution	• Maintained at facility unless requested by the director or the municipal operator	• Maintained at facility • Submitted to local police, fire, hospital, and State and local emergency response teams	• Maintain at facility if facility is normally attended at least 8 hours per day or at nearest field office if not so attended	• Submitted to permitting authority for approval	• Plan shall be written and kept at the workplace unless there are fewer than 10 employees, then oral communication is sufficient • Employer shall review the plan with each employee covered by the plan when: - Plan is initially developed - Plan changes - Employee's responsibility changes
Modification of Plan	• Plan fails to control pollutants in storm water • Change in design, construction, operation or maintenance • Requested by the director	• Facility permit revised • Plan fails during emergency • Facility changes • Emergency coordinator(s) change • Emergency equipment changes	• By the Regional Administrator where the plan does not meet requirements or is necessary to prevent and contain discharges of oil • By the owner/operator: - change in facility - if warranted by findings of 3 years evaluation	Not specifically addressed	Not specifically addressed

POTENTIALLY RELEVANT ELEMENTS OF OTHER FACILITY ENVIRONMENTAL PLANS (Continued)

Required Elements of Each Plan	Storm Water Pollution Prevention Plan	Preparedness Prevention and Contingency Plan (40 CFR 264 and 265)	Spill Control and Countermeasures (40 CFR 112)	NPDES Toxic Organic Management Plan (40 CFR 413, 433, 469)	OSHA Emergency Action Plan (29 CFR 1910)
Certification	• Certify that discharges have been tested for the presence of non-storm water discharges • Plans must be signed and certified in accordance with 40 CFR 122.22 • *Spill prevention and response plan for facilities subject to EPCRA Section 313 must be reviewed and certified every three years by a registered professional engineer*	Not specifically addressed	• Plan must be reviewed and certified by a registered professional engineer	No dumping of toxic organic compounds into the wastewater has occurred and the approved TOMP is being implemented	Not specifically addressed

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APPENDIX H

LIST OF HAZARDOUS SUBSTANCES AND REPORTABLE QUANTITIES

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LIST OF HAZARDOUS SUBSTANCES AND REPORTABLE QUANTITIES
40 CFR 302.4 and 117
Note: All comments are located at the end of this table.

Hazardous Substance	CASRN	Regulatory Synonyms	Statutory			Final RQ	
			RQ	Code†	RCRA Waste #	Category	Pounds (Kg)
Acenaphthene	83329		1*	2		B	100 (45.4)
Acenaphthylene	208968		1*	2		D	5000 (2270)
Acetaldehyde	75070	Ethanal	1000	1,4	U001	C	1000 (454)
Acetaldehyde, chloro-	107200	Chloroacetaldehyde	1*	4	P023	C	1000 (454)
Acetaldehyde, trichloro-	75876	Chloral	1*	4	U034	D	5000 (2270)
Acetamide, N-(aminothioxomethyl)-	591082	1-Acetyl-2-thiourea	1*	4	P002	C	1000 (454)
Acetamide, N-(4-ethoxyphenyl)-	62442	Phenacetin	1*	4	U187	B	100 (45.4)
Acetamide, 2-fluoro-	640197	Fluoroacetamide	1*	4	P057	B	100 (45.4)
Acetamide, N-9H-fluoren-2-yl-	53963	2-Acetylaminofluorene	1*	4	U005	X	1 (0.454)
Acetic acid	64197		1000	1		D	5000 (2270)
Acetic acid (2,4-dichlorophenoxy)-	94757	2,4-D Acid 2,4-D, salts and esters	100	1,4	U240	B	100 (45.4)
Acetic Acid, lead(2+) salt	301042	Lead acetate	5000	1,4	U144		#
Acetic acid, thallium(1+) salt	563688	Thallium(I) acetate	1*	4	U214	B	100 (45.4)
Acetic acid (2,4,5-trichlorophenoxy)-	93765	2,4,5-T 2,4,5-T acid	100	1,4	U232	C	1000 (454)
Acetic acid, ethyl ester	141786	Ethyl acetate	1*	4	U112	D	5000 (2270)
Acetic acid, fluoro-, sodium salt	62748	Fluoroacetic acid, sodium salt	1*	4	P058	A	10 (4.54)
Acetic anhydride	108247		1000	1		D	5000 (2270)
Acetone	67641	2-Propanone	1*	4	U002	D	5000 (2270)
Acetone cyanohydrin	75865	Propanenitrile, 2-hydroxy-2-methyl-2-Methyllactonitrile	10	1,4	P069	A	10 (4.54)
Acetonitrile	75058		1*	4	U003	D	5000 (2270)
Acetophenone	98862	Ethanone, 1-phenyl-	1*	4	U004	D	5000 (2270)
2-Acetylaminofluorene	53963	Acetamide, N-9H-fluoren-2-yl-	1*	4	U005	X	1 (0.454)
Acetyl bromide	506967		5000	1		D	5000 (2270)
Acetyl chloride	75365		5000	1,4	U006	D	5000 (2270)
1-Acetyl-2-thiourea	591082	Acetamide, N-(aminothioxomethyl)-	1*	4	P002	C	1000 (454)
Acrolein	107028	2-Propenal	1	1,2,4	P003	X	1 (0.454)
Acrylamide	79061	2-Propenamide	1*	4	U007	D	5000 (2270)

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Hazardous Substance	CASRN	Regulatory Synonyms	Statutory			Final RQ	
			RQ	Code†	RCRA Waste #	Category	Pounds (Kg)
Acrylic acid	79107	2-Propenoic acid	1*	4	U008	D	5000 (2270)
Acrylonitrile	107131	2-Propenenitrile	100	1,2,4	U009	B	100 (45.4)
Adipic acid	124049		5000	1		D	5000 (2270)
Aldicarb	116063	Propanal, 2-methyl-2-(methylthio)-,O-[(methylamino) carbonyl]oxime	1*	4	P070	X	1 (0.454)
Aldrin	309002	1,4,5,8-Dimethanonaphthalene, 1,2,3,4,10,10-10-hexachloro-1,4,4a,5,8,8a-hexahydro-, (1alpha,4alpha,4abeta,5alpha,8alpha,8abeta)-	1	1,2,4	P004	X	1 (0.454)
Allyl alcohol	107186	2-Propen-1-ol	100	1,4	P005	B	100 (45.4)
Allyl chloride	107051		1000	1		C	1000 (454)
Aluminum phosphide	20859738		1*	4	P006	B	100 (45.4)
Aluminum sulfate	10043013		5000	1		D	5000 (2270)
5-(Aminomethyl)-3-isoxazolol	2763964	Muscimol 3(2H)-Isoxazolone, 5-(aminomethyl)-	1*	4	P007	C	1000 (454)
4-Aminopyridine	504245	4-Pyridinamine	1*	4	P008	C	1000 (454)
Amitrole	61825	1H-1,2,4-Triazol-3-amine	1*	4	U011	A	10 (4.54)
Ammonia	7664417		100	1		B	100 (45.4)
Ammonium acetate	631618		5000	1		D	5000 (2270)
Ammonium benzoate	1863634		5000	1		D	5000 (2270)
Ammonium bicarbonate	1066337		5000	1		D	5000 (2270)
Ammonium bichromate	7789095		1000	1		A	10 (4.54)
Ammonium bifluoride	1341497		5000	1		B	100 (45.4)
Ammonium bisulfite	10192300		5000	1		D	5000 (2270)
Ammonium carbamate	1111780		5000	1		D	5000 (2270)
Ammonium carbonate	506876		5000	1		D	5000 (2270)
Ammonium chloride	12125029		5000	1		D	5000 (2270)
Ammonium chromate	7788989		1000	1		A	10 (4.54)
Ammonium citrate, dibasic	3012655		5000	1		D	5000 (2270)
Ammonium fluoborate	13826830		5000	1		D	5000 (2270)
Ammonium fluoride	12125018		5000	1		B	100 (45.4)
Ammonium hydroxide	1336216		1000	1		C	1000 (454)
Ammonium oxalate	6009707		5000	1		D	5000 (2270)

Hazardous Substance	CASRN	Regulatory Synonyms	Statutory RQ	Statutory Code†	Statutory RCRA Waste #	Final RQ Category	Final RQ Pounds (Kg)
	5972736		5000	1		D	5000 (2270)
	14258492		5000	1		D	5000 (2270)
Ammonium picrate	131748	Phenol, 2,4,6-trinitro-, ammonium salt	1*	4	P009	A	10 (4.54)
Ammonium silicofluoride	16919190		1000	1		C	1000 (454)
Ammonium sulfamate	7773060		5000	1		D	5000 (2270)
Ammonium sulfide	12135761		5000	1		B	100 (45.4)
Ammonium sulfite	10196040		5000	1		D	5000 (2270)
Ammonium tartrate	14307438		5000	1		D	5000 (2270)
	3164292		5000	1		D	5000 (2270)
Ammonium thiocyanate	1762954		5000	1		D	5000 (2270)
Ammonium vanadate	7803556	Vanadic acid, ammonium salt	1*	4	P119	C	1000 (454)
Amyl acetate	628637		1000	1		D	5000 (2270)
iso-Amyl acetate	123922		1000	1		D	5000 (2270)
sec-Amyl acetate	626380		1000	1		D	5000 (2270)
tert-Amyl acetate	625161		1000	1		D	5000 (2270)
Aniline	62533	Benzenamine	1000	1,4	U012	D	5000 (2270)
Anthracene	120127		1*	2		D	5000 (2270)
Antimony††	7440360		1*	2		D	5000 (2270)
ANTIMONY AND COMPOUNDS	N/A		1*	2			**
Antimony pentachloride	7647189		1000	1		C	1000 (454)
Antimony potassium tartrate	28300745		1000	1		B	100 (45.4)
Antimony tribromide	7789619		1000	1		C	1000 (454)
Antimony trichloride	10025919		1000	1		C	1000 (454)
Antimony trifluoride	7783564		1000	1		C	1000 (454)
Antimony trioxide	1309644		5000	1		C	1000 (454)
Argentate(1-), bis(cyano-C)-, potassium	506616	Potassium silver cyanide	1*	4	P099	X	1 (0.454)
Aroclor 1016	12674112	POLYCHLORINATED BIPHENYLS (PCBs)	10	1,2		X	1 (0.454)
Aroclor 1221	11104282	POLYCHLORINATED BIPHENYLS (PCBs)	10	1,2		X	1 (0.454)
Aroclor 1232	11141165	POLYCHLORINATED BIPHENYLS (PCBs)	10	1,2		X	1 (0.454)

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Hazardous Substance	CASRN	Regulatory Synonyms	Statutory			Final RQ	
			RQ	Code†	RCRA Waste #	Category	Pounds (Kg)
Aroclor 1242	53469219	POLYCHLORINATED BIPHENYLS (PCBs)	10	1,2		X	1 (0.454)
Aroclor 1248	12672296	POLYCHLORINATED BIPHENYLS (PCBs)	10	1,2		X	1 (0.454)
Aroclor 1254	11097691	POLYCHLORINATED BIPHENYLS (PCBs)	10	1,2		X	1 (0.454)
Aroclor 1260	11096825	POLYCHLORINATED BIPHENYLS (PCBs)	10	1,2		X	1 (0.454)
Arsenic††	7440382		1*	2,3		X	1 (0.454)
Arsenic acid	1327522	Arsenic acid H3AsO4	1*	4	P010	X	1 (0.454)
	7778394						
Arsenic acid H3AsO4	1327522	Arsenic acid	1*	4	P010	X	1 (0.454)
	7778394		1*	4	P010	X	1(0.454)
ARSENIC AND COMPOUNDS	N/A		1*	2			**
Arsenic disulfide	1303328		5000	1		X	1 (0.454)
Arsenic oxide As2O3	1327533	Arsenic trioxide	5000	1,4	P012	X	1 (0.454)
Arsenic oxide As2O5	1303282	Arsenic pentoxide	5000	1,4	P011	X	1 (0.454)
Arsenic pentoxide	1303282	Arsenic oxide As2O5	5000	1,4	P011	X	1 (0.454)
Arsenic trichloride	7784341		5000	1		X	1 (0.454)
Arsenic trioxide	1327533	Arsenic oxide As2O3	5000	1,4	P012	X	1 (0.454)
Arsenic trisulfide	1303338		5000	1		X	1 (0.454)
Arsine, diethyl-	692422	Diethylarsine	1*	4	P038	X	1 (0.454)
Arsinic acid, dimethyl-	75605	Cacodylic acid	1*	4	U136	X	1 (0.454)
Arsonous dichloride, phenyl-	696286	Dichlorophenylarsine	1*	4	P036	X	1 (0.454)
Asbestos†††	1332214		1*	2,3		X	1 (0.454)
Auramine	492808	Benzenamine, 4,4'-carbonimidoylbis (N,N-dimethyl-	1*	4	U014	B	100 (45.4)
Azaserine	115026	L-Serine, diazoacetate (ester)	1*	4	U015	X	1 (0.454)
Aziridine	151564	Ethylenimine	1*	4	P054	X	1 (0.454)
Aziridine, 2-methyl-	75558	1,2-Propylenimine	1*	4	P067	X	1 (0.454)
Azirino[2',3':3,4]pyrrolo[1,2-a]indole-4,7-dione,6-amino-8-[[(aminocarbonyl)oxy]methyl]-1,1a,2,8,8a,8b-hexahydro-8a-methoxy-5-methyl-,[1aS-(1aalpha,8beta,8aalpha,8balpha)]-	50077	Mitomycin C	1*	4	U010	A	10 (4.54)

Hazardous Substance	CASRN	Regulatory Synonyms	Statutory			Final RQ	
			RQ	Code†	RCRA Waste #	Category	Pounds (Kg)
Barium cyanide	542621		10	1,4	P013	A	10 (4.54)
Benz[j]aceanthrylene, 1,2-dihydro-3-methyl-	56495	3-Methylcholanthrene	1*	4	U157	A	10 (4.54)
Benz[c]acridine	225514		1*	4	U016	B	100 (45.4)
Benzal chloride	98873	Benzene, dichloromethyl-	1*	4	U017	D	5000 (2270)
Benzamide, 3,5-dichloro-N-(1,1-dimethyl-2-propynyl)-	23950585	Pronamide	1*	4	U192	D	5000 (2270)
Benz[a]anthracene	56553	Benzo[a]anthracene 1,2-Benzanthracene	1*	2,4	U018	A	10 (4.54)
1,2-Benzanthracene	56553	Benz[a]anthracene Benzo[a]anthracene	1*	2,4	U018	A	10 (4.54)
Benz[a]anthracene, 7,12-dimethyl-	57976	7,12-Dimethylbenz[a]anthracene	1*	4	U094	X	1 (0.454)
Benzenamine	62533	Aniline	1000	1,4	U012	D	5000 (2270)
Benzenamine, 4,4'-carbonimidoylbis (N,N-dimethyl-	492808	Auramine	1*	4	U014	B	100 (45.4)
Benzenamine, 4-chloro-	106478	p-Chloroaniline	1*	4	P024	C	1000 (454)
Benzenamine, 4-chloro-2-methyl-, hydrochloride	3165933	4-Chloro-o-toluidine, hydrochloride	1*	4	U049	B	100 (45.4)
Benzenamine, N,N-dimethyl-4(phenylazo-)	60117	p-Dimethylaminoazobenzene	1*	4	U093	A	10 (4.54)
Benzenamine, 2-methyl-	95534	o-Toluidine	1*	4	U328	B	100 (45.4)
Benzenamine, 4-methyl-	106490	p-Toluidine	1*	4	U353	B	100 (45.4)
Benzenamine, 4,4'-methylenebis(2-chloro-	101144	4,4'-Methylenebis(2-chloroaniline)	1*	4	U158	A	10 (4.54)
Benzenamine, 2-methyl-, hydrochloride	636215	o-Toluidine hydrochloride	1*	4	U222	B	100 (45.4)
Benzenamine, 2-methyl-5-nitro	99558	5-Nitro-o-toluidine	1*	4	U181	B	100 (45.4)
Benzenamine, 4-nitro-	100016	p-Nitroaniline	1*	4	P077	D	5000 (2270)
Benzene	71432		1000	1,2, 3,4	U019	A	10 (4.54)
Benzeneacetic acid, 4-chloro-alpha-(4-chlorophenyl)-alpha-hydroxy-, ethyl ester	510156	Chlorobenzilate	1*	4	U038	A	10 (4.54)
Benzene, 1-bromo-4-phenoxy-	101553	4-Bromophenyl phenyl ether	1*	2,4	U030	B	100 (45.4)
Benzenebutanoic acid, 4-[bis(2-chloroethyl)amino]-	305033	Chlorambucil	1*	4	U035	A	10 (4.54)
Benzene, chloro-	108907	Chlorobenzene	100	1,2,4	U037	B	100 (45.4)
Benzene, chloromethyl-	100447	Benzyl chloride	100	1,4	P028	B	100 (45.4)

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Hazardous Substance	CASRN	Regulatory Synonyms	Statutory			Final RQ	
			RQ	Code†	RCRA Waste #	Category	Pounds (Kg)
Benzenediamin, ar-methyl-	95807	Toluenediamine	1*	4	U221	A	10 (4.54)
	496720		1*	4	U221	A	10 (4.54)
	823405		1*	4	U221	A	10 (4.54)
1,2-Benzenedicarboxylic acid, dioctyl ester	117840	Di-n-octyl phthalate	1*	2,4	U107	D	5000 (2270)
1,2-Benzenedicarboxylic acid, [bis(2-ethylhexyl)]-ester	117817	Bis (2-ethylhexyl)phthalate Diethylhexyl phthalate	1*	2,4	U028	B	100 (45.4)
1,2-Benzenedicarboxylic acid, dibutyl ester	84742	Di-n-butyl phthalate Dibutyl phthalate n-Butyl phthalate	100	1,2,4	U069	A	10 (4.54)
1,2-Benzenedicarboxylic acid, diethyl ester	84662	Diethyl phthalate	1*	2,4	U088	C	1000 (454)
1,2-Benzenedicarboxylic acid, dimethyl ester	131113	Dimethyl phthalate	1*	2,4	U102	D	5000 (2270)
Benzene, 1,2-dichloro-	95501	o-Dichlorobenzene 1,2-Dichlorobenzene	100	1,2,4	U070	B	100 (45.4)
Benzene, 1,3-dichloro-	541731	m-Dichlorobenzene 1,3-Dichlorobenzene	1*	2,4	U071	B	100 (45.4)
Benzene, 1,4-dichloro-	106467	p-Dichlorobenzene 1,4-Dichlorobenzene	100	1,2,4	U072	B	100 (45.4)
Benzene, 1,1'-(2,2-dichloroethylidene)bis[4-chloro-	72548	DDD TDE 4,4' DDD	1	1,2,4	U060	X	1 (0.454)
Benzene, dichloromethyl-	98873	Benzal chloride	1*	4	U017	D	5000 (2270)
Benzene, 1,3-diisocyanatomethyl-	584849	Toluene diisocyanate	1*	4	U223	B	100 (45.4)
	91087		1*	4	U223	B	100 (45.4)
	26471625		1*	4	U223	B	100 (45.4)
Benzene, dimethyl	1330207	Xylene (mixed)	1000	1,4	U239	C	1000 (454)
m-Benzene, dimethyl	108383	m-Xylene	1000	1,4	U239	C	1000 (454)
o-Benzene, dimethyl	95476	o-Xylene	1000	1,4	U239	C	1000 (454)
p-Benzene, dimethyl	106423	p-Xylene	1000	1,4	U239	C	1000 (454)
1,3-Benzenediol	108463	Resorcinol	1000	1,4	U201	D	5000 (2270)
1,2-Benzenediol,4-[1-hydroxy-2-(methylamino)ethyl]-	51434	Epinephrine	1*	4	P042	C	1000 (454)
Benzeneethanamine, alpha,alpha-dimethyl-	122098	alpha,alpha-Dimethylphenethylamine	1*	4	P046	D	5000 (2270)
Benzene, hexachloro-	118741	Hexachlorobenzene	1*	2,4	U127	A	10 (4.54)
Benzene, hexahydro-	110827	Cyclohexane	1000	1,4	U056	C	1000 (454)

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Hazardous Substance	CASRN	Regulatory Synonyms	Statutory			Final RQ	
			RQ	Code†	RCRA Waste #	Category	Pounds (Kg)
Benzene, hydroxy-	108952	Phenol	1000	1,2,4	U188	C	1000 (454)
Benzene, methyl-	108883	Toluene	1000	1,2,4	U220	C	1000 (454)
Benzene, 2-methyl-1,3-dinitro-	606202	2,6-Dinitrotoluene	1000	1,2,4	U106	B	100 (45.4)
Benzene, 1-methyl-2,4-dinitro-	121142	2,4-Dinitrotoluene	1000	1,2,4	U105	A	10 (4.54)
Benzene, 1-methylethyl-	98828	Cumene	1*	4	U055	D	5000 (2270)
Benzene, nitro-	98953	Nitrobenzene	1000	1,2,4	U169	C	1000 (454)
Benzene, pentachloro-	608935	Pentachlorobenzene	1*	4	U183	A	10 (4.54)
Benzene, pentachloronitro-	82688	Pentachloronitrobenzene (PCNB)	1*	4	U185	B	100 (45.4)
Benzenesulfonic acid chloride	98098	Benzenesulfonyl chloride	1*	4	U020	B	100 (45.4)
Benzenesulfonyl chloride	98099	Benzenesulfonic acid chloride	1*	4	U020	B	100 (45.4)
Benzene, 1,2,4,5-tetrachloro-	95943	1,2,4,5-Tetrachlorobenzene	1*	4	U207	D	5000 (2270)
Benzenethiol	108985	Thiophenol	1*	4	P014	B	100 (45.4)
Benzene, 1,1'-(2,2,2-trichloroethylidene)bis[4-chloro-	50293	DDT 4,4'DDT	1	1,2,4	U061	X	1 (0.454)
Benzene, 1,1'-(trichloroethylidene)bis[4-methoxy-	72435	Methoxychlor	1	1,4	U247	X	1 (0.454)
Benzene, (trichloromethyl)-	98077	Benzotrichloride	1*	4	U023	A	10 (4.54)
Benzene, 1,3,5-trinitro-	99354	1,3,5-Trinitrobenzene	1*	4	U234	A	10 (4.554)
Benzidine	92875	(1,1'-Biphenyl)-4,4'diamine	1*	2,4	U021	X	1 (0.454)
1,2-Benzisothiazol-3(2H)-one, 1,1-dioxide	81072	Saccharin and salts	1*	4	U202	B	100 (45.4)
Benzo[a]anthracene	56553	Benz[a]anthracene 1,2-Benzanthracene	1*	2,4	U018	A	10 (4.54)
Benzo[b]fluoranthene	205992		1*	2		X	1 (0.454)
Benzo(k)fluoranthene	207089		1*	2		D	5000 (2270)
Benzo[j,k]fluorene	206440	Fluoranthene	1*	2,4	U120	B	100 (45.4)
1,3-Benzodioxole, 5-(1-propenyl)-	120581	Isosafrole	1*	4	U141	B	100 (45.4)
1,3-Benzodioxole, 5-(2-propenyl)-	94597	Safrole	1*	4	U203	B	100 (45.4)
1,3-Benzodioxole, 5-propyl-	94586	Dihydrosafrole	1*	4	U090	A	10 (4.54)
Benzoic acid	65850		5000	1		D	5000 (2270)
Benzonitrile	100470		1000	1		D	5000 (2270)
Benzo[rst]pentaphene	189559	Dibenz[a,i]pyrene	1*	4	U064	A	10 (4.54)
Benzo[ghi]perylene	191242		1*	2		D	5000 (2270)

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Hazardous Substance	CASRN	Regulatory Synonyms	Statutory			Final RQ	
			RQ	Code†	RCRA Waste #	Category	Pounds (Kg)
2H-1-Benzopyran-2-one, 4-hydroxy-3-(3-oxo-1-phenyl-butyl)-& salts, when present at concentrations greater than 0.3%	81812	Warfarin, & salts, when present at concentrations greater than 0.3%	1*	4	P001	B	100 (45.4)
Benzo[a]pyrene	50328	3,4-Benzopyrene	1*	2,4	U022	X	1 (0.454)
3,4-Benzopyrene	50328	Benzo[a]pyrene	1*	2,4	U022	X	1 (0.454)
p-Benzoquinone	106514	2,5-Cyclohexadiene-1,4-dione	1*	4	U197	A	10 (4.54)
Benzotrichloride	98077	Benzene, (trichloromethyl)-	1*	4	U023	A	10 (4.54)
Benzoyl chloride	98884		1000	1		C	1000 (454)
1,2-Benzphenanthrene	218019	Chrysene	1*	2,4	U050	B	100 (45.4)
Benzyl chloride	100447	Benzene, chloromethyl-	100	1,4	P028	B	100 (45.4)
Beryllium††	7440417	Beryllium dust ††	1*	2,3,4	P015	A	10 (4.54)
BERYLLIUM AND COMPOUNDS	N/A		1*	2			**
Beryllium chloride	7787475		5000	1		X	1 (0.454)
Beryllium dust††	7440417	Beryllium††	1*	2,3,4	P015	A	10 (4.54)
Beryllium fluoride	7787497		5000	1		X	1 (0.454)
Beryllium nitrate	13597994		5000	1		X	1 (0.454)
	7787555		5000	1		X	1 (0.454)
alpha-BHC	319846		1*	2		A	10 (4.54)
beta-BHC	319857		1*	2		X	1 (0.454)
delta-BHC	319868		1*	2		X	1 (0.454)
gamma-BHC	58899	Cyclohexane, 1,2,3,4,5,6-hexachloro-,(1alpha,2alpha,3beta,4alpha,5alpha,6 beta)- Hexachlorocyclohexane (gamma isomer) Lindane	1	1,2,4	U129	X	1 (0.454)
2,2'-Bioxirane	1464535	1,2:3,4-Diepoxybutane	1*	4	U085	A	10 (4.54)
[1,1'-Biphenyl]-4,4'diamine	92875	Benzidine	1*	2,4	U021	X	1 (0.454)
[1,1'-Biphenyl]-4,4'diamine,3,3'dichloro-	91941	3,3'-Dichlorobenzidine	1*	2,4	U073	X	1 (0.454)
[1,1'-Biphenyl]-4,4'diamine,3,3'dimethoxy-	119904	3,3'-Dimethoxybenzidine	1*	4	U091	B	100 (45.4)
[1,1'-Biphenyl]-4,4'-diamine,3,3'-dimethyl-	119937	3,3'-Dimethylbenzidine	1*	4	U095	A	10 (4.54)

Hazardous Substance	CASRN	Regulatory Synonyms	Statutory RQ	Statutory Code†	Statutory RCRA Waste #	Final RQ Category	Final RQ Pounds (Kg)
Bis (2-chloroethyl) ether	111444	Dichloroethyl ether Ethane, 1,1'-oxybis[2-chloro-	1*	2,4	U025	A	10 (4.54)
Bis(2-chloroethoxy) methane	111911	Dichloromethoxy ethane Ethane, 1,1'-[methylenebis(oxy)] bis[2-chloro-	1*	2,4	U024	C	1000 (454)
Bis (2-ethylhexyl)phthalate	117817	Diethylhexyl phthalate 1,2-Benzenedicarboxylic acid, [bis(2-ethylhexyl)] ester	1*	2,4	U028	B	100 (45.4)
Bromoacetone	598312	2-Propanone, 1-bromo-	1*	4	P017	C	1000 (454)
Bromoform	75252	Methane, tribromo	1*	2,4	U225	B	100 (45.4)
4-Bromophenyl phenyl ether	101553	Benzene, 1-bromo-4-phenoxy-	1*	2,4	U030	B	100 (45.4)
Brucine	357573	Strychnidin-10-one, 2,3-dimethoxy-	1*	4	P018	B	100 (45.4)
1,3-Butadiene, 1,1,2,3,4,4-hexachloro-	87683	Hexachlorobutadiene	1*	2,4	U128	X	1 (0.454)
1-Butanamine, N-butyl-N-nitroso-	924163	N-Nitrosodi-n-butylamine	1*	4	U172	A	10 (4.54)
1-Butanol	71363	n-Butyl alcohol	1*	4	U031	D	5000 (2270)
2-Butanone	78933	Methyl ethyl ketone (MEK)	1*	4	U159	D	5000 (2270)
2-Butanone peroxide	1338234	Methyl ethyl ketone peroxide	1*	4	U160	A	10 (4.54)
2 Butanone, 3,3-dimethyl-1-(methylthio)-, O[(methylamino) carbonyl] oxime.	39196184	Thiofanox	1*	4	P045	B	100 (45.4)
2-Butenal	123739	Crotonaldehyde	100	1,4	U053	B	100 (45.4)
	4170303						
2-Butene, 1,4-dichloro-	764410	1,4-Dichloro-2-butene	1*	4	U074	X	1 (0.454)
2-Butenoic acid, 2-methyl, 7[[2,3-dihydroxy-2-(1-methoxyethyl)-3-methyl-1-oxobutoxy]methyl]-2,3,5,7a-tetrahydro-1H-pyrrolizin-1-ylester, [1S-[1alpha(Z), 7(2S*,3R*),7aalpha]]-	303344	Lasiocarpine	1*	4	U143	A	10 (4.54)
Butyl acetate	123864		5000	1		D	5000 (2270)
iso-Butyl acetate	110190		5000	1		D	5000 (2270)
sec-Butyl acetate	105464		5000	1		D	5000 (2270)
tert-Butyl acetate	540885		5000	1		D	5000 (2270)
n-Butyl alcohol	71363	1-Butanol	1*	4	U031	D	5000 (2270)
Butylamine	109739		1000	1		C	1000 (454)
iso-Butylamine	78819		1000	1		C	1000 (454)

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Hazardous Substance	CASRN	Regulatory Synonyms	Statutory			Final RQ	
			RQ	Code†	RCRA Waste #	Category	Pounds (Kg)
sec-Butylamine	513495		1000	1		C	1000 (454)
	13952846		1000	1		C	1000 (454)
tert-Butylamine	75649		1000	1		C	1000 (454)
Butyl benzyl phthalate	85687		1*	2		B	100 (45.4)
n-Butyl phthalate	84742	Di-n-butyl phthalate Dibutyl phthalate 1,2-Benzenedicarboxylic acid, dibutyl ester	100	1,2,4	U069	A	10 (4.54)
Butyric acid	107926		5000	1		D	5000 (2270)
iso-Butyric acid	79312						
Cacodylic acid	75605	Arsenic acid, dimethyl-	1*	4	U136	X	1 (0.454)
Cadmium ††	7440439		1*	2		A	10 (4.54)
Cadmium acetate	543908		100	1		A	10 (4.54)
CADMIUM AND COMPOUNDS	N/A		1*	2			**
Cadmium bromide	7789426		100	1		A	10 (4.54)
Cadmium chloride	10108642		100	1		A	10 (4.54)
Calcium arsenate	7778441		1000	1		X	1 (0.454)
Calcium arsenite	52740166		1000	1		X	1 (0.454)
Calcium carbide	75207		5000	1		A	10 (4.54)
Calcium chromate	13765190	Chromic acid H_2CrO_4, calcium salt	1000	1,4	U032	A	10 (4.54)
Calcium cyanide	592018	Calcium cyanide $Ca(CN)_2$	10	1,4	P021	A	10 (4.54)
Calcium cyanide $Ca(CN)_2$	592018	Calcium cyanide	10	1,4	P021	A	10 (4.54)
Calcium dodecylbenzenesulfonate	26264062		1000	1		C	1000 (454)
Calcium hypochlorite	7778543		100	1		A	10 (4.54)
Camphene, octachloro-	8001352	Toxaphene	1	1,2,4	P123	X	1 (0.454)
Captan	133062		10	1		A	10 (4.54)
Carbamic acid, ethyl ester	51796	Ethyl carbamate (urethane)	1*	4	U238	B	100 (45.4)
Carbamic acid, methylnitroso-, ethyl ester	615532	N-Nitroso-N-methylurethane	1*	4	U178	X	1 (0.454)
Carbamic chloride, dimethyl-	79447	Dimethylcarbamoyl chloride	1*	4	U097	X	1 (0.454)
Carbamodithioic acid, 1,2-ethanediylbis-, salts & esters	111546	Ethylenebisdithiocarbamic acid, salts & esters	1*	4	U114	D	5000 (2270)
Carbamothioic acid, bis(1-methylethyl)-, S-(2,3-dichloro-2-propenyl) ester	2303164	Diallate	1*	4	U062	B	100 (45.4)

Hazardous Substance	CASRN	Regulatory Synonyms	Statutory RQ	Statutory Code†	Statutory RCRA Waste #	Final RQ Category	Final RQ Pounds (Kg)
Carbaryl	63252		100	1		B	100 (45.4)
Carbofuran	1563662		10	1		A	10 (4.54)
Carbon disulfide	75150		5000	1,4	P022	B	100 (45.4)
Carbon oxyfluoride	353504	Carbonic difluoride	1*	4	U033	C	1000 (454)
Carbon tetrachloride	56235	Methane, tetrachloro-	5000	1,2,4	U211	A	10 (4.54)
Carbonic acid, dithallium(1+) salt	653739	Thallium(I) carbonate	1*	4	U215	B	100 (45.4)
Carbonic dichloride	75445	Phosgene	5000	1,4	P095	A	10 (4.54)
Carbonic difluoride	353504	Carbon oxyfluoride	1*	4	U033	C	1000 (454)
Carbonochloridic acid, methyl ester	79221	Methyl chlorocarbonate Methyl chloroformate	1*	4	U156	C	1000 (454)
Chloral	75876	Acetaldehyde, trichloro-	1*	4	U034	D	5000 (2270)
Chlorambucil	305033	Benzenebutanoic acid, 4-[bis(2-chloroethyl)amino]-	1*	4	U035	A	10 (4.54)
Chlordane	57749	Chlordane, alpha & gamma isomers Chlordane, technical 4,7-Methano-1H-indene, 1,2,4,5,6,7,8,8-octachloro-2,3,3a,4,7,7a-hexahydro-	1	1,2,4	U036	X	1 (0.454)
CHLORDANE (TECHNICAL MIXTURE AND METABOLITES)	N/A		1*	2			**
Chlordane, alpha & gamma isomers	57749	Chlordane Chlordane, technical 4,7-Methano-1H-indene, 1,2,4,5,6,7,8,8-octachloro-2,3,3a,4,7,7a-hexahydro-	1	1,2,4	U036	X	1 (0.454)
Chlordane, technical	57749	Chlordane Chlordane, alpha & gamma isomers 4,7-Methano-1H-indene, 1,2,4,5,6,7,8,8-octachloro-2,3,3a,4,7,7a-hexahydro-	1	1,2,4	U036	X	1 (0.454)
CHLORINATED BENZENES	N/A		1*	2			**
CHLORINATED ETHANES	N/A		1*	2			**
CHLORINATED NAPHTHALENE	N/A		1*	2			**
CHLORINATED PHENOLS	N/A		1*	2			**
Chlorine	7782505		10	1		A	10 (4.54)
Chlornaphazine	494031	Naphthalenamine, N,N'-bis(2-chloroethyl)-	1*	4	U026	B	100 (45.4)
Chloroacetaldehyde	107200	Acetaldehyde, chloro-	1*	4	P023	C	1000 (454)

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Hazardous Substance	CASRN	Regulatory Synonyms	Statutory			Final RQ	
			RQ	Code†	RCRA Waste #	Category	Pounds (Kg)
CHLOROALKYL ETHERS	N/A		1*	2			**
p-Chloroaniline	106478	Benzenamine, 4-chloro-	1*	4	P024	C	1000 (454)
Chlorobenzene	108907	Benzene, chloro-	100	1,2,4	U037	B	100 (45.4)
Chlorobenzilate	510156	Benzeneacetic acid, 4-chloro-alpha-(4-chloro-phenyl)-alpha-hydroxy-, ethyl ester	1*	4	U038	A	10 (4.54)
4-Chloro-m-cresol	59507	p-Chloro-m-cresol Phenol, 4-chloro-3-methyl	1*	2,4	U039	D	5000 (2270)
p-Chloro-m-cresol	59507	Phenol, 4-chloro-3-methyl- 4-Chloro-m-cresol	1*	2,4	U039	D	5000 (2270)
Chlorodibromomethane	124481		1*	2		B	100 (45.4)
Chloroethane	75003		1*	2		B	100 (45.4)
2-Chloroethyl vinyl ether	110758	Ethene, 2-chloroethoxy-	1*	2,4	U042	C	1000 (454)
Chloroform	67663	Methane, trichloro-	5000	1,2,4	U044	A	10 (4.54)
Chloromethyl methyl ether	107302	Methane, chloromethoxy-	1*	4	U046	A	10 (4.54)
beta-Chloronaphthalene	91587	Naphthalene, 2-chloro- 2-Chloronaphthalene	1*	2,4	U047	D	5000 (2270)
2-Chloronaphthalene	91587	beta-Chloronaphthalene Naphthalene, 2-chloro-	1*	2,4	U047	D	5000 (2270)
2-Chlorophenol	95578	o-Chlorophenol Phenol, 2-chloro-	1*	2,4	U048	B	100 (45.4)
o-Chlorophenol	95578	Phenol, 2-chloro- 2-Chlorophenol	1*	2,4	U048	B	100 (45.4)
4-Chlorophenyl phenyl ether	7005723		1*	2		D	5000 (2270)
1-(o-Chlorophenyl)thiourea	5344821	Thiourea, (2-chlorophenyl)-	1*	4	P026	B	100 (45.4)
3-Chloropropionitrile	542767	Propanenitrile, 3-chloro-	1*	4	P027	C	1000 (454)
Chlorosulfonic acid	7790945		1000	1		C	1000 (454)
4-Chloro-o-toluidine, hydrochloride	3165933	Benzenamine, 4-chloro-2-methyl-, hydrochloride	1*	4	U049	B	100 (45.4)
Chlorpyrifos	2921882		1	1		X	1 (0.454)
Chromic acetate	1066304		1000	1		C	1000 (454)
Chromic acid	11115745		1000	1		A	10 (4.54)
	7738945		1000	1		A	10 (4.54)
Chromic acid H2CrO4, calcium salt	13765190	Calcium chromate	1000	1,4	U032	A	10 (4.54)
Chromic sulfate	10101538		1000	1		C	1000 (454)
Chromium††	7440473		1*	2		D	5000 (2270)

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Hazardous Substance	CASRN	Regulatory Synonyms	Statutory			Final RQ	
			RQ	Code†	RCRA Waste #	Category	Pounds (Kg)
CHROMIUM AND COMPOUNDS	N/A		1*	2			**
Chromous chloride	10049055		1000	1		C	1000 (454)
Chrysene	218019	1,2-Benzphenanthrene	1*	2,4	U050	B	100 (45.4)
Cobaltous bromide	7789437		1000	1		C	1000 (454)
Cobaltous formate	544183		1000	1		C	1000 (454)
Cobaltous sulfamate	14017415		1000	1		C	1000 (454)
Coke Oven Emissions	N/A		1*	3		X	1 (0.454)
Copper cyanide CuCN	544923	Copper cyanide	1*	4	P029	A	10 (4.54)
Copper††	7440508		1*	2		D	5000 (2270)
COPPER AND COMPOUNDS	N/A		1*	2			**
Copper cyanide	544923	Copper cyanide CuCN	1*	4	P029	A	10 (4.54)
Coumaphos	56724		10	1		A	10 (4.54)
Creosote	8001589		1*	4	U051	X	1 (0.454)
Cresol(s)	1319773	Cresylic acid Phenol, methyl-	1000	1,4	U052	C	1000 (454)
m-Cresol	108394	m-Cresylic acid	1000	1,4	U052	C	1000 (454)
o-Cresol	95487	o-Cresylic acid	1000	1,4	U052	C	1000 (454)
p-Cresol	106445	p-Cresylic acid	1000	1,4	U052	C	1000 (454)
Cresylic acid	1319773	Cresol(s) Phenol, methyl-	1000	1,4	U052	C	1000 (454)
m-Cresol	108394	m-Cresylic acid	1000	1,4	U052	C	1000 (454)
o-Cresol	95487	o-Cresylic acid	1000	1,4	U052	C	1000 (454)
p-Cresol	106445	p-Cresylic acid	1000	1,4	U052	C	1000 (454)
Crotonaldehyde	123739	2-Butenal	100	1,4	U053	B	100 (45.4)
	4170303						
Cumene	98828	Benzene, 1-methylethyl-	1*	4	U055	D	5000 (2270)
Cupric acetate	142712		100	1		B	100 (45.4)
Cupric acetoarsenite	12002038		100	1		X	1 (0.454)
Cupric chloride	7447394		10	1		A	10 (4.54)
Cupric nitrate	3251238		100	1		B	100 (45.4)
Cupric oxalate	5893663		100	1		B	100 (45.4)
Cupric sulfate	7758987		10	1		A	10 (4.54)
Cupric sulfate, ammoniated	10380297		100	1		B	100 (45.4)

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Hazardous Substance	CASRN	Regulatory Synonyms	Statutory			Final RQ	
			RQ	Code†	RCRA Waste #	Category	Pounds (Kg)
Cupric tartrate	815827		100	1		B	100 (45.4)
CYANIDES	N/A		1*	2			**
Cyanides (soluble salts and complexes) not otherwise specified	57125		1*	4	P030	A	10 (4.54)
Cyanogen	460195	Ethanedinitrile	1*	4	P031	B	100 (45.4)
Cyanogen bromide	506683	Cyanogen bromide (CN)Br	1*	4	U246	C	1000 (454)
Cyanogen bromide (CN)Br	506683	Cyanogen bromide	1*	4	U246	C	1000 (454)
Cyanogen chloride	506774	Cyanogen chloride (CN)Cl	10	1,4	P033	A	10 (4.54)
Cyanogen chloride (CN)Cl	506774	Cyanogen chloride	10	1,4	P033	A	10 (4.54)
2,5-Cyclohexadiene-1,4-dione	106514	p-Benzoquinone	1*	4	U197	A	10 (4.54)
Cyclohexane	110827	Benzene, hexahydro-	1000	1,4	U056	C	1000 (454)
Cyclohexane, 1,2,3,4,5,6-hexachloro-,(1alpha, 2alpha, 3beta,4alpha,5alpha,6,beta)-	58899	gamma—BHC	1	1,2,4	U129	X	1 (0.454)
Cyclohexanone	108941		1*	4	U057	D	5000 (2270)
2-Cyclohexyl-4,6-dinitrophenol	131895	Phenol, 2-cyclohexyl-4,6-dinitro-	1*	4	P034	B	100 (45.4)
1,3-Cyclopentadiene, 1,2,3,4,5,5-hexachloro-	77474	Hexachlorocyclopentadiene	1	1,2,4	U130	A	10 (4.54)
Cyclophosphamide	50180	2H-1,3,2-Oxazaphosphorin-2-amine, N,N-bis(2-chloroethyl) tetrahydro-,2-oxide	1*	4	U058	A	10 (4.54)
2,4-D Acid	94757	Acetic acid (2,4-dichlorophenoxy)-2,4-D, salts and esters	100	1,4	U240	B	100 (45.4)
2,4-D Ester	94111		100	1		B	100 (45.4)
	94791		100	1		B	100 (45.4)
	94804		100	1		B	100 (45.4)
	1320189		100	1		B	100 (45.4)
	1928387		100	1		B	100 (45.4)
	1928616		100	1		B	100 (45.4)
	1929733		100	1		B	100 (45.4)
	2971382		100	1		B	100 (45.4)
	25168267		100	1		B	100 (45.4)
	53467111		100	1		B	100 (45.4)
2,4-D, salts and esters	94757	Acetic acid (2,4-dichlorophenoxy)-2,4-D Acid	100	1,4	U240	B	100 (45.4)

Hazardous Substance	CASRN	Regulatory Synonyms	Statutory			Final RQ	
			RQ	Code†	RCRA Waste #	Category	Pounds (Kg)
Daunomycin	20830813	5,12-Naphthacenedione, 8-acetyl-10-[3-amino-2,3,6-trideoxy-alpha-L-lyxo-hexo-pyranosyl)oxy]-7,8,9,10-tetrahydro-6,8,11-trihydroxy-1-methoxy-, (8S-cis)-	1*	4	U059	A	10 (4.54)
DDD	72548	Benzene, 1,1'-(2,2-dichloroethylidene)bis[4-chloro- TDE 4,4' DDD	1	1,2,4	U060	X	1 (0.454)
4,4' DDD	72548	Benzene, 1,1'-(2,2-dichloroethylidene)bis[4-chloro- DDD TDE	1	1,2,4	U060	X	1 (0.454)
DDE	72559	4,4' DDE	1*	2		X	1 (0.454)
4,4' DDE	72559	DDE	1*	2		X	1 (0.454)
DDT	50293	Benzene, 1,1'-(2,2,2-trichloroethylidene)bis[4-chloro- 4,4'DDT	1	1,2,4	U061	X	1 (0.454)
4,4' DDT	50293	Benzene, 1,1'-(2,2,2-trichloroethylidene)bis[4-chloro- DDT	1	1,2,4	U061	X	1 (0.454)
DDT AND METABOLITES	N/A		1*	2			**
Diallate	2303164	Carbamothioic acid, bis(1-methylethyl)-, S-(2,3,-dich-loro-2-propenyl) ester	1*	4	U062	B	100 (45.4)
Diazinon	333415		1	1		X	1 (0.454)
Dibenz[a,h]anthracene	53703	Dibenzo[a,h]anthracene 1,2:5,6-Dibenzanthracene	1*	2,4	U063	X	1 (0.454)
1,2:5,6-Dibenzanthracene	53703	Dibenz[a,h]anthracene Dibenzo[a,h]anthracene	1*	2,4	U063	X	1 (0.454)
Dibenzo[a,h]anthracene	53703	Dibenz[a,h]anthracene 1,2:5,6-Dibenzanthracene	1*	2,4	U063	X	1 (0.454)
Dibenz[a,i]pyrene	189559	Benzo[rst]pentaphene	1*	4	U064	A	10 (4.54)
1,2-Dibromo-3-chloropropene	96128	Propane, 1,2-dibromo-3-chloro-	1*	4	U066	X	1 (0.454)
Dibutyl phthalate	84742	Dibutyl phthalate n-Butyl phthalate 1,2-Benzenedicarboxylic acid, dibutyl ester	100	1,2,4	U069	A	10 (4.54)
Di-n-butyl phthalate	84742	Dibutyl phthalate n-Butyl phthalate 1,2-Benzenedicarboxylic acid, dibutyl ester	100	1,2,4	U069	A	10 (4.54)
Dicamba	1918009		1000	1		C	1000 (454)

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Hazardous Substance	CASRN	Regulatory Synonyms	Statutory			Final RQ	
			RQ	Code†	RCRA Waste #	Category	Pounds (Kg)
Dichlobenil	1194656		1000	1		B	100 (45.4)
Dichlone	117806		1	1		X	1 (0.454)
Dichlorobenzene	25321226		100	1		B	100 (45.4)
1,2-Dichlorobenzene	95501	Benzene, 1,2-dichloro- o-Dichlorobenzene	100	1,2,4	U070	B	100 (45.4)
1,3-Dichlorobenzene	541731	Benzene, 1,3-dichloro m-Dichlorobenzene	1*	2,4	U071	B	100 (45.4)
1,4-Dichlorobenzene	106467	Benzene, 1,4-dichloro p-Dichlorobenzene	100	1,2,4	U072	B	100 (45.4)
m-Dichlorobenzene	541731	Benzene, 1,3-dichloro 1,3-Dichlorobenzene	1*	2,4	U071	B	100 (45.4)
o-Dichlorobenzene	95501	Benzene, 1,2-dichloro 1,2-Dichlorobenzene	100	1,2,4	U070	B	100 (45.4)
p-Dichlorobenzene	106467	Benzene, 1,4-dichloro 1,4-Dichlorobenzene	100	1,2,4	U072	B	100 (45.4)
DICHLOROBENZIDINE	N/A		1*	2			**
3,3'-Dichlorobenzidine	91941	[1,1'-Biphenyl]-4,4'diamine,3,3'dichloro-	1*	2,4	U073	X	1 (0.454)
Dichlorobromomethane	75274		1*	2		D	5000 (2270)
1,4-Dichloro-2-butene	764410	2-Butene, 1,4-dichloro-	1*	4	U074	X	1 (0.454)
Dichlorodifluoromethane	75718	Methane, dichlorodifluoro-	1*	4	U075	D	5000 (2270)
1,1-Dichloroethane	75343	Ethane, 1,1-dichloro- Ethylidene dichloride	1*	2,4	U076	C	1000 (454)
1,2-Dichloroethane	107062	Ethane, 1,2-dichloro- Ethylene dichloride	5000	1,2,4	U077	B	100 (45.4)
1,1-Dichloroethylene	75354	Ethene, 1,1-dichloro- Vinylidene chloride	5000	1,2,4	U078	B	100 (45.4)
1,2-Dichloroethylene	156605	Ethene 1,2-dichloro- (E)	1*	2,4	U079	C	1000 (454)
Dichloroethyl ether	111444	Bis (2-chloroethyl) ether Ethane, 1,1'-oxybis[2-chloro-	1*	2,4	U025	A	10 (4.54)
Dichloroisopropyl ether	108601	Propane, 2,2'-oxybis[2-chloro-	1*	2,4	U027	C	1000 (454)
Dichloromethoxy ethane	111911	Bis(2-chloroethoxy) methane Ethane, 1,1'-[methylenebis(oxy)] bis[2-chloro-	1*	2,4	U024	C	1000 (454)
Dichloromethyl ether	542881	Methane, oxybis(chloro-	1*	4	P016	A	10 (4.54)
2,4-Dichlorophenol	120832	Phenol, 2,4-dichloro-	1*	2,4	U081	B	100 (45.4)
2,6-Dichlorophenol	87650	Phenol, 2,6-dichloro-	1*	4	U082	B	100 (45.4)
Dichlorophenylarsine	696286	Arsonous dichloride, phenyl-	1*	4	P036	X	1 (0.454)

Hazardous Substance	CASRN	Regulatory Synonyms	Statutory			Final RQ	
			RQ	Code†	RCRA Waste #	Category	Pounds (Kg)
Dichloropropane	26638197		5000	1		C	1000 (454)
1,1-Dichloropropane	78999		5000	1		C	1000 (454)
1,3 Dichloropropane	142289		5000	1		C	1000 (454)
1,2-Dichloropropane	78875	Propane, 1,2-dichloro- Propylene dichloride	5000	1,2,4	U083	C	1000 (454)
Dichloropropane – Dichloropropene (mixture)	8003198		5000	1		B	100 (45.4)
Dichloropropene	26952238		5000	1		B	100 (45.4)
2,3-Dichloropropene	78886		5000	1		B	100 (45.4)
1,3-Dichloropropene	542756	1-Propene, 1,3-dichloro-	5000	1,2,4	U084	B	100 (45.4)
2,2-Dichloropropionic acid	75990		5000	1		D	5000 (2270)
Dichlorvos	62737		10	1		A	10 (4.54)
Dicofol	115322		5000	1		A	5000 (2270)
Dieldrin	60571	2,7:3,6-Dimethanonaphth[2,3-b]oxirene,3,4,5,6,9,9-hexachloro-1a,2,2a,3,6,6a,7,7a-octahydro-, (1aalpha,2beta,2aalpha,3beta,6beta,6aalpha,7beta, 7aalpha)-	1	1,2,4	P037	X	1 (0.454)
1,2:3,4-Diepoxybutane	1464535	2,2'-Bioxirane	1*	4	U085	A	10 (4.54)
Diethylamine	109897		1000	1		B	100 (454.4)
Diethylarsine	692422	Arsine, diethyl-	1*	4	P038	X	1 (0.454)
1,4-Diethylenedioxide	123911	1,4-Dioxane	1*	4	U108	B	100 (45.4)
Diethylhexyl phthalate	117817	Bis (2-ethylhexyl)phthalate 1,2,-Benzenedicarboxylic acid, [bis(2-ethylhexyl)] ester	1*	2,4	U028	B	100 (45.4)
N,N-'Diethylhydrazine	1615801	Hydrazine, 1,2-diethyl-	1*	4	U086	A	10 (4.54)
O,O-Diethyl S-methyl dithiophosphate	3288582	Phosphorodithioic acid, O,O-diethyl S-methyl ester	1*	4	U087	D	5000 (2270)
Diethyl-p-nitrophenyl phosphate	311455	Phosphoric acid, diethyl 4-nitrophenyl ester	1*	4	P041	B	100 (45.4)
Diethyl phthalate	84662	1,2-Benzenedicarboxylic acid, diethyl ester	1*	2,4	U088	C	1000 (454)
O,O-Diethyl O-pyrazinyl phosphorothioate	297972	Phosphorothioic acid, O,O-diethyl O-pyrazinyl ester	1*	4	P040	B	100 (45.4)
Diethylstilbestrol	56531	Phenol, 4,4'-(1,2-diethyl-1,2-ethenediyl)bis-, (E)	1*	4	U089	X	1 (0.454)
Dihydrosafrole	94586	1,3-Benzodioxole, 5-propyl-	1*	4	U090	A	10 (4.54)

Hazardous Substance	CASRN	Regulatory Synonyms	Statutory			Final RQ	
			RQ	Code†	RCRA Waste #	Category	Pounds (Kg)
Diisopropylfluorophosphate	55914	Phosphorofluoridic acid, bis(1-methylethyl) ester	1*	4	P043	B	100 (45.4)
1,4,5,8-Dimethanonaphthalene, 1,2,3,4,10,10-,10-hexachloro-1,4,4a,5,8,8a-hexahydro-, (1alpha,4alpha,4abeta,5alpha,' 8alpha,	309002	Aldrin	1	1,2,4	P004	X	1 (0.454)
8abeta)-1,4,5,8-Dimenthanonaphthalene, 1,2,3,4,10,10-hexachloro-1,4,4a,5,8,8a-hexahydro,(1alpha,4alpha,4abeta, 5abeta,8beta,	465736	Isodrin	1*	4	P060	X	1 (0.454)
8abeta)-2,7:3,6-Dimethanonaphth[2,3-b]oxirene, 3,4,5,6,9,9-hexachloro-1a,2,2a,3, 6,6a,7,7a-octahydro-, (1aalpha, 2beta,2aalpha,3beta,6beta,	60571	Dieldrin	1	1,2,4	P037	X	1 (0.454)
6aalpha,7beta,7aalpha)-2,7:3,6-Dimethanonaphth[2,3-b]oxirene, 3,4,5,6,9,9-hexachloro-1a,2,2a,3, 6,6a,7,7a-octa hydro-,(1aalpha, 2beta,2abeta,3alpha,6alpha,	72208	Endrin Endrin & metabolites	1	1,2,4	P051	X	1 (0.454)
6abeta,7beta,7aalpha)-Dimethoate	60515	Phosphorodithioic acid, O,O-dimethyl S-[2(methyla-mino)-2-oxoethyl] ester	1*	4	P044	A	10 (4.54)
3,3'-Dimethoxybenzidine	119904	[1,1'-Biphenyl]-4,4'diamine,3, 3'dimethyoxy-	1*	4	U091	B	100 (45.4)
Dimethylamine	124403	methanamine, N-methyl	1000	1,4	U092	C	1000 (454)
p-Dimethylaminoazobenzene	60117	Benzenamine, N,N-dimethyl-4-(phenylazo-)	1*	4	U093	A	10 (4.54)
7,12-Dimethylbenz[a]anthracene	57976	Benz[a]anthracene, 7,12-dimethyl-	1*	4	U094	X	1 (0.454)
3,3'-Dimethylbenzidine	119937	[1,1'Biphynyl]-4,4'diamine,3,3'-dimethyl-	1*	4	U095	A	10 (4.54)
alpha,alpha-Dimethylbenzylhydroperoxide	80159	Hydroperoxide, 1-mehtyl-1-phenylethyl-	1*	4	U096	A	10 (4.54)
Dimethylcarbamoyl chloride	79447	Carbamic chloride, dimethyl-	1*	4	U097	X	1 (0.454)
1,1-Dimethylhydrazine	57147	Hydrazine, 1,1-dimethyl-	1*	4	U098	A	10 (4.54)
1,2-Dimethylhydrazine	540738	Hydrazine, 1,2-dimethyl-	1*	4	U099	X	1 (0.454)
alpha,alpha-Dimethylphenethylamine	122098	Benzeneethanamine, alpha,alpha-dimethyl-	1*	4	P046	D	5000 (2270)
2,4-Dimethylphenol	105679	Phenol, 2,4-dimethyl-	1*	2,4	U101	B	100 (45.4)

Hazardous Substance	CASRN	Regulatory Synonyms	Statutory RQ	Statutory Code†	Statutory RCRA Waste #	Final RQ Category	Final RQ Pounds (Kg)
Dimethyl phthalate	131113	1,2-Benzenedicarboxylic acid, dimethyl ester	1*	2,4	U102	D	5000 (2270)
Dimethyl sulfate	77781	Sulfuric acid, dimethyl ester	1*	4	U103	B	100 (45.4)
Dinitrobenzene (mixed)	25154545		1000	1		B	100 (45.4)
m-Dinitrobenzene	99650		1000	1		B	100 (45.4)
o-Dinitrobenzene	528290		1000	1		B	100 (45.4)
p-Dinitrobenzene	100254		1000	1		B	100 (45.4)
4,6-Dinitro-o-cresol and salts	534521	Phenol, 2-methyl-4,6-dinitro-	1*	2,4	P047	A	10 (4.54)
Dinitrophenol	25550587		1000	1		A	10 (4.54)
2,5-Dinitrophenol	329715		1000	1		A	10 (4.54)
2,6-Dinitrophenol	573568		1000	1		A	10 (4.54)
2,4-Dinitrophenol	51285	Phenol, 2,4-dinitro-	1000	1,2,4	P048	A	10 (4.54)
Dinitrotoluene	25321146		1000	1,2		A	10 (4.54)
3,4-Dinitrotoluene	610399						
2,4-Dinitrotoluene	121142	Benzene, 1-methyl-2,4-dinitro-	1000	1,2,4	U105	A	10 (4.54)
2,6-Dinitrotoluene	606202	Benzene, 2-methyl-1,3-dinitro-	1000	1,2,4	U106	B	100 (45.4)
Dinoseb	88857	Phenol, 2-(1-methylpropyl)-4,6-dinitro	1*	4	P020	C	1000 (454)
Di-n-octyl phthalate	117840	1,2-Benzenedicarboxylic acid, dioctyl ester	1*	2,4	U107	D	5000 (2270)
1,4-Dioxane	123911	1,4-Diethylenedioxide	1*	4	U108	B	100 (45.4)
DIPHENYLHYDRAZINE	N/A		1*	2			**
1,2-Diphenylhydrazine	122667	Hydrazine, 1,2-diphenyl	1*	2,4	U109	A	10 (4.54)
Diphosphoramide, octamethyl-	152169	Octamethylpyrophosphoramide	1*	4	P085	B	100 (45.4)
Diphosphoric acid, tetraethyl ester	107493	Tetraethyl pyrophosphate	100	1,4	P111	A	10 (4.54)
Dipropylamine	142847	1-Propanamine, N-propyl-	1*	4	U110	D	5000 (2270)
Di-n-propylnitrosamine	621647	1-Propanamine, N-nitroso-N-propyl-	1*	2,4	U111	A	10 (4.54)
Diquat	85007		1000	1		C	1000 (454)
	2764729		1000	1		C	1000 (454)
Disulfoton	298044	Phosphorodithioic acid, o,o-diethyl S-[2-(ethylthio)ethyl]ester	1	1,4	P039	X	1 (0.454)
Dithiobiuret	541537	Thiomidodicarbonic diamide [(H2N)C(S)]2NH	1*	4	P049	B	100 (45.4)
Diuron	330541		100	1		B	100 (45.4)

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Hazardous Substance	CASRN	Regulatory Synonyms	Statutory			Final RQ	
			RQ	Code†	RCRA Waste #	Category	Pounds (Kg)
Dodecylbenzenesulfonic acid	27176870		1000	1		C	1000 (454)
Endosulfan	115297	6,9-Methano-2,4,3-benzodioxathiepin, 6,7,8,9,10,10-hexachloro-1,5,5a,6,9,9a-hexahydro-, 3-oxide	1	1,2,4	P050	X	1 (0.454)
alpha - Endosulfan	959988		1*	2		X	1 (0.454)
beta - Endosulfan	33213659		1*	2		X	1 (0.454)
ENDOSALFAN AND METABOLITES	N/A		1*	2			**
Endosulfan sulfate	1031078		1*	2		X	1 (0.454)
Endothall	145733	7-Oxabicyclo[2.2.1]heptane-2,3-dicarboxylic acid	1*	4	P088	C	1000 (454)
Endrin	72208	Endrin, & metabolites 2,7:3,6 Dimethanonaphth[2,3-b]oxirene,3,4,5,6,9,9 -hexachloro-1a,2,2a,3,6,6a,7,7a-octa-hydro-, (1 aalpha, 2beta,2abeta,3alpha, 6alpha,6abeta,7beta, 7aalpha)-	1	1,2,4	P051	X	1 (0.454)
Endrin aldehyde	7421934		1*	2		X	1 (0.454)
ENDRIN AND METABOLITES	N/A		1*	2			**
Endrin, & metabites	72208	Endrin 2,7:3,6-Dimethanonaphth[2,3-b] oxirene, 3,4,5,6,9,9-hexachloro-1a,2,2a,3,6,6a,7,7a-octa-hydro-, (1 aalpha,2beta, 2abeta,3alpha, 6alpha, ... 6abeta,7beta, 7aalpha)-	1	1,2,4	P051	X	1 (0.454)
Epichlorohydrin	106898	Oxirane, (chloromethyl)-	1000	1,4	U041	B	100 (45.4)
Epinephrine	51434	1,2-Benzenediol,4-[1-hydroxy-2-(methylamino)ethyl]-	1*	4	P042	C	1000 (454)
Ethanal	75070	Acetaldehyde	1000	1,4	U001	C	1000 (454)
Ethanamine, N-ethyl-N-nitroso-	55185	N-Nitrosodiethylamine	1*	4	U174	X	1 (0.454)
1,2-Ethanediamine, N,N-dimethyl-N'-2-pyridinyl-N'-(2-thienylmethyl)-	91805	Methapyrilene	1*	4	U155	D	5000 (2270)
Ethane, 1,2-dibromo-	106934	Ethylene dibromide	1000	1,4	U067	X	1 (0.454)
Ethane, 1,1-dichloro-	75343	Ethylidene dichloride 1,1-Dichloroethane	1*	2,4	U076	C	1000 (454)
Ethane, 1,2-dichloro-	107062	Ethylene dichloride 1,2-Dichlorethane	5000	1,2,4	U077	B	100 (45.4)
Ethanedinitrile	460195	Cyanogen	1*	4	P031	B	100 (45.4)

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Hazardous Substance	CASRN	Regulatory Synonyms	Statutory RQ	Statutory Code†	Statutory RCRA Waste #	Final RQ Category	Final RQ Pounds (Kg)
Ethane, hexachloro-	67721	Hexachloroethane	1*	2,4	U131	B	100 (45.4)
Ethane, 1,1'-[methylenebis(oxy)]bis(2-chloro-	111911	Bis(2-chloroethoxy) methane Dichloromethoxy ethane	1*	2,4	U024	C	1000 (454)
Ethane, 1,1'-oxybis-	60297	Ethyl ether	1*	4	U117	B	100 (45.4)
Ethane, 1,1'-oxybis[2-chloro-	111444	Bis (2-chloroethyl) ether Dichloroethyl ether	1*	2,4	U025	A	10 (4.54)
Ethane, pentachloro-	76017	Pentachloroethane	1*	4	U184	A	10 (4.54)
Ethane, 1,1,1,2-tetrachloro	630206	1,1,1,2-Tetrachloroethane	1*	4	U208	B	100 (45.4)
Ethane, 1,1,2,2-tetrachloro	79345	1,1,2,2-Tetrachloroethane	1*	2,4	U209	B	100 (45.4)
Ethanethioamide	62555	Thioacetamide	1*	4	U218	A	10 (4.54)
Ethane, 1,1,1-trichloro	71556	Methyl chloroform 1,1,1-Trichloroethane	1*	2,4	U226	C	1000 (454)
Ethane, 1,1,2-trichloro-	79005	1,1,2-Trichloroethane	1*	2,4	U227	B	100 (45.4)
Ethanimidothioic acid, N-[[(methylamino)carbonyl]oxy]-, methyl ester	16752775	Methomyl	1*	4	P066	B	100 (45.4)
Ethanol, 2-ethoxy-	110805	Ethylene glycol monoethyl ether	1*	4	U359	C	1000 (454)
Ethanol, 2,2'-(nitrosoimino)bis-	1116547	N-Nitrosodiethanolamine	1*	4	U173	X	1 (0.454)
Ethanone, 1-phenyl-	98862	Acetophenone	1*	4	U004	D	5000 (2270)
Ethene, chloro-	75014	Vinyl chloride	1*	2,3,4	U043	X	1 (0.454)
Ethene, 2-Cloroethoxy-	110758	2-Chloroethyl vinyl ether	1*	2,4	U042	C	1000 (454)
Ethene, 1,1-dichloro-	75354	Vinylidene chloride 1,1-Dichloroethylene	5000	1,2,4	U078	B	100 (45.4)
Ethene, 1,2-dichloro-	156605	1,2-Dichloroethylene	1*	2,4	U079	C	1000 (45.4)
Ethene, tetrachloro-	127184	Perchloroethylene Tetrachlorethene Tetrachloroethylene	1*	2,4	U210	B	100 (45.4)
Ethene, trichloro-	79016	Trichloroethene Trichloroethylene	1000	1,2,4	U228	B	100 (45.4)
Ethion	563122		10	1		A	10 (4.54)
Ethyl acetate	141786	Acetic acid, ethyl ester	1*	4	U112	D	5000 (2270)
Ethyl acrylate	140885	2-Propenoic acid, ethyl ester	1*	4	U113	C	1000 (454)
Ethylbenzene	100414		1000	1,2		C	1000 (454)
Ethyl carbamate (urethane)	51796	Carbamic acid, ethyl ester	1*	4	U238	B	100 (45.4)
Ethyl cyanide	107120	Propanenitril	1*	4	P101	A	10 (4.54)

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Hazardous Substance	CASRN	Regulatory Synonyms	Statutory			Final RQ	
			RQ	Code†	RCRA Waste #	Category	Pounds (Kg)
Ethylenebisdithiocarbamic acid, salts & esters	111546	Carbamodithioic acid, 1,2-ethanediylbis-, salts & esters	1*	4	U114	D	5000 (2270)
Ethylenediamine	107153		1000	1		D	5000 (2270)
Ethylenediamine-tetraacetic acid (EDTA)	60004		5000	1		D	5000 (2270)
Ethylene dibromide	106934	Ethane, 1,2-dibromo-	1000	1,4	U067	X	1 (0.454)
Ethylene dichloride	107062	Ethane, 1,2-dichloro- 1,2-Dichloroethane	5000	1,2,4	U077	B	100 (45.4)
Ethylene glycol monoethy ether	110805	Ethanol, 2-ethoxy-	1*	4	U359	C	1000 (454)
Ethylene oxide	75218	Oxirane	1*	4	U115	A	10 (4.54)
Ethylenethiourea	96457	2-Imidazolidinethione	1*	4	U116	A	10 (4.54)
Ethylenimine	151564	Aziridine	1*	4	P054	X	1 (0.454)
Ethyl ether	60297	Ethane, 1,1'-oxybis	1*	4	U117	B	100 (45.4)
Ethylidene dichloride	75343	Ethane, 1,1'-dichloro- 1,1-Dichloroethane	1*	2,4	U076	C	1000 (454)
Ethyl methacrylate	97632	2-Propenoic acid, 2-methyl-, ethyl ester	1*	4	U118	C	1000 (454)
Ethyl methanesulfonate	62500	Methanesulfonic acid, ethyl ester	1*	4	U119	X	1 (0.454)
Famphur	52857	Phosphorothioic acid, O,[4-[(dimethylamino) sulfonyl] phenyl] O,O-dimethyl ester	1*	4	P097	C	1000 (454)
Ferric ammonium citrate	1185575		1000	1		C	1000 (454)
Ferric ammonium oxalate	2944674		1000	1		C	1000 (454)
	55488874		1000	1		C	1000 (454)
Ferric chloride	7705080		1000	1		C	1000 (454)
Ferric flouride	7783508		100	1		B	100 (45.4)
Ferric nitrate	10421484		1000	1		C	1000 (454)
Ferric sulfate	10028225		1000	1		C	1000 (454)
Ferrous ammonium sulfate	10045893		1000	1		C	1000 (454)
Ferrous chloride	7758943		100	1		B	100 (45.4)
Ferrous sulfate	7720787		1000	1		C	1000 (454)
	7782630		1000	1		C	1000 (454)
Flouranthene	206440	Benzo[j,k]flourene	1*	2,4	U120	B	100 (45.4)
Flourene	86737		1*	2		D	5000 (2270)
Flourine	7782414		1*	4	P056	A	10 (4.54)

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Hazardous Substance	CASRN	Regulatory Synonyms	Statutory			Final RQ	
			RQ	Code†	RCRA Waste #	Category	Pounds (Kg)
Flouroacetamide	640197	Acetamide, 2-fluoro-	1*	4	P057	B	100 (45.4)
Flouracetic acid, sodium salt	62748	Acetic acid, fluoro-, sodium salt	1*	4	P058	A	10 (4.54)
Formaldehyde	50000		1000	1,4	U122	B	100 (45.4)
Formic acid	64186		5000	1,4	U123	D	5000 (2270)
Fulminic acid, mercury(2+)salt	628864	Mercury fulminate	1*	4	P065	A	10 (4.54)
Fumaric acid	110178		5000	1		D	5000 (2270)
Furan	110009	Furfuran	1*	4	U124	B	100 (45.4)
Furan, tetrahydro-	109999	Tetrahydrofuran	1*	4	U213	C	1000 (454)
2-Furancarboxaldehyde	98011	Furfural	1000	1,4	U125	D	5000 (2270)
2,5-Furandione	108316	Maleic anhydride	5000	1,4	U147	D	5000 (2270)
Furfural	98011	2-Furancarboxaldehyde	1000	1,4	U125	D	5000 (2270)
Furfuran	110009	Furan	1*	4	U124	B	100 (45.4)
Glucopyranose, 2-deoxy-2-(3-methyl-3-nitrosoureido)-	18883664	D-Glucose, 2-deoxy-2-[[(methylnitrosoamino)-carbonyl]amino] Streptozotocin	1*	4	U206	X	1 (0.454)
D-Glucose, 2-deoxy-2-[[(methylnitrosoamino)-carbonyl]amino]-	18883664	Glucopyranose, 2-deoxy-2-(3-methyl-3-nitrosoureido)-	1*	4	U206	X	1 (0.45)
Glycidylaldehyde	765344	Oxiranecarboxyaldehyde	1*	4	U126	A	10 (4.54)
Guanidien, N-methyl-N'-nitro-N-nitroso-	70257	MNNG	1*	4	U163	A	10 (4.54)
Guthion	865500		1	1		X	1 (0.454)
HALOETHERS	N/A		1*	2			**
HALOMETHANES	N/A		1*	2			**
Heptachlor	76448	4,7-Methano-1H-indene, 1,4,5,6,7,8,8-heptachloro-3a,4,7,7a-tetrahydro-	1	1,2,4	P059	X	1 (0.454)
HEPTACHLOR AND METABOLITES	N/A		1*	2			**
Heptachlor epoxide	1024573		1*	2		X	1 (0.454)
Hexachlorobenzene	118741	Benzene, hexachloro-	1*	2,4	U127	A	10 (4.54)
Hexachlorobutadiene	87683	1,3-Butadiene, 1,1,2,3,4,5-hexachloro-	1*	2,4	U128	X	1 (0.454)
HEXACHLOROCYCLOHEXANE (all isomers)	608731		1*	2			**

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Hazardous Substance	CASRN	Regulatory Synonyms	Statutory			Final RQ	
			RQ	Code†	RCRA Waste #	Category	Pounds (Kg)
Hexachlorocyclohexane (gamma isomer)	58899	Cyclohexane, 1,2,3,4,5,6-hexachloro-,(1alpha,2alpha,3beta,4alpha,5alpha,6beta)-gamma-BHC Lindane	1	1,2,4	U129	X	1 (0.454)
Hexachlorocyclopentadiene	77474	1,3-Cyclopentadiene,1,2,3,4,5,5-hexachloro-	1	1,2,4	U130	A	10 (4.54)
Hexachloroethane	67721	Ethane, hexachloro-	1*	2,4	U131	B	100 (45.4)
Hexachlorophene	70304	Phenol, 2,2'-methylenebis(3,4,6-trichloro-	1*	4	U132	B	100 (45.4)
Hexachloropropene	1888717	1-Propene, 1,1,2,3,3,3-hexachloro-	1*	4	U243	C	1000 (454)
Hexaethyl tetraphosphate	757584	Tetraphosphoric acid, hexaethyl ester	1*	4	P062	B	100 (45.4)
Hydrazine	302012		1*	4	U133	X	1 (0.454)
Hydrazine, 1,2-diethyl-	1615801	N,N'-Diethylhydrazine	1*	4	U086	A	10 (4.54)
Hydrazine, 1,1-dimethyl-	57147	1,1-Dimethylhydrazine	1*	4	U098	A	10 (4.54)
Hydrazine, 1,2-dimethyl-	540738	1,2-Dimethylhydrazine	1*	4	U099	X	1 (0.454)
Hydrazine, 1,2-diphenyl-	122667	1,2-Diphenylhydrazine	1*	2,4	U109	A	10 (4.54)
Hydrazine, methyl-	60344	Methyl hydrazine	1*	4	P068	A	10 (4.54)
Hydrazinecarbothioamide	79196	Thiosemicarbazide	1*	4	P116	B	100 (45.4)
Hydrochloric acid	7647010	Hydrogen chloride	5000	1		D	5000 (2270)
Hydrocyanic acid	74908	Hydrogen cyanide	10	1,4	P063	A	10 (4.54)
Hydrofluoric acid	7664393	Hydrogen flouride	5000	1,4	U134	B	100 (45.4)
Hydrogen chloride	7647010	Hydrochloric acid	5000	1		D	5000 (2270)
Hydrogen cyanide	74908	Hydrocyanic acid	10	1,4	P063	A	10 (4.54)
Hydrogen fluoride	7664393	Hydrofluoric acid	5000	1,4	U134	B	100 (45.4)
Hydrogen sulfide	7783064	Hydrogen sulfide H2S	100	1,4	U135	B	100 (45.4)
Hydrogen sulfide H2S	7783064	Hydrogen sulfide	100	1,4	U135	B	100 (45.4)
Hydroperoxide, 1-methyl-1-phenylethyl-	80159	alpha,alpha-Dimethylbenzylhydroperoxide	1*	4	U096	A	10 (4.54)
2-Imidazolidinethione	96457	Ethylenethiourea	1*	4	U116	A	10 (4.54)
Indeno(1,2,3-cd)pyrene	193395	1,10-(1,2-Phenylene)pyrene	1*	2,4	U137	B	100 (45.4)
1,3-Isobenzofurandione	85449	Phthalic anhydride	1*	4	U190	D	5000 (2270)
Isobutyl alcohol	78831	1-Propanol, 2-methyl-	1*	4	U140	D	5000 (2270)

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Hazardous Substance	CASRN	Regulatory Synonyms	Statutory			Final RQ	
			RQ	Code†	RCRA Waste #	Category	Pounds (Kg)
Isodrin	465736	1,4,5,8-Dimethanonaphthalene, 1,2,3,4,10,10-hexachloro-1,4,4a,5,8,8a-hexahydro-(1alpha,4alpha,4abeta,5beta,8beta,8abeta)-	1*	4	P060	X	1 (0.454)
Isophorone	78591		1*	2		D	5000 (2270)
Isoprene	78795		1000	1		B	100 (45.4)
Isopropanolamine dodecylbenzenesulfonate	42504461		1000	1		C	1000 (454)
Isosafrole	120581	1,3-Benzodioxole, 5-(1-propenyl)-	1*	4	U141	B	100 (45.4)
3(2H)-Isoxazolone, 5-(aminomethyl)-	2763964	Muscimol 5-(Aminomethyl)-3-isoxazolol	1*	4	P007	C	1000 (454)
Kepone	143500	1,2,4-Metheno-2H-cyclobuta[cd]pentalen-2-one, 1,1a,3,3a,4,5,5,5a,5b,6-decachlorooctahydro-	1	1,4	U142	X	1 (0.454)
Lasiocarpine	303344	2-Butenoic acid, 2-methyl-, 7[[2,3-dihydroxy-2-(1-methoxyethyl)-3-methyl-1-oxobutoxy]methyl]-2,3,5,7a-tetrahydro-1H-pyrrolizin-1-yl ester, [1S-[1alpha(Z), 7(2S*,3R*), 7aalpha]]-	1*	4	U143	A	10 (4.54)
Lead††	7439921		1*	2	U143	A	10 (4.54)
Lead acetate	301042	Acetic acid, lead(2+) salt	5000	1,4	U144		#
LEAD AND COMPOUNDS	N/A		1*	2			**
Lead arsenate	7784409		5000	1		X	1 (0.454)
	7645252		5000	1		X	1 (0.454)
	10102484		5000	1		X	1 (0.454)
Lead, bis(acetato-O)tetrahydroxytri	1335326	Lead subacetate	1*	4	U146	B	100 (45.4)
Lead chloride	7758954		5000	1		B	100 (45.4)
Lead fluoborate	13814965		5000	1		B	100 (45.4)
Lead fluoride	7783462		1000	1		B	100 (45.4)
Lead iodide	10101630		5000	1		B	100 (45.4)
Lead nitrate	10099748		5000	1		B	100 (45.4)
Lead phosphate	7446277	Phosphoric acid, lead(2+) salt (2:3)	1*	4	U145		#
Lead stearate	7428480		5000	1		D	# 5000 (2270)
	1072351		5000	1		D	# 5000 (2270)

Hazardous Substance	CASRN	Regulatory Synonyms	Statutory			Final RQ	
			RQ	Code†	RCRA Waste #	Category	Pounds (Kg)
	52652592		5000	1		D	# 5000 (2270)
	56189094		5000	1		D	# 5000 (2270)
Lead subacetate	1335326	Lead, bis(acetato-O)tetrahydroxytri	1*	4	U146	B	100 (45.4)
Lead sulfate	15739807		5000	1		B	100 (45.4)
	7446142		5000	1		B	100 (45.4)
			5000	1		B	100 (45.4)
Lead sulfide	1314870		5000	1		D	# 5000 (2270)
Lead thiocyanate	592870		5000	1		B	100 (45.4)
Lindane	58899	Cyclohexane, 1,2,3,4,5,6-hexachloro-,(1alpha,2alpha,3beta,4alpha,5alpha,6beta)-gamma-BHC Hexachlorocyclohexane (gamma isomer)	1	1,2,4	U129	X	1 (0.454)
Lithium Chromate	14307358		1000	1		A	10 (4.54)
Malathion	121755		10	1		B	100 (45.4)
Maleic acid	110167		5000	1		D	5000 (2270)
Maleic anhydride	108316	2,5-Furandione	5000	1,4	U147	D	5000 (2270)
Maleic hydrazide	123331	3,6-Pyridazinedione, 1,2-dihydro-	1*	4	U148	D	5000 (2270)
Malononitrile	109773	Propanedinitrile	1*	4	U149	C	1000 (454)
Melphalan	148823	L-Phenylalanine, 4-[bis(2-chloroethyl)amino]	1*	4	U150	X	1 (0.454)
Mercaptodimethur	2032657		100	1		A	10 (4.54)
Mercuric cyanide	592041		1	1		X	1 (0.454)
Mercuric nitrate	10045940		10	1		A	10 (4.54)
Mercuric sulfate	7783359		10	1		A	10 (4.54)
Mercuric thiocyanate	592858		10	1		A	10 (4.54)
Mercurous nitrate	10415755		10	1		A	10 (4.54)
	7782867		10	1		A	10 (4.54)
Mercury	7439976		1*	2,3,4	U151	X	1 (0.454)
MERCURY AND COMPOUNDS	N/A		1*	2			**
Mercury, (acetato-O)phenyl	62384	Phenylmercury acetate	1*	4	P092	B	100 (45.4)
Mercury fulminate	628864	Fulminic acid, mercury(2+)salt	1*	4	P065	A	10 (4.54)

Hazardous Substance	CASRN	Regulatory Synonyms	Statutory			Final RQ	
			RQ	Code†	RCRA Waste #	Category	Pounds (Kg)
Methacrylonitrile	126987	2-Propenenitrile, 2-methyl-	1*	4	U152	C	1000 (454)
Methanamine, N-methyl-	124403	Dimethylamine	1000	1,4	U092	C	1000 (454)
Methanamine, N-methyl-N-nitroso-	62759	N-Nitrosodimethylamine	1*	2,4	P082	A	10 (4.54)
Methane, bromo-	74839	Methyl bromide	1*	2,4	U029	C	1000 (454)
Methane, chloro-	74873	Methyl chloride	1*	2,4	U045	B	100 (45.4)
Methane, chloromethoxy-	107302	Chloromethyl methyl ether	1*	4	U046	A	10 (4.54)
Methane, dibromo-	74953	Methylene bromide	1*	4	U068	C	1000 (454)
Methane, dichloro-	75092	Methylene chloride	1*	2,4	U080	C	1000 (454)
Methane, dichlorodifluoro-	75718	Dichlorodifluoromethane	1*	4	U075	D	5000 (2270)
Methane, iodo-	74884	Methyl iodide	1*	4	U138	B	100 (45.4)
Methane, isocyanato-	624839	Methyl isocyanate	1*	4	P064		##
Methane, oxybis(chloro-	542881	Dichloromethyl ether	1*	4	P016	A	10 (4.54)
Methanesulfenyl chloride, trichloro-	594423	Trichloromethanesulfenyl chloride	1*	4	P118	B	100 (45.4)
Methanesulfonic acid, ethyl ester	62500	Ethyl methanesulfonate	1*	4	U119	X	1 (0.454)
Methane, tetrachloro-	56235	Carbon tetrachloride	5000	1,2,4	U211	A	10 (4.54)
Methane, tetranitro	509148	Tetranitromethane	1*	4	P112	A	10 (4.54)
Methane, tribromo-	75252	Bromoform	1*	2,4	U225	B	100 (45.4)
Methane, trichloro-	67663	Chloroform	5000	1,2,4	U044	A	10 (4.54)
Methane, trichlorofluoro	75694	Trichloromonofluoromethane	1*	4	U121	D	5000 (2270)
Methanethiol	74931	Methylmercaptan Thiomethanol	100	1,4	U153	B	100 (45.4)
6,9-Methano-2,4,3-benzodioxathiepin,6,7,8,9,10,10-hexachloro-1,5,5a,6,9,9a-hexahydro-, 3-oxide	115297	Endosulfan	1	1,2,4	P050	X	1 (0.454)
1,3,4-Metheno-2H-cyclobuta[cd]pentalen-2-one, 1,1a,3,3a,4,5,5,5a,5b,6-decachlorooctahydro-	143500	Kepone	1	1,4	U142	X	1 (0.454)
4,7-Methano-1H-indene, 1,4,5,6,7,8,8-heptachloro-3a,4,7,7a-tetrahydro-	76448	Heptachlor	1	1,2,4	P059	X	1 (0.454)
4,7-Methano-1H-indene, 1,2,3,4,5,6,8,8-octachloro-2,3,3a,4,5,5a-hexahydro-	57749	Chlordane Chlordane, alpha & gamma isomers Chlordane, technical	1	1,2,4	U036	X	1 (0.454)
Methanol	67561	Methyl alcohol	1*	4	U154	D	5000 (2270)

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Hazardous Substance	CASRN	Regulatory Synonyms	Statutory RQ	Statutory Code†	Statutory RCRA Waste #	Final RQ Category	Final RQ Pounds (Kg)
Methapyrilene	91806	1,2-Ethanediamine, N,N-dimethyl-N'-2-pyridinyl-N'-(2-thienylmethyl)-	1*	4	U155	D	5000 (2270)
Methomyl	16752775	Ethanimidothioic acid, N-[[(methylamino)carbonyl]oxy]-, methyl ester	1*	4	P066	B	100 (45.4)
Methoxychlor	72435	Benzene, 1,1'-(2,2,2-trichloroethylidene)bis[4-methoxy-	1	1,4	U247	X	1 (0.454)
Methyl alchohol	67561	Methanol	1*	4	U154	D	5000 (2270)
Methyl bromide	74839	Methane, bromo-	1*	2,4	U029	C	1000 (454)
1-Methylbutadiene	504609	1,3-Pentadiene	1*	4	U186	B	100 (45.4)
Methyl chloride	74873	Methane, chloro-	1*	2,4	U045	B	100 (45.4)
Methyl chlorocarbonate	79221	Carbonochloridic acid, methyl ester Methyl chloroformate	1*	4	U156	C	1000 (454)
Methyl chloroform	71556	Ethane, 1,1,1-trichloro- 1,1,1-Trichloroethane	1*	2,4	U226	C	1000 (454)
Methyl chloroformate	79221	Carbonochloridic acid, methyl ester Methyl chlorocarbonate	1*	4	U156	C	1000 (454)
3-Methylcholanthrene	56495	Benz[j]aceanthrylene, 1,2-dihydro-3-methyl-	1*	4	U157	A	10 (4.54)
4,4'-Methylenebis(2-chloroaniline)	101144	Benzenamine, 4,4'-methylenebis(2-chloro-	1*	4	U158	A	10 (4.54)
Methylene bromide	74953	Methane, dibromo-	1*	4	U068	C	1000 (454)
Methylene chloride	75092	Methane, dichloro-	1*	2,4	U080	C	1000 (454)
Methyl ethyl ketone (MEK)	78933	2-Butanone	1*	4	U159	D	5000 (2270)
Methyl ethyl ketone peroxide	1338234	2-Butanone peroxide	1*	4	U160	A	10 (4.54)
Methyl hydrazine	60344	Hydrazine, methyl-	1*	4	P068	A	10 (4.54)
Methyl iodide	74884	Methane, iodo-	1*	4	U138	B	100 (45.4)
Methly isobutyl ketone	108101	4-Methyl-2-pentanone	1*	4	U161	D	5000 (2270)
Methyl isocyanate	624839	Methane, isocyanato-	1*	4	P064		##
2-Methyllactonitrile	75865	Acetone cyanohydrin Propanenitrile, 2-hydroxy-2-methyl-	10	1,4	P069	A	10 (4.54)
Methylmercaptan	74931	Methanethiol Thiomethanol	100	1,4	U153	B	100 (45.4)
Methyl methacrylate	80626	2-Propenoic acid, 2-methyl, methyl ester	5000	1,4	U162	C	1000 (454)
Methyl parathion	298000	Phosphorothioic acid,),)-dimethyl O-(4-nitro-phenyl) ester	100	1,4	P071	B	100 (45.4)
4-Methyl-2-pentanone	108101	Methyl isobutyl ketone	1*	4	U161	D	5000 (2270)

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Hazardous Substance	CASRN	Regulatory Synonyms	Statutory			Final RQ	
			RQ	Code†	RCRA Waste #	Category	Pounds (Kg)
Methylthiouracil	56042	4(1H)-Pyrimidinone, 2,3-dihydro-6-methyl-2-thioxo-	1*	4	U164	A	10 (4.54)
Mevinphos	7786347		1	1		A	10 (4.54)
Mexacarbate	315184		1000	1		C	1000 (454)
Mitomycin C	50077	Azirino[2',3':3,4]pyrrolo[1,2-a]indole-4,7-dione,6-amino-8-[[(aminocarbonyl)oxy]methyl]-1,1a,2,8,8a,8b-hexahydro-8a-methoxy-5-methyl-, [1aS-(1aalpha, 8beta,8aalpha, 8balpha)]-	1*	4	U010	A	10 (4.54)
MNNG	70257	Guanidine, N-methyl-N'-nitro-N-nitroso-	1*	4	U163	A	10 (4.54)
Monoethylamine	75047		1000	1		B	100 (45.4)
Monomethylamine	74895		1000	1		B	100 (45.4)
Multi Source Leachate			1*	4	F039	X	1 (0.454)
Muscimol	2763964	3(2H)-Isoxazolone, 5-(aminomethyl)- 5-(Amino-methyl)-3-isoxazolol	1*	4	P007	C	1000 (454)
Naled	300765		10	1		A	10 (4.54)
5,12-Naphthacenedione, 8-acetyl-10-[(3-amino-2,3,6-trideoxy-alpha-L-lyxo-hexopyranosyl)oxy]-7,8,9,10-tetrahydro-6,8,11-trihydroxy-1-methoxy-, (8S-cis)-	20830813	Daunomycin	1*	4	U059	A	10 (4.54)
1-Naphthalenamine	134327	alpha-Naphthylamine	1*	4	U167	B	100 (45.4)
2-Naphthalenamine	91598	beta-Naphthylamine	1*	4	U168	A	10 (4.54)
Naphthalenamine,N,N'-bis(2-chloroethyl)-	494031	Chlornaphazine	1*	4	U026	B	100 (45.4)
Naphthalene	91203		5000	1,2,4	U165	B	100 (45.4)
Naphthalene, 2-chloro-	91587	beta-Chloronaphthalene 2-Chloronaphthalene	1*	2,4	U047	D	5000 (2270)
1,4-Naphthalenedione	130154	1,4-Naphthoquinone	1*	4	U166	D	5000 (2270)
2,7-Naphthalenedisulfonic acid, 3,3'-[(3,3'-dimethyl-(1,1'-byphenyl)-4,4'-diyl)-bis(azo)]bis(5-amino-4-hydroxy)tetrasodium salt	72571	Trypan blue	1*	4	U236	A	10 (4.54)
Naphthenic acid	1338245		100	1		B	100 (45.4)
1,4-Naphthoquinone	130154	1,4-Naphthalenedione	1*	4	U166	D	5000 (2270)
alpha-Naphthylamine	134327	1,-Naphthalenamine	1*	4	U167	B	100 (45.4)
beta-Naphthylamine	91598	2,-Naphthalenamine	1*	4	U168	A	10 (4.54)

Hazardous Substance	CASRN	Regulatory Synonyms	Statutory			Final RQ	
			RQ	Code†	RCRA Waste #	Category	Pounds (Kg)
alpha-Naphthylthiourea	86884	Thiourea, 1-naphthalenyl-	1*	4	P072	B	100 (45.4)
Nickel††	7440020		1*	2		B	100 (45.4)
Nickel ammonium sulfate	15699180		5000	1		B	100 (45.4)
NICKEL AND COMPOUNDS	N/A		1*	2			**
Nickel carbonyl	13463393	Nickel carbonyl Ni(CO)4, (T-4)-	1*	4	P073	A	10 (4.54)
Nickel carbonyl Ni(CO)4, (T-4)-	13463393	Nickel carbonyl	1*	4	P073	A	10 (4.54)
Nickel chloride	7718549		5000	1		B	100 (45.4)
	37211055		5000	1		B	100 (45.4)
Nickel cyanide	557197	Nickel cyanide Ni(CN)2	1*	4	P074	A	10 (4.54)
Nickel cyanide Ni(CN)2	557197	Nickel cyanide	1*	4	P074	A	10 (4.54)
Nickel hydroxide	12054487		1000	1		A	10 (4.54)
Nickel nitrate	14216752		5000	1		B	100 (45.4)
Nickel sulfate	7786814		5000	1		B	100 (45.4)
Nicotine, & salts	54115	Pyridine, 3-(1-methyl-2-pyrrolidinyl)-, (S)-	1*	4	P075	B	100 (45.4)
Nitric acid	7697372		1000	1		C	1000 (454)
Nitric acid, thallium (1+) salt	10102451	Thallium (I) nitrate	1*	4	U217	B	100 (45.4)
Nickel oxide	10102439	Nitrogen oxide NO	1*	4	P076	A	10 (4.54)
p-Nitroaniline	100016	Benzenamine, 4-nitro-	1*	4	P077	D	5000 (2270)
Nitrobenzene	98953	Benzene, nitro-	1000	1,2,4	U169	C	1000 (454)
Nitrogen dioxide	10102440	Nitrogen oxide NO2	1000	1,4	P078	A	10 (4.54)
	10544726		1000	1,4	P078	A	10 (4.54)
Nitrogen oxide NO	10102439	Nitric oxide	1*	4	P076	A	10 (4.54)
Nitrogen oxide NO2	10102440	Nitrogen dioxide	1000	1,4	P078	A	10 (4.54)
	10544726						
Nitroglycerine	55630	1,2,3-Propanetriol, trinitrate-	1*	4	P081	A	10 (4.54)
Nitrophenol (mixed)	25154556		1000	1		B	100 (45.4)
m-Nitrophenol	554847					B	100 (45.4)
o-Nitrophenol	88755	2-Nitrophenol					
p-Nitrophenol	100027	Phenol, 4-nitro- 4-Nitrophenol					
o-Nitrophenol	88755	2-Nitrophenol	1000	1,2		B	100 (45.4)
p-Nitrophenol	100027	Phenol, 4-nitro- 4-Nitrophenol	1000	1,2,4	U170	B	100 (45.4)

Hazardous Substance	CASRN	Regulatory Synonyms	Statutory			Final RQ	
			RQ	Code†	RCRA Waste #	Category	Pounds (Kg)
2-Nitrophenol	88755	o-Nitrophenol	1000	1,2		B	100 (45.4)
4-Nitrophenol	100027	p-Nitrophenol Phenol, 4-nitro-	1000	1,2,4	U170	B	100 (45.4)
NITROPHENOLS	N/A		1*	2			**
2-Nitropropane	79469	Propane, 2-nitro-	1*	4	U171	A	10 (4.54)
NITROSAMINES	N/A		1*	2			**
N-Nitrosodi-n-butylamine	924163	1-Butanamine, N-butyl-N-nitroso-	1*	4	U172	A	10 (4.54)
N-Nitrosodiethanolamine	1116547	Ethanol, 2,2'-(nitrosoimino)bis-	1*	4	U173	X	1 (0.454)
N-Nitrosodiethylamine	55185	Ethanamine, N-ethyl-N-nitroso-	1*	4	U174	X	1 (0.454)
N-Nitrosodimethylamine	62759	Methanamine, N-methyl-N-nitroso-	1*	2,4	P082	A	10 (4.54)
N-Nitrosodiphenylamine	86306		1*	2		B	100 (45.4)
N-Nitroso-N-ethylurea	759739	Urea, N-ethyl-N-nitroso-	1*	4	U176	X	1 (0.454)
N-Nitroso-N-methylurea	684935	Urea, N-methyl-N-nitroso	1*	4	U177	X	1 (0.454)
N-Nitroso-N-methylurethane	615532	Carbamic acid, methylnitroso-, ethyl ester	1*	4	U178	X	1 (0.454)
N-Nitrosomethylvinylamine	4549400	Vinylamine, N-methyl-N-nitroso-	1*	4	P084	A	10 (4.54)
N-Nitrosopiperidine	100754	Piperidine, 1-nitroso-	1*	4	U179	A	10 (4.54)
N-Nitrosopyrrolidine	930552	Pyrrolidine, 1-nitroso-	1*	4	U180	X	1 (0.454)
Nitrotoluene	1321126		1000	1		C	1000 (454)
m-Nitrotoluene	99081						
o-Nitrotoluene	88722						
p-Nitrotoluene	99990						
5-Nitro-o-toluidine	99558	Benzenamine, 2-methyl-5-nitro-	1*	4	U181	B	100 (45.4)
Octamethylpyrophosphoramide	152169	Diphosphoramide, octamethyl-	1*	4	P085	B	100 (45.4)
Osmium oxide OsO4 (T-4)-	20816120	Osmium tetroxide	1*	4	P087	C	1000 (454)
Osmium tetroxide	20816120	Osmium oxide OsO4 (T-4)-	1*	4	P087	C	1000 (454)
7-Oxabicyclo[2.2.1]heptane-2,3-dicarboxylic acid	145733	Endothall	1*	4	P088	C	1000 (454)
1,2-Oxathiolane, 2,2-dioxide	1120714	1,3-Propane sultone	1*	4	U193	A	10 (4.54)
2H-1,3,2-Oxazaphosphorin-2-amine, N,N-bis(2-chloroethyl) tetrahydro-, 2-oxide	50180	Cyclophosphamide	1*	4	U058	A	10 (4.54)
Oxirane	75218	Ethylene oxide	1*	4	U115	A	10 (4.54)
Oxiranecarboxyaldehyde	765344	Glycidylaldehyde	1*	4	U126	A	10 (4.54)

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Oxirane, (chloromethyl)-	106898	Epichlorohydrin	1000	1,4	U041	B	100 (45.4)
Paraformaldehyde	30525894		1000	1		C	1000 (454)
Paraldehyde	123637	1,3,5-Trioxane, 2,4,6-trimethyl-	1*	4	U182	C	1000 (454)
Parathion	56382	Phosphorothioic acid, O,O-diethyl O-(4-nitrophenyl) ester	1	1,4	P089	A	10 (4.54)
Pentachlorobenzene	608935	Benzene, pentachloro-	1*	4	U183	A	10 (4.54)
Pentachloroethane	76017	Ethane, pentachloro-	1*	4	U184	A	10 (4.54)
Pentachloronitrobenzene (PCNB)	82688	Benzene, pentachloronitro-	1*	4	U185	B	100 (45.4)
Pentachlorophenol	87865	Phenol, pentachloro-	10	1,2,4	U242	A	10 (4.54)
1,3-Pentadiene	504609	1-Methylbutadiene	1*	4	U186	B	100 (45.4)
Perchloroethylene	127184	Ethene, tetrachloro- Tetrachloroethene Tetrachlor-oethylene	1*	2,4	U210	B	100 (45.4)
Phenacetin	62442	Acetamide, N-(4-ethoxyphenyl)-	1*	4	U187	B	100 (45.4)
Phenanthrene	85018		1*	2		D	5000 (2270)
Phenol	108952	Benzene, hydroxy-	1000	1,2,4	U188	C	1000 (454)
Phenol, 2-chloro-	95578	o-Chlorophenol 2-Chlorophenol	1*	2,4	U048	B	100 (45.4)
Phenol, 4-chloro-3-methyl-	59507	p-Chloro-m-cresol 4-Chloro-m-cresol	1*	2,4	U039	D	5000 (2270)
Phenol, 2-cyclohexyl-4,6-dinitro-	131895	2-Cyclohexyl-4,6-dinitrophenol	1*	4	P034	B	100 (45.4)
Phenol, 2,4-dichloro-	120832	2,4-Dichlorophenol	1*	2,4	U081	B	100 (45.4)
Phenol, 2,6-dichloro	87650	2,6-Dichlorophenol	1*	4	U082	B	100 (45.4)
Phenol, 4,4'-(1,2-diethyl-1,2-ethenediyl)bis-, (E)	56531	Diethylstilbestrol	1*	4	U089	X	1 (0.454)
Phenol, 2,4-dimethyl-	105679	2,4-Dimethylphenol	1*	2,4	U101	B	100 (45.4)
Phenol, 2,4-dinitro-	51285	2,4-Dinitrophenol	1000	1,2,4	P048	A	10 (4.54)
Phenol, methyl-	1319773	Cresol(s) Cresylic acid	1000	1,4	U052	C	1000 (454)
m-Cresol	108394	m-Cresylic acid	1000	1,4	U052	C	1000 (454)
o-Cresol	95487	o-Cresylic acid	1000	1,4	U052	C	1000 (454)
p-Cresol	106445	p-Cresylic acid	1000	1,4	U052	C	1000 (454)
Phenol, 2-methyl-4,6-dinitro-	534521	4,6-Dinitro-o-cresol and salts	1*	2,4	P047	A	10 (4.54)
Phenol, 2,2'-methylenebis[3,4,6-trichloro-	70304	Hexachlorophene	1*	4	U132	B	100 (45.4)
Phenol, 2-(1-methylpropyl)-4,6-dinitro	88857	Dinoseb	1*	4	P020	C	1000 (454)

Hazardous Substance	CASRN	Regulatory Synonyms	Statutory			Final RQ	
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Phenol, 4-nitro-	100027	p-Nitrophenol 4-Nitrophenol	1000	1,2,4	U170	B	100 (45.4)
Phenol, pentachloro-	87865	Pentachlorophenol	10	1,2,4	U242	A	10 (4.54)
Phenol, 2,3,4,6-tetrachloro-	58902	2,3,4,6-Tetrachlorophenol	1*	4	U212	A	10 (4.54)
Phenol, 2,4,5-trichloro-	95954	2,4,5-Trichlorophenol	10	1,4	U230	A	10 (4.54)
Phenol, 2,4,6-trichloro-	88062	2,4,6-Trichlorophenol	10	1,2,4	U231	A	10 (4.54)
Phenol, 2,4,6-trinitro-, ammonium salt	131748	Ammonium picrate	1*	4	P009	A	10 (4.54)
L-Phenylalanine, 4-[bis(2-chloroethyl) amino]]	148823	Melphalan	1*	4	U150	X	1 (0.454)
1,10-(1,2-Phenylene)pyrene	193395	Indeno(1,2,3-cd)pyrene	1*	2,4	U137	B	100 (45.4)
Phenylmercury acetate	62384	Mercury, (acetato-O)phenyl-	1*	4	P092	B	100 (45.4)
Phenylthiourea	103855	Thiourea, phenyl-	1*	4	P093	B	100 (45.4)
Phorate	298022	Phosphorodithioic acid, O,O-diethyl S-(ethylthio), methyl ester	1*	4	P094	A	10 (4.54)
Phosgene	75445	Carbonic dichloride	5000	1,4	P095	A	10 (4.54)
Phosphine	7803512		1*	4	P096	B	100 (45.4)
Phosphoric acid	7664382		5000	1		D	5000 (2270)
Phosphoric acid, diethyl 4-nitrophenyl ester	311455	Diethyl-p-nitrophenyl phosphate	1*	4	P041	B	100 (45.4)
Phosphoric acid, lead(2+) salt (2:3)	7446277	Lead phosphate	1*	4	U145		#
Phosphorodithioic acid, O,O-diethyl S-[2-(ethylthio)ethyl]ester	298044	Disulfoton	1	1,4	P039	X	1 (0.454)
Phosphorodithioic acid, O,O-diethyl S-(ethylthio), methyl ester	298022	Phorate	1*	4	P094	A	10 (4.54)
Phosphorodithioic acid, O,O-diethyl S-methyl ester	3288582	O,O-Diethyl S-methyl dithiophosphate	1*	4	U087	D	5000 (2270)
Phosphorodithioic acid, O,O-dimethyl S-[2(methylamino)-2-oxoethyl] ester	60515	Dimethoate	1*	4	P044	A	10 (4.54)
Phosphorofluoridic acid, bis(1-methylethyl) ester	55914	Diisopropylfluorophosphate	1*	4	P043	B	100 (45.4)
Phosphorothioic acid, O,O-diethyl O-(4-nitrophenyl) ester	56382	Parathion	1	1,4	P089	A	10 (4.54)
Phosphorothioic acid, O,[4-[(dimethylamino)sulfonyl] phenyl]O,O-dimethyl ester	52857	Famphur	1*	4	P097	C	1000 (454)

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Phosphorothioic acid, O,O-dimethyl O-(4-nitrophenyl) ester	298000	Methyl parathion	100	1,4	P071	B	100 (45.4)
Phosphorothioic acid, O,O-diethyl O-pyrazinyl ester	297972	O,O-Diethyl O-pyrazinyl phosphorothioate	1*	4	P040	B	100 (45.4)
Phosphorus	7723140		1	1		X	1 (0.454)
Phosphorus oxychloride	10025873		5000	1		C	1000 (454)
Phosphorus pentasulfide	1314803	Phosphorus sulfide Sulfur phosphide	100	1,4	U189	B	100 (45.4)
Phosphorus sulfide	1314803	Phosphorus pentasulfide Sulfur phosphide	100	1,4	U189	B	100 (45.4)
Phosophorus trichloride	7719122		5000	1		C	1000 (454)
PHTHALATE ESTERS	N/A		1*	2			**
Phthalic anhydride	85449	1,3-Isobenzofurandione	1*	4	U190	D	5000 (2270)
2-Picoline	109068	Pyridine, 2-methyl-	1*	4	U191	D	5000 (2270)
Piperidine, 1-nitroso-	100754	N-Nitrosopiperidine	1*	4	U179	A	10 (4.54)
Plumbane, tetraethyl-	78002	Tetraethyl lead	100	1,4	P110	A	10 (4.54)
POLYCHLORINATED BIPHENYLS (PCBs)	1336363		10	1,2		X	1 (0.454)
Aroclor 1016	12674112	POLYCHLORINATED BIPHENYLS (PCBs)					
Aroclor 1221	11104282	POLYCHLORINATED BIPHENYLS (PCBs)					
Aroclor 1232	11141165	POLYCHLORINATED BIPHENYLS (PCBs)					
Aroclor 1242	53469219	POLYCHLORINATED BIPHENYLS (PCBs)					
Aroclor 1248	12672296	POLYCHLORINATED BIPHENYLS (PCBs)					
Aroclor 1254	11097691	POLYCHLORINATED BIPHENYLS (PCBs)					
Aroclor 1260	11096825	POLYCHLORINATED BIPHENYLS (PCBs)					
POLYNUCLEAR AROMATIC HYDROCARBONS	N/A		1*	2			**
Potassium arsenate	7784410		1000	1		X	1 (0.454)
Potassium arsenite	10124502		1000	1		X	1 (0.454)
Potassium bichromate	7778509		1000	1		A	10 (4.54)
Potassium chromate	7789006		1000	1		A	10 (4.54)

Hazardous Substance	CASRN	Regulatory Synonyms	Statutory			Final RQ	
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Potassium cyanide	151508	Potassium cyanide K (CN)	10	1,4	P098	A	10 (4.54)
Potassium cyanide K(CN)	151508	Potassium cyanide	10	1,4	P098	A	10 (4.54)
Potassium hydroxide	1310583		1000	1		C	1000 (454)
Potassium permanganate	7722647		100	1		B	100 (45.4)
Potassium silver cyanide	506616	Argentate (1-), bis(cyano-C)-, potassium	1*	4	P099	X	1 (0.454)
Pronamide	23950585	Benzamide, 3,5-dichloro-N-(1,1-dimethyl-2-propynyl)-	1*	4	U192	D	5000 (2270)
Propanal, 2-methyl-2-(methylthio)-, O-[(methylamino)carbonyl]oxime	116063	Aldicarb	1*	4	P070	X	1 (0.454)
1-Propanamine	107108	n-Propylamine	1*	4	U194	D	5000 (2270)
1-Propanamine, N-propyl-	142847	Dipropylamine	1*	4	U110	D	5000 (2270)
1-Propanamine, N-nitroso-N-propyl-	621647	Di-n-propylnitrosamine	1*	2,4	U111	A	10 (4.54)
Propane, 1,2-dibromo-3-chloro-	96128	1,2-Dibromo-3-chloropropane	1*	4	U066	X	1 (0.454)
Propane, 2-nitro-	79469	2-Nitropropane	1*	4	U171	A	10 (4.54)
1,3-Propane sultone	1120714	1,2-Oxathiolane, 2,2-dioxide	1*	4	U193	A	10 (4.54)
Propane, 1,2-dichloro-	78875	Propylene dichloride 1,2-Dichloropropane	5000	1,2,4	U083	C	1000 (454)
Propanedinitrile	109773	Malononitrile	1*	4	U149	C	1000 (454)
Propanenitrile	107120	Ethyl cynide	1*	4	P101	A	10 (4.54)
Propanenitrile, 3-chloro-	542767	3-Chloropropionitrile	1*	4	P027	C	1000 (454)
Propanenitrile, 2-hydroxy-2-methyl-	75865	Acetone cyanohydrin 2-Methyllactonitrile	10	1,4	P069	A	10 (4.54)
Propane, 2,2'-oxybis[2-chloro-	108601	Dichloroisopropyl ether	1*	2,4	U027	C	1000 (454)
1,2,3-Propanetriol, trinitrate-	55630	Nitroglycerine	1*	4	P081	A	10 (4.54)
1-Propanol, 2,3-dibromo-, phosphate (3:1)	126727	Tris(2,3-dibromopropyl) phosphate	1*	4	U235	A	10 (4.54)
1-Propanol, 2-methyl-	78831	Isobutyl alcohol	1*	4	U140	D	5000 (2270)
2-Propanone	67641	Acetone	1*	4	U002	D	5000 (2270)
2-Propanone, 1-bromo-	598312	Bromoacetone	1*	4	P017	C	1000 (454)
Propargite	2312358		10	1		A	10 (4.54)
Propargyl alcohol	107197	2-Propyn-1-ol	1*	4	P102	C	1000 (454)
2-Propenal	107028	Acrolein	1	1,2,4	P003	X	1 (0.454)
2-Propenamide	79061	Acrylamide	1*	4	U007	D	5000 (2270)

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1-Propene, 1,1,2,3,3,3-hexachloro-	1888717	Hexachloropropene	1*	4	U243	C	1000 (454)
1-Propene, 1,3-dichloro-	542756	1,3-Dichloropropene	5000	1,2,4	U084	B	100 (45.4)
2-Propenenitrile	107131	Acrylonitrile	100	1,2,4	U009	B	100 (45.4)
2-Propenenitrile, 2-methyl-	126987	Methacrylonitrile	1*	4	U152	C	1000 (454)
2-Propenoic acid	79107	Acrylic acid	1*	4	U008	D	5000 (2270)
2-Propenoic acid, ethyl ester	140885	Ethyl acrylate	1*	4	U113	C	1000 (454)
2-Propenoic acid, 2-methyl-, ethyl ester	97632	Ethyl methacrylate	1*	4	U118	C	1000 (454)
2-Propenoic acid, 2-methyl-, methyl ester	80626	Methyl methacrylate	5000	1,4	U162	C	1000 (454)
2-Propen-1-ol	107186	Allyl alcohol	100	1,4	P005	B	100 (45.4)
Propionic acid	79094		5000	1		D	5000 (2270)
Propionic acid, 2-(2,4,5-trichlorophenoxy)-	93721	Silvex (2,4,5-TP) 2,4,5-TP acid	100	1,4	U233	B	100 (45.4)
Propionic anhydride	123626		5000	1		D	5000 (2270)
n-Propylamine	107108	1-Propanamine	1*	4	U194	D	5000 (2270)
Propylene dichloride	78875	Propane, 1,2-dichloro- 1,2-Dichloropropane	5000	1,2,4	U083	C	1000 (454)
Propylene oxide	75569		5000	1		B	100 (45.4)
1,2-Propylenimine	75558	Aziridine, 2-methyl-	1*	4	P067	X	1 (0.454)
2-Propyn-1-ol	107197	Propargyl alcohol	1*	4	P102	C	1000 (454)
Pyrene	129000		1*	2		D	5000 (2270)
Pyrethrins	121299		1000	1		X	1 (0.454)
	121211		1000	1		X	1 (0.454)
	8003347		1000	1		X	1 (0.454)
3,6-Pyridazinedione, 1,2-dihydro-	123331	Maleic hydrazide	1*	4	U148	D	5000 (2270)
4-Pyridinamine	504245	4-Aminopyridine	1*	4	P008	C	1000 (454)
Pyridine	110861		1*	4	U196	C	1000 (454)
Pyridine, 2-methyl-	109068	2-Picoline	1*	4	U191	D	5000 (2270)
Pyridine, 3-(1-methyl-2-pyrrolidinyl)-, (S)	54115	Nicotine, & salts	1*	4	P075	B	100 (45.4)
2,4-(1H,3H)-Pyrimidinedione, 5-[bis(2-chloroethyl)amino]-	66751	Uracil mustard	1*	4	U237	A	10 (4.54)
4(1H)-Pyrimidinone, 2,3-dihydro-6-methyl-2-thioxo-	56042	Methylthiouracil	1*	4	U164	A	10 (4.54)

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Pyrrolidine, 1-nitroso-	930552	N-Nitrosopyrrolidine	1*	4	U180	X	1 (0.454)
Quinoline	91225		1000	1		D	5000 (2270)
RADIONUCLIDES	N/A		1*	3			§
Reserpine	50555	Yohimban-16-carboxylic acid, 11,17-dimethoxy-18-[(3,4,5-trimethoxybenzoyl)oxy-, methyl ester (3beta, 16beta, 17alpha, 18beta, 20alpha)-	1*	4	U200	D	5000 (2270)
Resorcinol	108463	1,3-Benzenediol	1000	1,4	U201	D	5000 (2270)
Saccharin and salts	81072	1,2-Benzisothiazol-3(2H)-one, 1,1-dioxide	1*	4	U202	B	100 (45.4)
Safrole	94597	1,3-Benzodioxole, 5-(2-propenyl)-	1*	4	U203	B	100 (45.4)
Selenious acid	7783008		1*	4	U204	A	10 (4.54)
Selenious acid, dithallium (1+) salt	12039520	Thallium selenite	1*	4	P114	C	1000 (454)
Selenium††	7782492		1*	2		B	100 (45.4)
SELENIUM AND COMPOUNDS	N/A		1*	2			**
Selenium dioxide	7446084	Selenium oxide	1000	1,4	U204	A	10 (4.54)
Selenium oxide	7446084	Selenium dioxide	1000	1,4	U204	A	10 (4.54)
Selenium sulfide	7488564	Selenium sulfide SeS2	1*	4	U205	A	10 (4.54)
Selenium sulfide SeS2	7488564	Selenium sulfide	1*	4	U205	A	10 (4.54)
Selenourea	630104		1*	4	P103	C	1000 (454)
L-Serine, diazoacetate (ester)	115026	Azaserine	1*	4	U015	X	1 (0.454)
Silver††	7440224		1*	2		C	1000 (454)
SILVER AND COMPOUNDS	N/A		1*	2			**
Silver cyanide	506649	Silver cyanide Ag(CN)	1*	4	P104	X	1 (0.454)
Silver cyanide Ag (CN)	506649	Silver cyanide	1*	4	P104	X	1 (0.454)
Silver nitrate	7761888		1	1		X	1 (0.454)
Silvex (2,4,5-TP)	93721	Propionic acid, 2-(2,4,5-trichlorophenoxy)- 2,4,5-TP acid	100	1,4	U233	B	100 (45.4)
Sodium	7440235		1000	1		A	10 (4.54)
Sodium arsenate	7631892		1000	1		X	1 (0.454)
Sodium arsenite	7784465		1000	1		X	1 (0.454)
Sodium azide	26628228		1*	4	P105	C	1000 (454)
Sodium bichromate	10588019		1000	1		A	10 (4.54)

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Sodium bifluoride	1333831		5000	1		B	100 (45.4)
Sodium bisulfite	7631905		5000	1		D	5000 (2270)
Sodium chromate	7775113		1000	1		A	10 (4.54)
Sodium cyanide	143339	Sodium cyanide Na(CN)	10	1,4	P106	A	10 (4.54)
Sodium cyanide Na (CN)	143339	Sodium cyanide	10	1,4	P106	A	10 (4.54)
Sodium dodecylbenzenesulfonate	25155300		1000	1		C	1000 (454)
Sodium fluoride	7681494		5000	1		C	1000 (454)
Sodium hydrosulfide	16721805		5000	1		D	5000 (2270)
Sodium hydroxide	1310732		1000	1		C	1000 (454)
Sodium hypochlorite	7681529		100	1		B	100 (45.4)
	10022705		100	1		B	100 (45.4)
Sodium methylate	124414		1000	1		C	1000 (454)
Sodium nitrite	7632000		100	1		B	100 (45.4)
Sodium phosphate, dibasic	7558794		5000	1		D	5000 (2270)
	10039324		5000	1		D	5000 (2270)
	10140655		5000	1		D	5000 (2270)
Sodium phosphate, tribasic	7601549		5000	1		D	5000 (2270)
	7758294		5000	1		D	5000 (2270)
	7785844		5000	1		D	5000 (2270)
	10101890		5000	1		D	5000 (2270)
	10124568		5000	1		D	5000 (2270)
	10361894		5000	1		D	5000 (2270)
Sodium selenite	10102188		1000	1		B	100 (45.4)
	7782823						
Streptozotocin	18883664	D-Glucose, 2-deoxy-2-[[(methylnitrosoamino)-carbonyl] amino]- Glucopyranose, 2-deoxy-2-(3-methyl-3-nitrosoureido)-	1*	4	U206	X	1 (0.454)
Strontium chromate	7789062		1000	1		A	10 (4.54)
Strychnidin-10-one	57249	Strychnine, & salts	10	1,4	P108	A	10 (4.54)
Strychnidin-10-one, 2,3-dimethoxy-	357573	Brucine	1*	4	P018	B	100 (45.4)
Strychnine, & salts	57249	Strychnidin-10-one	10	1,4	P108	A	10 (4.54)

Hazardous Substance	CASRN	Regulatory Synonyms	Statutory			Final RQ	
			RQ	Code†	RCRA Waste #	Category	Pounds (Kg)
Styrene	100425		1000	1		C	1000 (454)
Sulfur monochloride	12771083		1000	1		C	1000 (454)
Sulfur phosphide	1314803	Phosphorus pentasulfide Phosphorus sulfide	100	1,4	U189	B	100 (45.4)
Sulfuric acid	7664939		1000	1		C	1000 (454)
	8014957		1000	1		C	1000 (454)
Sulfuric acid, dithallium (1+) salt	7446186	Thallium (I) sulfate	1000	1,4	P115	B	100 (45.4)
	10031591		1000	1,4	P115	B	100 (45.4)
Sulfuric acid, dimethyl ester	77781	Dimethyl sulfate	1*	4	U103	B	100 (45.4)
2,4,5-T acid	93765	Acetic acid, (2,4,5-trichlorophenoxy) 2,4,5-T	100	1,4	U232	C	1000 (454)
2,4,5-T amines	2008460		100	1		D	5000 (2270)
	1319728		100	1		D	5000 (2270)
	3813147		100	1		D	5000 (2270)
	6369966		100	1		D	5000 (2270)
	6369977		100	1		D	5000 (2270)
2,4,5-T esters	93798		100	1		C	1000 (454)
	1928478		100	1		C	1000 (454)
	2545597		100	1		C	1000 (454)
	25168154		100	1		C	1000 (454)
	61792072		100	1		C	1000 (454)
2,4,5-T salts	13560991		100	1		C	1000 (454)
2,4,5-T	93765	Acetic acid, (2,4,5-trichlorophenoxy) 2,4,5-T acid	100	1,4	U232	C	1000 (454)
TDE	72548	Benzene, 1,1'-(2,2-dichloroethylidene)bis[4-chloro- DDD 4,4' DDD	1	1,2,4	U060	X	1 (0.454)
1,2,4,5-Tetrachlorobenzene	95943	Benzene, 1,2,4,5-tetrachloro-	1*	4	U207	D	5000 (2270)
2,3,7,8-Tetrachlorodibenzo-p-dioxin (TCDD)	1746016		1*	2		X	1 (0.454)
1,1,1,2-Tetrachloroethane	630206	Ethane, 1,1,1,2-tetrachloro-	1*	4	U208	B	100 (45.4)
1,1,2,2-Tetrachloroethane	79345	Ethane, 1,1,2,2-tetrachloro-	1*	2,4	U209	B	100 (45.4)

Hazardous Substance	CASRN	Regulatory Synonyms	Statutory			Final RQ	
			RQ	Code†	RCRA Waste #	Category	Pounds (Kg)
Tetrachloroethene	127184	Ethene, tetrachloro- Perchloroethylene Tetrachloroethylene	1*	2,4	U210	B	100 (45.4)
Tetrachloroethylene	127184	Ethene, tetrachloro- Perchloroethylene Tetrachloroethene	1*	2,4	U210	B	100 (45.4)
2,3,4,6-Tetrachlorophenol	58902	Phenol, 2,3,4,6-tetrachloro-	1*	4	U212	A	10 (4.54)
Tetraethyl lead	78002	Plumbane, tetraethyl-	100	1,4	P110	A	10 (4.54)
Tetraethyl pyrophosphate	107493	Diphosphoric acid, tetraethyl ester	100	1,4	P111	A	10 (4.54)
Tetraethyldithiopyrophosphate	3689245	Thiodiphosphoric acid, tetraethyl ester	1*	4	P109	B	100 (45.4)
Tetrahydrofuran	109999	Furan, tetrahydro-	1*	4	U213	C	1000 (454)
Tetranitromethane	509148	Methane, tetranitro-	1*	4	P112	A	10 (4.54)
Tetraphosphoric acid, hexaethyl ester	757584	Hexaethyl tetraphosphoate	1*	4	P062	B	100 (45.4)
Thallic oxide	1314325	Thallium oxide Tl2O3	1*	4	P113	B	100 (45.4)
Thallium††	7440280		1*	2		C	1000 (454)
Thallium and compounds	N/A		1*	2			**
Thallium (I) acetate	563688	Acetic acid, thallium (1+) salt	1*	4	U214	B	100 (45.4)
Thallium (I) carbonate	6533739	Carbonic acid, dithallium (1+) salt	1*	4	U215	B	100 (45.4)
Thallium (I) chloride	7791120	Thallium chloride TlCl	1*	4	U216	B	100 (45.4)
Thallium chloride TlCl	7791120	Thallium (I) chloride	1*	4	U216	B	100 (45.4)
Thallium (I) nitrate	10102451	Nitric acid, thallium (1+) salt	1*	4	U217	B	100 (45.4)
Thallium oxide Tl2O3	1314325	Thallic oxide	1*	4	P113	B	100 (45.4)
Thallium selenite	12039520	Selenious acid, dithallium (1+) salt	1*	4	P114	C	1000 (454)
Thallium (I) sulfate	7446186	Sulfuric acid, dithallium (1+) salt	1000	1,4	P115	B	100 (45.4)
	10031591		1000	1,4	P115	B	100 (45.4)
Thioacetamide	62555	Ethanethioamide	1*	4	U218	A	10 (4.54)
Thiodiphosphoric acid, tetraethyl ester	3689245	Tetraethyldithiopyrophosphate	1*	4	P109	B	100 (45.4)
Thiofanox	39196184	2-Butanone, 3,3-dimethyl-1-(methylthio)-, O[(methylamino) carbonyl] oxime	1*	4	P045	B	100 (45.4)
Thioimidodicarbonic diamide [(H2N)C(S)] 2NH	541537	Dithiobiuret	1*	4	P049	B	100 (45.4)
Thiomethanol	74931	Methanethiol Methylmercaptan	100	1,4	U153	B	100 (45.4)

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Thioperoxydicarbonic diamide [(H2N)C(S)]2S2, tetramethyl-	137268	Thiram	1*	4	U244	A	10 (4.54)
Thiophenol	108985	Benzenethiol	1*	4	P014	B	100 (45.4)
Thiosemicarbazide	79196	Hydrazinecarbothioamide	1*	4	P116	B	100 (45.4)
Thiourea	62566		1*	4	U219	A	10 (4.54)
Thiourea, (2-chlorophenyl)-	5344821	1-(o-Chlorophenyl)thiourea	1*	4	P026	B	100 (45.4)
Thiourea, 1-naphthalenyl-	86884	alpha-Naphthylthiourea	1*	4	P072	B	100 (45.4)
Thiourea, phenyl-	103855	Phenylthiourea	1*	4	P093	B	100 (45.4)
Thiram	137268	Thioperoxydicarbonic diamide [(H2N)C(S)]2S2, tetramethyl-	1*	4	U244	A	10 (4.54)
Toluene	108883	Benzene, methyl	1000	1,2,4	U220	C	1000 (454)
Toluenediamine	95807	Benzenediamine, ar-methyl-	1*	4	U221	A	10 (4.54)
	496720		1*	4	U221	A	10 (4.54)
	823405		1*	4	U221	A	10 (4.54)
	25376458		1*	4	U221	A	10 (4.54)
Toluene diisocyanate	584849	Benzene, 1,3-diisocyanatomethyl-	1*	4	U223	B	100 (45.4)
	91087		1*	4	U223	B	100 (45.4)
	26471625		1*	4	U223	B	100 (45.4)
o-Toluidine	95534	Benzenamine, 2-methyl-	1*	4	U328	B	100 (45.4)
p-Toluidine	106490	Benzenamine, 4-methyl-	1*	4	U353	B	100 (45.4)
o-Toluidine hydrochloride	636215	Benzenamine, 2-methyl-, hydrochloride	1*	4	U222	B	100 (45.4)
Toxaphene	8001352	Camphene, octachloro-	1*	1,2,4	P123	X	1 (0.454)
2,4,5-TP acid	93721	Propionic acid 2-(2,4,5-trichlorophenoxy)- Silvex (2,4,5-TP)	100	1,4	U233	B	100 (45.4)
2,4,5-TP esters	32534955		100	1		B	100 (45.4)
1H-1,2,4-Triazol-3-amine	61825	Amitrole	1*	4	U011	A	10 (4.54)
Trichlorfon	52686		1000	1		B	100 (45.4)
1,2,4-Trichlorobenzene	120821		1*	2		B	100 (45.4)
1,1,1-Trichloroethane	71556	Ethane, 1,1,1-trichloro- Methyl chloroform	1*	2,4	U226	C	1000 (454)
1,1,2-Trichloroethane	79005	Ethane, 1,1,2-trichloro-	1*	2,4	U227	B	100 (45.4)
Trichloroethene	79016	Ethene, trichloro- Trichloroethylene	1000	1,2,4	U228	B	100 (45.4)

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			RQ	Code†	RCRA Waste #	Category	Pounds (Kg)
Trichloroethylene	79016	Ethene, trichloro- Trichloroethene	1000	1,2,4	U228	B	100 (45.4)
Trichloromethanesulfenyl chloride	594423	Methanesulfenyl chloride, trichloro-	1*	4	P118	B	100 (45.4)
Trichloromonofluoromethane	75694	Methane, trichlorofluoro-	1*	4	U121	D	5000 (2270)
Trichlorophenol	25167822		10	1		A	10 (4.54)
2,3,4-Trichlorophenol	15950660		10	1		A	10 (4.54)
2,3,5-Trichlorophenol	933788		10	1		A	10 (4.54)
2,3,6-Trichlorophenol	933755		10	1		A	10 (4.54)
2,4,5-Trichlorophenol	95954	Phenol, 2,4,5-trichloro-	10*	1,4	U230	A	10 (4.54)
2,4,6-Trichlorophenol	88062	Phenol, 2,4,6-trichloro-	10*	1,2,4	U231	A	10 (4.54)
3,4,5-Trichlorophenol	609198						
2,4,5-Trichlorophenol	95954	Phenol, 2,4,5-trichloro-	10*	1,4	U230	A	10 (4.54)
2,4,6-Trichlorophenol	88062	Phenol, 2,4,6-trichloro-	10	1,2,4	U231	A	10 (4.54)
Triethanolamine dodecylbenzenesulfonate	27323417		1000	1		C	1000 (454)
Triethylamine	121448		5000	1		D	5000 (2270)
Trimethylamine	75503		1000	1		B	100 (45.4)
1,3,5-Trinitrobenzene	99354	Benzene, 1,3,5-trinitro-	1*	4	U234	A	10 (4.54)
1,3,5-Trioxane, 2,4,6-trimethyl-	123637	Paraldehyde	1*	4	U182	C	1000 (454)
Tris(2,3-dibromopropyl) phosphate	126727	1-Propanol, 2,3-dibromo-, phosphate [(3:1)	1*	4	U235	A	10 (4.54)
Trypan blue	72571	2,7-Naphthalenedisulfonic acid, 3,3'-3,3'-dimethyl-(1,1'-biphenyl)-4,4'-diyl)-bis(azo)]bis(5-amino-4-hydroxy)-tetrasodium salt	1*	4	U236	A	10 (4.54)
Unlisted Hazardous Wastes Characteristic of Corrosivity	N/A		1*	4	D002	B	100 (45.4)
Unlisted Hazardous Wastes Characteristics: Characteristic of Toxicity:	N/A		1*	4			
Arsenic (D004)	N/A		*1	4	D004	X	1 (0.454)
Barium (D005)	N/A		*1	4	D005	C	1000 (454)
Benzene (D018)	N/A		1000	1,2,3,4	D018	A	10 (4.54)
Cadmium (D006)	N/A		*1	4	D006	A	10 (4.54)
Carbon tetrachloride (D019)	N/A		5000	1,2,4	D019	A	10 (4.54)

Hazardous Substance	CASRN	Regulatory Synonyms	Statutory			Final RQ	
			RQ	Code†	RCRA Waste #	Cate-gory	Pounds (Kg)
Chlordane (D020)	N/A		1	1,2,4	D020	X	1 (0.454)
Chlorobenzene (D021)	N/A		100	1,2,4	D021	B	100 (45.4)
Chloroform (D022)	N/A		5000	1,2,4	D022	A	10 (4.54)
Chromium (D007)	N/A		*1	4	D007	A	10 (4.54)
o-Cresol (D023)	N/A		1000	1,4	D023	C	1000 (454)
m-Cresol (D024)	N/A		1000	1,4	D024	C	1000 (454)
p-Cresol (D025)	N/A		1000	1,4	D025	C	1000 (454)
Cresol (D026)	N/A		1000	1,4	D026	C	1000 (454)
2,4-D (D016)	N/A		100	1,4	D016	B	100 (45.4)
1,4-Dichlorobenzene (D027)	N/A		100	1,2,4	D027	B	100 (45.4)
1,2-Dichloroethane (D028)	N/A		5000	1,2,4	D028	B	100 (45.4)
1,1-Dichloroethylene (D029)	N/A		5000	1,2,4	D029	B	100 (45.4)
2,4-Dinitrotoluene (D030)	N/A		1000	1,2,4	D030	A	10 (4.54)
Endrin (D012)	N/A		1	1,4	D012	X	1 (0.454)
Heptachlor (and epoxide) (D031)	N/A		1	1,2,4	D031	X	1 (0.454)
Hexachlorobenzene (D032)	N/A		*1	2,4	D032	A	10 (4.54)
Hexachlorobutadiene (D033)	N/A		*1	2,4	D033	X	1 (0.454)
Hexachloroethane (D034)	N/A		*1	2,4	D034	B	100 (45.4)
Lead (D008)	N/A		*1	4	D008		(#)
Lindane (D013)	N/A		1	1,4	D013	X	1 (0.454)
Mercury (D009)	N/A		*1	4	D009	X	1 (0.454)
Methoxychlor (D014)	N/A		1	1,4	D014	X	1 (0.454)
Methyl ethyl ketone (D035)	N/A		*1	4	D035	D	5000 (2270)
Nitrobenzene (D036)	N/A		1000	1,2,4	D036	C	1000 (454)
Pentachlorophenol (D037)	N/A		10	1,2,4	D037	A	10 (4.54)
Pyridine (D038)	N/A		*1	4	D038	C	1000 (454)
Selenium (D010)	N/A		*1	4	D010	A	10 (4.54)
Silver (D011)	N/A		*1	4	D011	X	1 (0.454)
Teterachloroethylene (D039)	N/A		*1	2,4	D039	B	100 (45.4)
Toxaphene (D015)	N/A		1	1,4	D015	X	1 (0.454)
Trichloroethylene (D040)	N/A		1000	1,2,4	D040	B	100 (45.4)
2,4,5-Trichlorophenol (D041)	N/A		10	1,4	D041	A	10 (4.54)

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Hazardous Substance	CASRN	Regulatory Synonyms	Statutory			Final RQ	
			RQ	Code†	RCRA Waste #	Category	Pounds (Kg)
2,4,6-Trichlorophenol (D042)	N/A		10	1,2,4	D042	A	10 (4.54)
2,4,5-TP (D017)	N/A		100	1,4	D017	B	100 (45.4)
Vinyl chloride (D043)	N/A		*1	2,3,4	D043	X	1 (0.454)
Unlisted Hazardous Wastes Characteristic of Ignitability	N/A		1*	4	D001	B	100 (45.4)
Unlisted Hazardous Wastes Characteristic of Reactivity	N/A		1*	4	D003	B	100 (45.4)
Uracil mustard	66751	2,4-(1H,3H)-Pyrimidinedione, 5-[bis(2-chloroethyl)amino]-	1*	4	U237	A	10 (4.54)
Uranyl acetate	541093		5000	1		B	100 (45.4)
Uranyl nitrate	10102064		5000	1		B	100 (45.4)
	36478769					B	
Urea, N-ethyl-N-nitroso-	759739	N-Nitroso-N-ethylurea	1*	4	U176	X	1 (0.454)
Urea, N-methyl-N-nitroso	684935	N-Nitroso-N-methylurea	1*	4	U177	X	1 (0.454)
Vanadic acid, ammonium salt	7803556	Ammonium vanadate	1*	4	P119	C	1000 (454)
Vanadium oxide V2O5	1314621	Vanadium pentoxide	1000	1,4	P120	C	1000 (454)
Vanadium pentoxide	1314621	Vanadium oxide V2O5	1000	1,4	P120	C	1000 (454)
Vanadyl sulfate	27774136		1000	1		C	1000 (454)
Vinyl chloride	75014	Ethene, chloro-	1*	2,3,4	U043	X	1 (0.454)
Vinyl acetate	108054	Vinyl acetate monomer	1000	1		D	5000 (2270)
Vinyl acetate monomer	108054	Vinyl acetate	1000	1		D	5000 (2270)
Vinylamine, N-methyl-N-nitroso-	4549400	N-Nitrosomethylvinylamine	1*	4	P084	A	10 (4.54)
Vinylidene chloride	75354	Ethene, 1,1-dichloro- 1,1-Dichloroethylene	5000	1,2,4	U078	B	100 (45.4)
Warfarin, & salts, when present at concentrations greater than 0.3%	81812	2H-1-Benzopyran-2-one, 4-hydroxy-3-(3-oxo-1-phenyl-butyl)-, & salts, when present at concentrations greater than 0.3%	1*	4	P001	B	100 (45.4)
Xylene (mixed)	1330207	Benzene, dimethyl	1000	1,4	U239	C	1000 (454)
m-Benzene, dimethyl	108383	m-Xylene	1000	1,4	U239	C	1000 (454)
o-Benzene, dimethyl	95476	o-Xylene	1000	1,4	U239	C	1000 (454)
p-Benzene, dimethyl	106423	p-Xylene	1000	1,4	U239	C	1000 (454)

Hazardous Substance	CASRN	Regulatory Synonyms	Statutory			Final RQ	
			RQ	Code†	RCRA Waste #	Category	Pounds (Kg)
Xylenol	1300716		1000	1		C	1000 (454)
Yohimban-16-carboxylic acid, 11,17-dimethoxy-18-[(3,4,5-trimethoxybenzoyl)oxy]-, methyl ester (3beta,16beta,17alpha, 18beta,20alpha)-	50555	Reserpine	1*	4	U200	D	5000 (2270)
Zinc††	7440666		1*	2		C	1000 (454)
ZINC AND COMPOUNDS	N/A		1*	2			**
Zinc acetate	557346		1000	1		C	1000 (454)
Zinc ammonium chloride	52628258		5000	1		C	1000 (454)
	14639975		5000	1		C	1000 (454)
	14639986		5000	1		C	1000 (454)
Zinc borate	1332076		1000	1		C	1000 (454)
Zinc bromide	7699458		5000	1		C	1000 (454)
Zinc carbonate	3486359		1000	1		C	1000 (454)
Zinc chloride	7646857		5000	1		C	1000 (454)
Zinc cyanide	557211	Zinc cyanide Zn(CN)2	10	1,4	P121	A	10 (4.54)
Zinc cyanide Zn(CN)2	557211	Zinc cyanide	10	1,4	P121	A	10 (4.54)
Zinc fluoride	7783495		1000	1		C	1000 (454)
Zinc formate	557415		1000	1		C	1000 (454)
Zinc hydrosulfite	7779864		1000	1		C	1000 (454)
Zinc nitrate	7779886		5000	1		C	1000 (454)
Zinc phenolsulfonate	127822		5000	1		D	5000 (2270)
Zinc phosphide	1314847	Zinc phosphide Zn3P2, when present at concentrations greater than 10%	1000	1,4	P122	B	100 (45.4)
Zinc phosphide Zn3P2, when present at concentrations greater than 10%	1314847	Zinc phosphide	1000	1,4	P122	B	100 (45.4)
Zinc silicofluoride	16871719		5000	1		D	5000 (2270)
Zinc sulfate	7733020		1000	1		C	1000 (454)
Zirconium nitrate	13746899		5000	1		D	5000 (2270)
Zirconium potassium fluoride	16923958		5000	1		C	1000 (454)
Zirconium sulfate	14644612		5000	1		D	5000 (2270)
Zirconium tetrachloride	10026116		5000	1		D	5000 (2270)

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Hazardous Substance	CASRN	Regulatory Synonyms	Statutory RQ	Statutory Code†	Statutory RCRA Waste #	Final RQ Category	Final RQ Pounds (Kg)
F001			1*	4	F001	A	10 (4.54)
The following spent halogenated solvents used in degreasing; all spent solvent mixtures/blends used in degreasing containing, before use, a total of ten percent or more (by volume) of one or more of the above halogenated solvents or those solvents listed in F002, F004, and F005; and still bottoms from the recovery of these spent solvents and spent solvent mixtures.							
(a) Tetrachloroethylene	127184		1*	2,4	U210	B	100 (45.4)
(b) Trichloroethylene	79016		1000	1,2,4	U228	B	100 (45.4)
(c) Methylene chloride	75092		1*	2,4	U080	C	1000 (454)
(d) 1,1,1-Trichloroethane	71556		1*	2,4	U226	C	1000 (454)
(e) Carbon tetrachloride	56235		5000	1,2,4	U211	A	10 (4.54)
(f) Chlorinated fluorocarbons	N/A					D	5000 (2270)
F002			1*	2,4	F002	A	10 (4.54)
The following spent halogenated solvents; all spent solvent mixtures/blends containing, before use, a total of ten percent or more (by volume) of one or more of the above halogenated solvents or those solvents listed in F002,F004, and F005; and still bottoms from the recovery of these spent solvents and spent solvent mixtures.							
(a) Tetracholoroethylene	127184		1*	4	U210	B	100 (45.4)
(b) Methylene chloride	75092		1*	2,4	U080	C	1000 (454)
(c) Trichloroethylene	79016		1000	1,2,4	U228	B	100 (45.4)
(d) 1,1,1-Trichloroethane	71556		1*	2,4	U226	C	1000 (454)
(e) Chlorobenzene	108907		100	1,2,4	U037	B	100 (45.4)
(f) 1,1,2-Trichloro-1,2,2-trifluoroethane	76131					D	5000 (2270)
(g) o-Dichlorobenzene	95501		100	1,2,4	U070	B	100 (45.4)
(h) Trichlorofluoromethane	75694		1*	4	U121	D	5000 (2270)
(i) 1,1,2-Trichloroethane	79005		1*	2,4	U227	B	100 (45.4)
F003			1*	4	F003	B	100 (45.4)

Hazardous Substance	CASRN	Regulatory Synonyms	Statutory			Final RQ	
			RQ	Code†	RCRA Waste #	Category	Pounds (Kg)
The following spent non-halogenated solvents and the still bottoms from the recovery of these solvents:							
(a) Xylene	1330207					C	1000 (454)
(b) Acetone	67641					D	5000 (2270)
(c) Ethyl acetate	141786					D	5000 (2270)
(d) Ethylbenzene	100414					C	1000 (454)
(e) Ethyl ether	60297					B	100 (45.4)
(f) Methyl isobutyl ketone	108101					D	5000 (2270)
(g) n-Butyl alcohol	71363					D	5000 (2270)
(h) Cyclohexanone	108941					D	5000 (2270)
(i) Methanol	67561					D	5000 (2270)
F004			1*	4	F004	C	1000 (454)
The following spent non-halogenated solvents and the still bottoms from the recovery of these solvents:							
(a) Cresols/Cresylic acid	1319773		1000	1,4	U052	C	1000 (454)
(b) Nitrobenzene	98953		1000	1,2,4	U169	C	1000 (454)
F005			1*	4	F005	B	100 (45.4)
The following spent non-halogenated solvents and the still bottoms from the recovery of these solvents:							
(a) Toluene	108883		1000	1,2,4	U220	C	1000 (454)
(b) Methyl ethyl ketone	78933		1*	4	U159	D	5000 (2270)
(c) Carbon disulfide	75150		5000	1,4	P022	B	100 (45.4)
(d) Isobutanol	78831		1*	4	U140	D	5000 (2270)
(e) Pyridine	110861		1*	4	U196	C	1000 (454)
F005			1*	4	F005	A	10 (4.54)

Hazardous Substance	CASRN	Regulatory Synonyms	Statutory			Final RQ	
			RQ	Code†	RCRA Waste #	Category	Pounds (Kg)
Wastewater treatment sludges from electroplating operations except from the following processes: (1) sulfuric acid anodizing of aluminum, (2) tin plating on carbon steel, (3) zinc plating (segregated basis) on carbon steel, (4) aluminum or zinc-aluminum plating on carbon steel, (5) cleaning/stripping associated with tin, zinc and aluminum plating on carbon steel, and (6) chemical etching and milling of aluminum.							
F007			1*	4	F007	A	10 (4.54)
Spent cyanide plating bath solutions from electroplating operations.							
F008			1*	4	F008	A	10 (4.54)
Plating bath residues from the bottom of plating baths from electroplating operations where cyanides are used in the process.							
F009			1*	4	F009	A	10 (4.54)
Spent stripping and cleaning bath solutions from electroplating operations where cyanides are used in the process.							
F010			1*	4	F010	A	10 (4.54)
Quenching bath residues from oil baths from metal heat treating operations where cyanides are used in the process.							
F011			1*	4	F011	A	10 (4.54)
Spent cyanide solution from salt bath pot cleaning from metal heat treating operations.							
F012			1*	4	F012	A	10 (4.54)
Quenching wastewater treatment sludges from metal heat treating operations where cyanides are used in the process.							
F019			1	4	F019	A	10 (4.54)

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Hazardous Substance	CASRN	Regulatory Synonyms	Statutory			Final RQ	
			RQ	Code †	RCRA Waste #	Category	Pounds (Kg)
Wastewater treatment sludges from the chemical conversion coating of aluminum except from zirconium phosphating in aluminum can washing when such phosphating is an exclusive conversion coating process.							
F020			1*	4	F020	X	1 (0.454)
Wastes (except wastewater and spent carbon from hydrogen chloride purification) from the production or manufacturing use (as a reactant, chemical intermediate, or component in a formulating process) of tri-or-tetrachlorophenol, or of intermediates used to produce their pesticide derivatives. (This listing does not include wastes from the production of hexachlorophene from highly purified 2,4,5-trichlorophenol.)							
F021			1*	4	F021	X	1 (0.454)
Wastes (except wastewater and spent carbon from hydrogen chloride purification) from the production or manufacturing use (as a reactant, chemical intermediate, or component in a formulating process) of pentachlorophenol, or of intermediates used to produce its derivatives.							
F022			1*	4	F022	X	1 (0.454)
Wastes (except wastewater and spent carbon from hydrogen chloride purification) from the manufacturing use (as a reactant, chemical intermediate, or component in a formulating process) of tetra-, penta-, or hexachlorobenzenes under alkaline conditions.							
F023			1*	4	F023	X	1 (0.454)

R0044203

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Hazardous Substance	CASRN	Regulatory Synonyms	Statutory RQ	Statutory Code†	Statutory RCRA Waste #	Final RQ Category	Final RQ Pounds (Kg)
Wastes (except wastewater and spent carbon from hydrogen chloride purification) from the production of materials on equipment previously used for the production or manufacturing use (as a reactant, chemical intermediate, or component in a formulating process) of tri- and tetrachlorophenols. (This listing does not include wastes from equipment used only for the production or use of hexachlorophene from highly purified 2,4,5-tri-chlorophenol.)							
F024			1*	4	F024	X	1 (0.454)
Wastes, including but not limited to distillation residues, heavy ends, tars, and reactor cleanout wastes, from the production of chlorinated aliphatic hydrocarbons, having carbon content from one to five, utilizing free radical catalyzed processes. (This listing does not include light ends, spent filters and filter aids, spent dessicants(sic), wastewater, wastewater treatment sludges, spent catalysts, and wastes listed in Section 261.32.)							
F025			1*	4	F025	X	##1 (0.454)
Condensed light ends, spent filters and filter aids, and spent dessicant wastes from the production of certain chlorinated aliphatic hydrocarbons, by free radical catalyzed processes. These chlorinated aliphatic hydrocarbons are those having carbon chain lengths ranging from one to and including five, with varying amounts and positions of chlorine substitution.							

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R0044204

Hazardous Substance	CASRN	Regulatory Synonyms	Statutory RQ	Statutory Code†	Statutory RCRA Waste #	Final RQ Category	Final RQ Pounds (Kg)
F026			1*	4	F026	X	1 (0.454)
Wastes (except wastewater and spent carbon from hydrogen chloride purification) from the production of materials on equipment previously used for the manufacturing use (as a reactant, chemical intermediate, or component in a formulating process) of tetra-, penta-, or hexachlorobenzene under alkaline conditions.							
F027			1*	4	F027	X	1 (0.454)
Discarded unused formulations containing tri-, tetra-, or pentachlorophenol or discarded unused formulations containing compounds derived from these chlorophenols. (This listing does not include formulations containing hexachlorophene synthesized from prepurified 2,4,5-tri-chlorophenol as the sole component.)							
F028			1*	4	F028	X	1 (0.454)
Residues resulting from the incineration or thermal treatment of soil contaminated with EPA Hazardous Waste Nos. F020, F021, F022, F023, F026, and F027.							
F032			1*	4	F032	X	1 (0.454)
Wastewaters, process residuals, preservative drippage, and spent formulations from wood preserving processes generated at plants that currently use or have previously used chlorophenolic formulations (except wastes from processes that have had the F032 waste code deleted in accordance with §261.35 and do not resume or initiate use of chlorophenolic formulations). This listing does not include K001 bottom sediment sludge from the treatment of wastewater from wood preserving processes that use creosote and/or pentachlorophenol.							
F034			1*	4	F034	X	1 (0.454)

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Hazardous Substance	CASRN	Regulatory Synonyms	Statutory			Final RQ	
			RQ	Code†	RCRA Waste #	Category	Pounds (Kg)
Wastewaters, process residuals, preservative drippage, and spent formulations from wood preserving processes generated at plants that use creosote formulations. This listing does not include K001 bottom sediment sludge from the treatment of wastewater from wood preserving processes that use creosote and/or pentachlorophenol.							
F035			1*	4	F035	X	1 (0.454)
Wastewaters, process residuals, preservative drippage, and spent formulations from wood preserving processes generated at plants that use inorganic preservatives containing arsenic or chromium. This listing does not include K001 bottom sediment sludge from the treatment of wastewater from wood preserving processes that use creosote and/or penetachlorophenol.							
F037			1*	4	F037	X	1 (0.454)

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Hazardous Substance	CASRN	Regulatory Synonyms	Statutory			Final RQ	
			RQ	Code†	RCRA Waste #	Category	Pounds (Kg)
Petroleum refinery primary oil/water/solids separation sludge--Any sludge generated from the gravitational separation of oil/water/solids during the storage or treatment of process wastewaters and oily cooling wastewaters from petroleum refineries. Such sludges include, but are not limited to, those generated in: oil/water/solids separators; tanks and impoundments; ditches and other conveyances; sumps; and stormwater units receiving dry weather flow. Sludge generated in stormwater units that do not receive dry weather flow, sludges generated from non-contact once-through cooling waters segregated for treatment from other process or oily cooling waters, sludges generated in aggressive biological treatment units as defined in §261.31(b)(2) (including sludges generated in one or more additional units after wastewaters have been treated in aggressive biological treatment units) and K051 wastes are not included in this listing.							
F038			1*	4	F038	X	1 (0.454)

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R0044207

Hazardous Substance	CASRN	Regulatory Synonyms	Statutory			Final RQ	
			RQ	Code†	RCRA Waste #	Category	Pounds (Kg)
Petroleum refinery secondary (emulsified) oil/water/solids separation sludge--Any sludge and/or float generated from the physical and/or chemical separation of oil/water/solids in process wastewaters and oily cooling wastewaters from petroleum refineries. Such wastes include, but are not limited to, all sludges and floats generated in: induced air flotation (IAF) units, tanks and impoundments, and all sludges generated in DAF units. Sludges generated in stormwater units that do not receive dry weather flow, sludges generated from once-through non-contact cooling waters segregated for treatment from other process or oil cooling wastes, sludges and floats generated in aggressive biological treatment units as defined in §261.31(b)(2) (including sludges and floats generated in one or more additional units after wastewaters have been treated in aggressive biological treatment units) and F037, K048, and K051 wastes are not included in this listing.							
K001			1*	4	K001	X	1 (0.454)
Bottom sediment sludge from the treatment of wastewaters from wood preserving processes that use creosote and/or pentachlorophenol.							
K002			1*	4	K002		#
Wastewater treatment sludge from the production of chrome yellow and organge pigments.							
K003			1*	4	K003		#
Wastewater treatment sludge from the production of molybdate orange pigments.							
K004			1*	4	K004	A	10 (4.54)
Wastewater treatment sludge from the production of zinc yellow pigments.							
K005			1*	4	K005		#

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R0044208

Hazardous Substance	CASRN	Regulatory Synonyms	Statutory RQ	Statutory Code†	Statutory RCRA Waste #	Final RQ Category	Final RQ Pounds (Kg)
Wastewater treatment sludge from the production of chrome green pigments.							
K006			1*	4	K006	A	10 (4.54)
Wastewater treatment sludge from the production of chrome oxide green pigments (anhydrous and hydrated).							
K007			1*	4	K007	A	10 (4.54)
Wastewater treatment sludge from the production or iron blue pigments.							
K008			1*	4	K008	A	10 (4.54)
Oven residue from the production of chrome oxide green pigments.							
K009			1*	4	K009	A	10 (4.54)
Distillation bottoms from the production of acetaldehyde from ethylene.							
K010			1*	4	K010	A	10 (4.54)
Distillation side cuts from the production of acetaldehyde from ethylene.							
K011			1*	4	K011	A	10 (4.54)
Bottom stream from the wastewater stripper inthe production of acrylonitrile.							
K013			1*	4	K013	A	10 (4.54)
Bottom stream from the acetonitrile column in the production of acrylonitrile.							
K014			1*	4	K014	D	5000 (2270)
Bottoms from the acetonitrile purification column in the production of acrylonitrile.							
K015			1*	4	K015	A	10 (4.54)
Still bottoms from the distillation of benzyl chloride.							
K016			1*	4	K016	X	1 (0.454)

Hazardous Substance	CASRN	Regulatory Synonyms	Statutory			Final RQ	
			RQ	Code†	RCRA Waste #	Category	Pounds (Kg)
Heavy ends or distillation residues from the production of carbon tetrachloride.							
K017			1*	4	K017	A	10 (4.54)
Heavy ends (still bottoms) from the purification column in the production of epi-chlorohydrin.							
K018			1*	4	K018	X	1 (0.454)
Heavy ends from the fractionation column in ethyl chloride production.							
K019			1*	4	K019	X	1 (0.454)
Heavy ends from the distillation of ethylene dichloride in ethylene dichloride production.							
K020			1*	4	K020	X	1 (0.454)
Heavy ends from the distillation of vinyl chloride in vinyl chloride monomer production.							
K021			1*	4	K021	A	10 (4.54)
Aqueous spent antimony catalyst waste from fluoromethanes production.							
K022			1*	4	K022	X	1 (0.454)
Distillation bottom tars from the production of phenol/acetone from cumene.							
K023			1*	4	K023	D	5000 (2270)
Distillation light ends from the production of phthalic anhydride from naphthalene.							
K024			1*	4	K024	D	5000 (2270)
Distillation bottoms from the production of phthalic anhydride from naphthalene.							
K025			1*	4	K025	A	10 (4.54)
Distillation bottoms from the production of nitrobenzene by the nitration of benzene.							
K026			1*	4	K026	C	1000 (454)

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Hazardous Substance	CASRN	Regulatory Synonyms	Statutory			Final RQ	
			RQ	Code†	RCRA Waste #	Category	Pounds (Kg)
Stripping still tails from the production of methyl ethyl pyridines.							
K027			1*	4	K027	A	10 (4.54)
Centrifuge and distillation residues from tolune diisocyenate production.							
K028			1*	4	K028	X	1 (0.454)
Spent catalyst from the hydrochlorinator reactor in the production of 1,1,1-trichloroethane.							
K029			1*	4	K029	X	1 (0.454)
Waste from the product steam stripper in the production of 1,1,1-trichloroethane.							
K030			1*	4	K030	X	1 (0.454)
Column bottoms or heavy ends from the combined production of trichloroethylene and perchloroethylene.							
K031			1*	4	K031	X	1 (0.454)
By-product salts generated in the production of MSMA and cacodylic acid.							
K032			1*	4	K032	A	10 (4.54)
Wastewater treatment sludge from the production of chlordane.							
K033			1*	4	K033	A	10 (4.54)
Wastewater and scrub water from the chlorination of cyclopentadiene in the production of chlordane.							
K034			1*	4	K034	A	10 (4.54)
Filter solids from the filtration of hexachlorocyclo-pentadiene in the production of chlordane.							
K035			1*	4	K035	X	1 (0.454)
Wastewater treatment sludges generated in the production of creosote.							
K036			1*	4	K036	X	1 (0.454)

Hazardous Substance	CASRN	Regulatory Synonyms	Statutory			Final RQ	
			RQ	Code†	RCRA Waste #	Category	Pounds (Kg)
Still bottoms from toluene reclamation distillation in the production of disulfoton.							
K037			1*	4	K037	X	1 (0.454)
Wastewater treatment sludges from the production of disulfoton.							
K038			1*	4	K038	A	10 (4.54)
Wastewater from the washing and stripping of phorate production.							
K039			1*	4	K039	A	10 (4.54)
Filter cake from the filtration of diethylphosphorodithioic acid in the production of phorate.							
K040			1*	4	K040	A	10 (4.54)
Wastewater treatment sludge from the production of phorate.							
K041			1*	4	K041	X	1 (0.454)
Wastewater treatment sludge from the production of toxaphene.							
K042			1*	4	K042	A	10 (4.54)
Heavy ends or distillation residues from the distillation of tetrachlorobenzene in the production of 2,4,5-T.							
K043			1*	4	K043	A	10 (4.54)
2,6-Dichlorophenol waste from the production of 2,4-D.							
K044			1*	4	K044	A	10 (4.54)
Wastewater treatment sludges from the manufacturing and processing of explosives.							
K045			1*	4	K045	A	10 (4.54)
Spent carbon from the treatment of wastewater containing explosives.							
K046			1*	4	K046	B	100 (45.4)
Wastewater treatment sludges from the manufacturing, formulation and loading of lead-based initiating compounds.							

Hazardous Substance	CASRN	Regulatory Synonyms	Statutory			Final RQ	
			RQ	Code†	RCRA Waste #	Category	Pounds (Kg)
K047			1*	4	K047	A	10 (4.54)
Pink/red water from TNT operations.							
K048			1*	4	K048		#
Dissolved air flotation (DAF) float from the petroleum refining industry.							
K049			1*	4	K049		#
Slop oil emulsion solids from the petroleum refining industry.							
K050			1*	4	K050	A	10 (4.54)
Heat exchanger bundle cleaning sludge from the petroleum refining industry.							
K051			1*	4	K051		#
API separator sludge from the petroleum refining industry.							
K052			1*	4	K052	A	10 (4.54)
Tank bottoms (leaded) from the petroleum refining industry.							
K060			1*	4	K060	X	1 (0.454)
Ammonia still lime sludge coking operations.							
K061			1*	4	K061		#
Emission control dust/sludge from the primary production of steel in electric furnances.							
K062			1*	4	K062		#
Spent pickle liquor generated by steel finishing operations of facilities within the iron and steel industry (SIC Codes 331 and 332).							
K064			1*	4	K064		##
Acid plant blowdown slurry/sludge resulting from thickening of blowdown slurry from primary copper production.							
K065			1*	4	K065		##

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Hazardous Substance	CASRN	Regulatory Synonyms	Statutory			Final RQ	
			RQ	Code†	RCRA Waste #	Category	Pounds (Kg)
Surace impoundment solids contained in and dredged from surface impoundments at primary lead smelting facilities.							
K066			1*	4	K066		##
Sludge from treatment of process wastewater and/or acid plant blowdown from primary zinc production.							
K069			1*	4	K069		#
Emission control dust/sludge from secondary lead smelting.							
K071			1*	4	K071	X	1 (0.454)
Brine purification muds from the mercury cell process in chlorine production, where separately prepurified brine is not used.							
K073			1*	4	K073	A	10 (4.54)
Chlorinated hydrocarbon waste from the purification step of the diaphragm cell process using graphite anodes in chlorine production.							
K083			1*	4	K083	B	100 (45.4)
Distillatin bottoms from aniline extraction.							
K084			1*	4	K084	X	1 (0.454)
Wastewater treatment sludges generated during the production of veterinary pharmaceuticals from arsenic or organo-arsenic compounds.							
K085			1*	4	K085	A	10 (4.54)
Distillation or fractionation column bottoms from the production of chlorobenzenes.							
K086			1*	4	K086		#

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Hazardous Substance	CASRN	Regulatory Synonyms	Statutory			Final RQ	
			RQ	Code†	RCRA Waste #	Category	Pounds (Kg)
Solvent washes and sludges, caustic washes and sludges, or water washes and sludges from cleaning tubs and equipment used in the formulation of ink from pigments, driers, soaps, and stabilizers containing chromium and lead.							
K087			1*	4	K087	B	100 (45.4)
Decanter tank tar sludge from coking operations.							
K088			1*	4	K088		
Spent potliners from primary aluminum reduction.							
K090			1*	4	K090		
Emission control dust or sludge from ferrochromiumsilicon production.							
K091			1	4	K091		
Emission control dust or sludge from ferrochromium production.							
K093			1*	4	K093	D	5000 (2270)
Distillation light ends from the production of phthalic anhydride from ortho-xylene.							
K094			1*	4	K094	D	5000 (2270)
Distillation bottoms from the production of phthalic anhydride from ortho-xylene.							
K095			1*	4	K095	B	100 (45.4)
Distillation bottoms from the production of 1,1,1-trichloroethane.							
K096			1*	4	K096	B	100 (45.4)
Heavy ends from the heavy ends column from the production of 1,1,1-trichloroethane.							
K097			1*	4	K097	X	1 (0.454)
Vacuum stripper discharge from the chlordane chlorinator in the production of chlordane.							
K098			1*	4	K098	X	1 (0.454)

Hazardous Substance	CASRN	Regulatory Synonyms	Statutory			Final RQ	
			RQ	Code†	RCRA Waste #	Category	Pounds (Kg)
Untreated process wastewater from the production of toxaphene.							
K099			1*	4	K099	A	10 (4.54)
Untreated wastewater from the production of 2,4-D.							
K100			1*	4	K100		#
Waste leaching solution from acid leaching of emission control dust/sludge from secondary lead smelting.							
K101			1*	4	K101	X	1 (0.454)
Distillation tar residues from the distillation of aniline-based compounds in the production of veterinary pharmaceuticals from arsenic or organo-arsenic compounds.							
K102			1*	4	K102	X	1 (0.454)
Residue from the use of activated carbon for decolorization in the production of veterinary pharmaceuticals from arsenic or organo-arsenic compounds.							
K103			1*	4	K103	B	100 (45.4)
Process residues from aniline extraction from the production of aniline.							
K104			1*	4	K104	A	10 (4.54)
Combined wastewater streams generated from nitrobenzene/aniline production.							
K105			1*	4	K105	A	10 (4.54)
Separated aqueous stream from the reactor product washing step in the production of chlorobenzenes.							
K106			1*	4	K106	X	1 (0.454)
Wastewater treatment sludge from the mercury cell process in chlorine production.							
K107			10	4	K107	X	10 (4.54)

Hazardous Substance	CASRN	Regulatory Synonyms	Statutory			Final RQ	
			RQ	Code†	RCRA Waste #	Cate-gory	Pounds (Kg)
Column bottoms from product separation from the production of 1,1-dimethylhydrazine (UDMH) from carboxylic acid hydrazines.							
K108			10	4	K108	X	10 (4.54)
Condensed column overheads from product separation and condensed reactor vent gases from the production of 1,1-dimethylhydrazine (UDMH) from carboxylic acid hydrazides.							
K109			10	4	K109	X	10 (4.54)
Spent filter cartridges from product purification from the production of 1,1-dimethylhydrazine (UDMH) from carboxylic acid hydrazides.							
K110			10	4	K110	X	10 (4.54)
Condensed column overheads from intermediate separation from the production of 1,1-dimethylhydrazine (UDMH) from carboxylic acid hydrazides.							
K111			1*	4	K111	A	10 (4.54)
Product washwaters from the production of dinitrotoluene via nitration of toluene.							
K112			1*	4	K112	A	10 (4.54)
Reaction by-product water from the drying column in the production of toluenediamine via hydrogenation of dinitrotoluene.							
K113			1*	4	K113	A	10 (4.54)
Condensed liquid light ends from the purification of toluenediamine in the production of toluenediamine via hydrogenation of dinitrotoluene.							
K114			1*	4	K114	A	10 (4.54)
Vicinals from the purification of toluenediamine in the production of toluenediamine via hydrogenation of dinitrotoluene.							
K115			1*	4	K115	A	10 (4.54)

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Hazardous Substance	CASRN	Regulatory Synonyms	Statutory			Final RQ	
			RQ	Code †	RCRA Waste #	Category	Pounds (Kg)
K116 Heavy ends from the purification of toluenediamine in the production of toluenediamine via hydrogenation of dinitrotoluene.			1*	4	K116	A	10 (4.54)
K117 Organic condensate from the solvent recovery column in the production of toluene diisocyanate via phosgenation of toluenediamine.			1*	4	K117	X	1 (0.454)
K118 Wastewater from the reaction vent gas scrubber in the production of ethylene bromide via bromination of ethene			1*	4	K118	X	1 (0.454)
K123 Spent absorbent solids from purification of ethylene dibromide in the production of ethylene dibromide.			1*	4	K123	A	10 (4.54)
K124 Process wastewater (including supernates, filtrates, and washwaters) from the production of ethylene-bisdithiocarbamic acid and its salts.			1*	4	K124	A	10 (4.54)
K125 Reactor vent scrubber water from the production of ethylenebisdithiocarbamic acid and its salts.			1*	4	K125	A	10 (4.54)
K126 Filtration, evaporation, and centrifugation solids from the production of ethylenebisdithiocarbamic acid and its salts.			1*	4	K126	A	10 (4.54)
K131 Baghouse dust and floor sweepings in milling and packaging operations from the production or formulation of ethylenebisdithiocarbamic acid and its salts.			100	4	K131	X	100 (45.4)

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Hazardous Substance	CASRN	Regulatory Synonyms	Statutory			Final RQ	
			RQ	Code†	RCRA Waste #	Category	Pounds (Kg)
Wastewater from the reactor and spent sulfuric acid from the acid dryer in the production of methyl bromide.							
K132			1000	4	K132	X	1000 (454)
Spent absorbent and wastewater solids from the production of methyl bromide.							
K136			1*	4	K136	X	1 (0.454)
Still bottoms from the purification of ethylene dibromide in the production of ethylene dibromide via bromination of ethene.							

†Indicates the statutory source as defined by 1,2,3, and 4 below.
††No reporting of releases of this hazardous substance is required if the diameter of the pieces of the solid metal released is equal to or exceeds 100 micrometers (0.004 inches).
†††The RQ for asbestos is limited to friable forms only.
1--Indicates that the statutory source for designation of this hazardous substance under CERCLA is CWA Section 311(b)(4).
2--Indicates that the statutory source for designation of this hazardous substance under CERCLA is CWA Section 307(a).
3--Indicates that the statutory source for designation of this hazardous substance under CERCLA is CAA Section 112.
4--Indicates that the statutory source for designation of this hazardous substance under CERCLA is RCRA Section 3001.
1*--Indicates that the 1-pound RQ is a CERCLA statutory RQ.
#Indicates that the RQ is subject to change when the assessment of potential carcinogenicity is completed.
##The Agency may adjust the statutory RQ for this hazardous substance in a future rulemaking; until then the statutory RQ applies.
§--The adjusted RQs for radionuclides may be found in Appendix B to this table.
**--Indicates that no RQ is being assigned to the generic or broad class.

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APPENDIX I

SECTION 313 WATER PRIORITY CHEMICALS

SECTION 313 WATER PRIORITY CHEMICALS	
CAS Number	Common Name
75-07-0	Acetaldehyde
75865	Acetane cynohydrin
107-02-8	Acrolein
107-13-1	Acrylonitrile
309-00-2	Aldrin[1,4:5,8-Dimethanonaphthalene, 1,2,3,4,10,10-hexachloro-1,4,4a,5,8,8a-hexahydro-(1.alpha.,4.alpha.,4a.beta.,5.alpha.,8.alpha.,8a.beta.)-]
107-05-1	Allyl Chloride
7429-90-5	Aluminum (fume or dust)
7664-41-7	Ammonia
62-53-3	Aniline
120-12-7	Anthracene
7440-36-0	Antimony
7647189	Antimony pentachloride
28300745	Antimony potassium tartrate
7789619	Antimony tribromide
10025919	Antimony trichloride
7783564	Antimony trifluoride
1309644	Antimony trioxide
7440-38-2	Arsenic
1303328	Arsenic disulfide
1303282	Arsenic pentoxide
7784341	Arsenic trichloride
1327533	Arsenic trioxide
1303339	Arsenic trisulfide
1332-21-4	Asbestos (friable)
542621	Barium cyanide
71-43-2	Benzene
92-87-5	Benzidine
100470	Benzonitrile
98-88-4	Benzoyl chloride

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SECTION 313 WATER PRIORITY CHEMICALS	
CAS Number	Common Name
100-44-7	Benzyl chloride
7440-41-7	Beryllium
7787475	Beryllium chloride
7787497	Beryllium fluoride
7787555	Beryllium nitrate
111-44-4	Bis(2-chloroethyl) ether
75-25-2	Bromoform
74-83-9	Bromomethane (Methyl bromide)
85-68-7	Butyl benzyl phthalate
7440-43-9	Cadmium
543908	Cadmium acetate
7789426	Cadmium bromide
10108642	Cadmium chloride
7778441	Calcium arsenate
52740166	Calcium arsenite
13765190	Calcium chromate
592018	Calcium cyanide
133-06-2	Captan [1H-Isoindole-1,3(2H)-dione,3a,4,7,7a-tetrahydro-2-[(trichloromethyl)thio]-]
63-25-2	Carbaryl [1-Naphthalenol, methylcarbamate]
75-15-0	Carbon disulfide
56-23-5	Carbon tetrachloride
57-74-9	Chlordane [4,7-Methanoindan,1,2,4,5,6,7,8,8-octachloro-2,3,3a,4,7,7a-hexahydro-]
7782-50-5	Chlorine
59-50-7	Chloro-4-methyl-3-phenol *p*-Chloro-*m*-cresol
108-90-7	Chlorobenzene
75-00-3	Chloroethane (Ethyl chloride)
67-66-3	Chloroform
74-87-3	Chloromethane (Methyl chloride)
95-57-8	2-Chlorophenol

SECTION 313 WATER PRIORITY CHEMICALS	
CAS Number	Common Name
106-48-9	4-Chlorophenol
1066304	Chromic acetate
11115745	Chromic acid
10101538	Chromic sulfate
7440-47-3	Chromium
1308-14-1	Chromium (Tri)
10049055	Chromous chloride
7789437	Cobaltous bromide
544183	Cobaltous formate
14017415	Cobaltous sulfamate
7440-50-8	Copper
108-39-4	*m*-Cresol
9548-7	*o*-Cresol
106-44-5	*p*-Cresol
1319-77-3	Cresol (mixed isomers)
142712	Cupric acetate
12002038	Cupric acetoarsenite
7447394	Cupric chloride
3251238	Cupric nitrate
5893663	Cupric oxalate
7758987	Cupric sulfate
10380297	Cupric sulfate, ammoniated
815827	Cupric tartrate
57-12-5	Cyanide
506774	Cyanogen chloride
110-82-7	Cyclohexane
94-75-7	2,4-D [Acetic acid, (2,4-dichlorophenoxy)-]
106-93-4	1,2-Dibromoethane (Ethylene dibromide)
84-74-2	Dibutyl phthalate
25321-22-6	Dichlorobenzene (mixed isomers)

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SECTION 313 WATER PRIORITY CHEMICALS	
CAS Number	Common Name
95-50-1	1,2-Dichlorobenzene
541-73-1	1,3-Dichlorobenzene
106-46-7	1,4-Dichlorobenzene
91-94-1	3,3'-Dichlorobenzidine
75-27-4	Dichlorobromomethane
107-06-2	1,2-Dichloroethane (Ethylene dichloride)
540-59-0	1,2-Dichloroethylene
120-83-2	2,4-Dichlorophenol
78-87-5	1,2-Dichloropropane
542-75-6	1,3-Dichloropropylene
62-73-7	Dichlorvos [Phosphoric acid, 2,2-dichloroethenyl dimethyl ester]
115-32-2	Dicofol [Benzenemethanol, 4-chloro-.alpha.-(4-chlorophenyl)-.alpha.-(trichloromethyl)-]
177-81-7	Di-(2-ethylhexyl phthalate (DEHP)
84-66-2	Diethyl phthalate
105-67-9	2,4-Dimethylphenol
131-11-3	Dimethyl phthalate
534-52-1	4,6-Dinitro-o-cresol
51-28-5	2,4-Dinitrophenol
121-14-2	2,4-Dinitrotoluene
606-20-2	2,6-Dinitrotoluene
117-84-0	*n*-Dioctyl phthalate
122-66-7	1,2-Diphenylhydrazine (Hydrazobenzene)
106-89-8	Epichlorohydrin
100-41-4	Ethylbenzene
106934	Ethylene dibromide
50-00-0	Formaldehyde
76-44-8	Heptachlor [1,4,5,6,7,8,8-Heptachloro-3a,4,7,7a-tetrahydro-4,7-methano-1H-indene]
118-74-1	Hexachlorobenzene
87-68-3	Hexachloro-1,3-butadiene

SECTION 313 WATER PRIORITY CHEMICALS	
CAS Number	Common Name
77-47-4	Hexachlorocyclopentadiene
67-72-1	Hexachloroethane
7647-01-0	Hydrochloric acid
74-90-8	Hydrogen cyanide
7664-39-3	Hydrogen fluoride
7439-92-1	Lead
301042	Lead acetate
7784409	Lead arsenate
7645252	• •
10102484	• •
7758954	Lead chloride
13814965	Lead fluoborate
7783462	Lead fluoride
10101630	Lead iodide
10099748	Lead nitrate
7428480	Lead stearate
1072351	• •
52652592	• •
7446142	Lead sulfate
1314870	Lead sulfide
592870	Lead thiocyanate
58-89-9	Lindane [Cyclohexane, 1,2,3,4,5,6-hexachloro- (1.alpha.,3.beta., 4.alpha.,5.alpha.,6.beta.)-]
14307358	Lithium chromate
108-31-6	Maleic anhydride
592041	Mercuric cyanide
10045940	Mercuric nitrate
7783359	Mercuric sulfate
592858	Mercuric thiocyanate
7782867	Mercurous nitrate
7439-97-6	Mercury

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SECTION 313 WATER PRIORITY CHEMICALS	
CAS Number	Common Name
72-43-5	Methoxychlor (Benzene, 1,1'-(2,2,2-trichloroethylidene)bis(4- methoxy-)
80-62-6	Methyl methacrylate
91-20-3	Naphthalene
7440-02-0	Nickel
15699180	Nickel ammonium sulfate
37211055	Nickel chloride
7718549	• •
12054487	Nickel hydroxide
14216752	Nickel nitrate
7786814	Nickel sulfate
7697-37-2	Nitric acid
98-95-3	Nitrobenzene
88-75-5	2-Nitrophenol
100-02-7	4-Nitrophenol
62-75-9	*N*-Nitrosodimethylamine
86-30-6	*N*-Nitrosodiphenylamine
621-64-7	*N*-Nitrosodi-*n*-propylamine
56-38-2	Parathion (Phosphorothioic acid, O,O-diethyl-O-(4-nitrophenyl) ester)
87-86-5	Pentachlorophenol (PCP)
108-95-2	Phenol
75-44-5	Phosgene
7664-38-2	Phosphoric acid
7723-14-0	Phosphorus (yellow or white)
1336-36-3	Polychlorinated biphenyls (PCBs)
7784410	Potassium arsenate
10124502	Potassium arsenite
7778509	Potassium bichromate
7789006	Potassium chromate
151508	Potassium cyanide
75-56-9	Propylene oxide

SECTION 313 WATER PRIORITY CHEMICALS	
CAS Number	**Common Name**
91-22-5	Quinoline
7782-49-2	Selenium
7446084	Selenium oxide
7440-22-4	Silver
7761888	Silver nitrate
7631892	Sodium arsenate
7784465	Sodium arsenite
10588019	Sodium bichromate
7775113	Sodium chromate
143339	Sodium cyanide
10102188	Sodium selenite
7782823	• •
7789062	Strontium chromate
100-42-5	Styrene
7664-93-9	Sulfuric acid
79-34-5	1,1,2,2-Tetrachloroethane
127-18-4	Tetrachloroethylene (Perchloroethylene)
935-95-5	2,3,5,6-Tetrachlorophenol
78002	Tetraethyl lead
7440-28-0	Thallium
10031591	Thallium sulfate
108-88-3	Toluene
8001-35-2	Toxaphene
52-68-6	Trichlorfon (Phosphonic acid, (2,2,2-trichloro-1-hydroxyethyl)-dimethylester)
120-82-1	1,2,4-Trichlorobenzene
71-55-6	1,1,1-Trichloroethane (Methyl chloroform)
79-00-5	1,1,2-Trichloroethane
79-01-6	Trichloroethylene
95-95-4	2,4,5-Trichlorophenol
88-06-2	2,4,6-Trichlorophenol

SECTION 313 WATER PRIORITY CHEMICALS	
CAS Number	Common Name
7440-62-2	Vanadium (fume or dust)
108-05-4	Vinyl acetate
75-01-4	Vinyl chloride
75-35-4	Vinylidene chloride
108-38-3	*m*-Xylene
95-47-6	*o*-Xylene
106-42-3	*p*-Xylene
1330-20-7	Xylene (mixed isomers)
7440-66-6	Zinc (fume or dust)
557346	Zinc acetate
14639975	Zinc ammonium chloride
14639986	" " "
52628258	" " "
1332076	Zinc borate
7699458	Zinc bromide
3486359	Zinc carbonate
7646857	Zinc chloride
557211	Zinc cyanide
7783495	Zinc fluoride
557415	Zinc formate
7779864	Zinc hydrosulfite
7779886	Zinc nitrate
127822	Zinc phenolsulfonate
1314847	Zinc phosphide
16871719	Zinc silicofluoride
7733020	Zinc sulfate

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APPENDIX J

TABLE OF MONITORING REQUIREMENTS IN EPA'S GENERAL PERMIT

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EPA FINAL GENERAL PERMIT MONITORING REQUIREMENTS[1]				
Type of Facility	Type of Storm Water Discharge	Parameters	Monitoring Frequency	Reporting Frequency
EPCRA, Section 313 Facilities Subject to Reporting Requirements for Water Priority Chemicals	Storm water discharges that come into contact with any equipment, tank, container, or other vessel or area used for storage of a Section 313 water priority chemical, or located at a truck or rail car loading or unloading area where a Section 313 water priority chemical is handled	Oil and Grease, BOD5, COD, TSS, Total Kjeldahl Nitrogen, Total Phosphorus, pH, acute whole effluent toxicity[2], any Section 313 water priority chemical for which the facility reports	Semi-annual	Annual
Primary Metal Industries (SIC 33)	All storm water discharges associated with industrial activity	Oil and Grease, COD, TSS, pH, acute whole effluent toxicity[2], Total Recoverable Lead, Total Recoverable Cadmium, Total Recoverable Copper, Total Recoverable Arsenic, Total Recoverable Chromium, and any pollutant limited in an effluent guideline to which the facility is subject	Semi-annual	Annual
Land Disposal Units/ Incinerators/ BIFs	Storm water discharges from active or inactive land disposal units without a stabilized cover that have received any waste from industrial facilities other than construction sites; and storm water discharges from incinerators and BIFs that burn hazardous waste	Total Recoverable Magnesium, Magnesium (dissolved), Total Kjeldahl Nitrogen, COD, TDS, TOC, Oil and Grease, pH, Total Recoverable Arsenic, Total Recoverable Barium, Total Recoverable Cadmium, Total Recoverable Chromium, Total Cyanide, Total Recoverable Lead, Total Mercury, Total Recoverable Selenium, Total Recoverable Silver, acute whole effluent toxicity[2]	Semi-annual	Annual

EPA FINAL GENERAL PERMIT MONITORING REQUIREMENTS[1]				
Type of Facility	Type of Storm Water Discharge	Parameters	Monitoring Frequency	Reporting Frequency
Wood Treatment Facilities	Storm water discharges from areas that are used for wood treatment, wood surface application or storage of treated or surface protected wood	Oil and Grease, pH, COD, TSS	Semi-annual	Annual
	Facilities that use chlorophenolic formulations	Plus Pentachlorophenol and acute whole effluent toxicity[2]		
	Facilities that use creosote formulations	Plus acute whole effluent toxicity[2]		
	Facilities that use chromium-arsenic formulations	Plus Total Recoverable Arsenic, Total Recoverable Chromium, Total Recoverable Copper		
Industrial Facilities with Coal Piles	Storm water discharges from coal pile runoff	Oil and Grease, pH, TSS, Total Recoverable Copper, Total Recoverable Nickel, Total Recoverable Zinc	Semi-annual	Annual
Battery Reclaimers	Storm water discharges from areas for storage of lead acid batteries, reclamation products, or waste products, and areas used for lead acid battery reclamation	Oil and Grease, COD, TSS, pH, Total Recoverable Copper, Total Recoverable Lead	Semi-annual	Annual
Airports (with over 50,000 flight operations per year)	Storm water discharges from aircraft or airport deicing areas	Oil and Grease, BOD5, COD, TSS, pH, and the primary ingredient used in the deicing materials	Annual	Retain onsite
Coal-fired Steam Electric Facilities	Storm water discharges from coal handling sites (other than runoff from coal piles which is not eligible for coverage under this permit)	Oil and Grease, pH, TSS, Total Recoverable Copper, Total Recoverable Nickel, Total Recoverable Zinc	Annual	Retain onsite

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EPA FINAL GENERAL PERMIT MONITORING REQUIREMENTS[1]

Type of Facility	Type of Storm Water Discharge	Parameters	Monitoring Frequency	Reporting Frequency
Animal Handling/ Meat Packing Facilities	Storm water discharges from animal handling areas, manure management areas, production waste management areas exposed to precipitation at meat packing plants, poultry packing plants, facilities that manufacture animal and marine fats and oils	BOD5, Oil and Grease, COD, TSS, Total Kjeldahl Nitrogen (TKN), Total Phosphorus, pH, Fecal Coliform	Annual	Retain onsite
Chemical and Allied Product Manufacturers/ Rubber Manufacturers (SIC 28 and 30)	Storm water discharges that come into contact with solid chemical storage piles	Oil and Grease, COD, TSS, pH, any pollutant limited in an effluent guideline to which the facility is subject	Annual	Retain onsite
Automobile Junkyards	Storm water discharges exposed to: (a) over 250 auto/truck bodies with drivelines, 250 drivelines, or any combination thereof (b) over 500 auto/truck units (c) over 100 units dismantled per year where automotive fluids are drained or stored	Oil and Grease, COD, TSS, pH, any pollutant limited in an effluent guideline to which the facility is subject	Annual	Retain onsite
Lime Manufacturing Facilities	Storm water discharges that have come into contact with lime storage piles	Oil and Grease, COD, TSS, pH, any pollutant limited in an effluent guideline to which the facility is subject	Annual	Retain onsite
Oil-fired Steam Electric Power Generating Facilities	Storm water discharges from oil handling sites	Oil and Grease, COD, TSS, pH, any pollutant limited in an effluent guideline to which the facility is subject	Annual	Retain onsite
Cement Manufacturing Facilities and Cement Kilns	All storm water discharges associated with industrial activity (except those from material storage piles that are not eligible for coverage under this permit)	Oil and Grease, COD, TSS, pH, any pollutant limited in an effluent guideline to which the facility is subject	Annual	Retain onsite

EPA FINAL GENERAL PERMIT MONITORING REQUIREMENTS[1]				
Type of Facility	Type of Storm Water Discharge	Parameters	Monitoring Frequency	Reporting Frequency
Ready-mix Concrete Facilities	All storm water discharges associated with industrial activity	Oil and Grease, COD, TSS, pH, any pollutant limited in an effluent guideline to which the facility is subject	Annual	Retain onsite
Ship Building and Repairing Facilities	All storm water discharges associated with industrial activity	Oil and Grease, COD, TSS, pH, any pollutant limited in an effluent guideline to which the facility is subject	Annual	Retain onsite

[1]A discharger is not subject to the monitoring requirements provided the discharger makes a certification for a given outfall, on an annual basis, under penalty of law, that material handling equipment or activities, raw materials, intermediate products, final products, waste materials, by-products, industrial machinery or operations, significant materials from past industrial activities, or, in the case of airports, deicing activities, that are located in areas of the facility that are within the drainage area of the outfall are not presently exposed to storm water and will not be exposed to storm water for the certification period.

[2]A discharger may, in lieu of monitoring for acute whole effluent toxicity, monitor for pollutants identified in Tables II and III of Appendix D of 40 CFR Part 122 that the discharger knows or has reason to believe are present at the facility site. Such determinations are to be based on reasonable best efforts to identify significant quantities of materials or chemical present at the facility.